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Influence of packing media on nitrogen removal in a subsurface infiltration system

ZHANG Jian[1*], HUANG Xia[1], SHAO Chang-fei[2], LIU Chao-xiang[1], SHI Han-chang[1], HU Hong-ying[1], Liu Zhi-qiang[2]

(1. Environmental Simulation and Pollution Control State Key Joint Laboratory, Department of Environmental Sciences and Engineering, Tsinghua University, Beijing 100084, China. E-mail: zhangjian00@mails.tsinghua.edu.cn; 2. Department of Environmental Engineering, Qingdao Institute of Architecture and Engineering, Qingdao 266033, China)

Abstract: Influence of packing media on nitrogen removal in a subsurface infiltration system was studied. System A was filled with loamy soil and system B was filled with mixed soil of 75% red clay with 25% cinder. Both systems were fed with sewage at the same hydraulic loading of 2 cm/d at continuous operation mode. The same excellent removal performances of COD and T-P could be achieved in both infiltration systems with removal rates about 85% and 98%, respectively. In system A, NH_4^+-N removal rate was as high as 96.5% and T-N removal rate was relatively much lower as 55.7%. And in system B, NH_4^+-N removal rate was as low as 75.4% and T-N removal rate was relatively much higher as 75.5%. The difference was attributed to different soil oxidation-reduction condition that was greatly influenced by soil texture in subsurface infiltration system. Loamy soil led to oxidative condition that was favorable to nitrification and disadvantageous to denitrification. The results were just adverse to the system filled with clay. Intermittent operation was adopted to improve nitrogen removal in system B. NH_4^+-N removal rate could be increased to about 95% and T-N removal rate could be increased to about 90% at intermittent operation mode in system B. Analysis of nitrogen removal mechanisms indicated that nitrification-denitrification was the primary nitrogen removal path in subsurface infiltration system and crop uptake was another important nitrogen removal way. It was the key to improve the total N removal performance that a suitable packing soil was available to present favorable oxidation-reduction condition for simultaneous nitrification and denitrification.

Keywords: subsurface infiltration system; nitrogen removal; oxidation-reduction potential; soil texture

Introduction

Subsurface infiltration system is one of preferable processes suitable to rural area for domestic wastewater treatment(USEPA, 1992). It is an effective way to renovate wastewater according to integrated mechanisms of chemical, physical and biological reactions if the infiltration system is carefully designed and managed. Compared to the conventional activated sludge process, the system can offer many advantages including excellent performance of nitrogen and phosphorus removals, lower construction and operation costs, and easy maintenance (USEPA, 1992; Sun, 1998; Yamguchi, 1996; Yang, 1999).

Nitrogen in wastewater is the main cause of lake eutrophication. Many researches have been carried out to study nitrogen removal performance in subsurface infiltration system. Nitrogen removal rates in the infiltration system varied from 10% to 90% according to wastewater composition, environmental conditions and operating conditions(Lance, 1976; Pell, 1989; Yamguchi, 1996; Sun, 1998; Yang, 1999). J. C. Lance(Lance, 1986) reported that nitrification and denitrification were the main reactions capable of removing nitrogen from sewage water in subsurface infiltration system. In systems filled with loamy soil that had a good aeration condition favorable to nitrification, NH_4^+-N was easily nitrified and carbon source was the restrictive factor to biological nitrogen removal(Pell, 1989; Sun, 1998; Yamguchi, 1996).

Since wastewater composition, soil texture, environmental condition and microbiological process are very complex, few studies could explain exactly the biological nitrogen removal mechanism and the relationship between nitrogen removal performance and environmental condition.

In the study, two laboratorial systems packed with different soil were constructed to investigate influence of packing media on nitrogen removal in subsurface infiltration system. Nitrogen removal path was studied and the relationship between nitrogen removal performance and soil texture was investigated as well.

1 Materials and methods

1.1 Experimental systems

Schematic diagram of the two laboratorial infiltration systems is shown in Fig. 1. The raw sewage after pre-sedimentation was pumped into the distributing pipes that were installed at the bottom of the infiltration trench. Treated effluent was collected through the collecting pipes at the bottom of the system. The surface soil of the infiltration system was seeded with grass. The spacing interval between infiltration trenches was 1.5 m. The hydraulic loading of both infiltration systems was 4 cm/d.

System A was filled with loamy soil in north China, whose permeability coefficient(K) was about 50 cm/d. And system B was filled with mixed soil of 75% red clay in south China with 25% cinder, whose permeability coefficient was about 30 cm/d.

In order to monitor oxidation-reduction potential(ORP) in soil of infiltration systems, Pt electrodes were buried in soil in advance at the depth of 10 cm, 20 cm in the infiltration trench and 20 cm, 40 cm, 60 cm between the infiltration trench(Fig. 1).

* Corresponding author

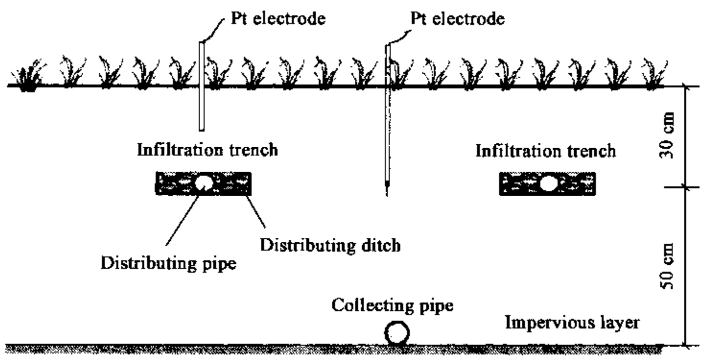

Fig.1 Schematic diagram of the subsurface infiltration systems

1.2 Quality of raw sewages and soils

Quality of raw sewages and packing soils used in the study is shown in Table 1.

Table 1 Quality of raw sewages and packing soils

Items	Soil	*K*, cm/d	COD, mg/L	T-P, mg/L	T-N, mg/L	NH_4^+-N, mg/L
System A	Loamy soil	50	60—190	3.0—6.0	40—60	30—55
System B	Red clay	30	30—150	0.5—7.0	10—40	8—30

1.3 Analysis items and methods

The analysis of COD, NH_4^+-N, NO_3^--N, NO_2^--N, total nitrogen (T-N) and total phosphorous(T-P) was performed according to standard methods(Chinese EPA, 1997). T-N and T-P of plants were also analyzed(Hart, 1994). Nitrifying potentials of soil in the infiltration systems were measured according to methods described by Nanjing Soil Research Institute(Nanjing Soil Research Institute, 1999).

2 Results and discussion

2.1 Pollutants removal performance in two systems

Table 2 shows average pollutants removal performance of two infiltration systems over two months operation at continuous operation mode. And profiles of NH_4^+-N and T-N removal performance over the operation period are shown in Fig.2 and Fig.3, respectively.

Table 2 Average pollutants removal performance of system A and system B

Items	COD	T-P	T-N	NH_4^+-N
System A, %	81.6	99.9	55.7	96.5
System B, %	85.2	98.0	75.5	75.4

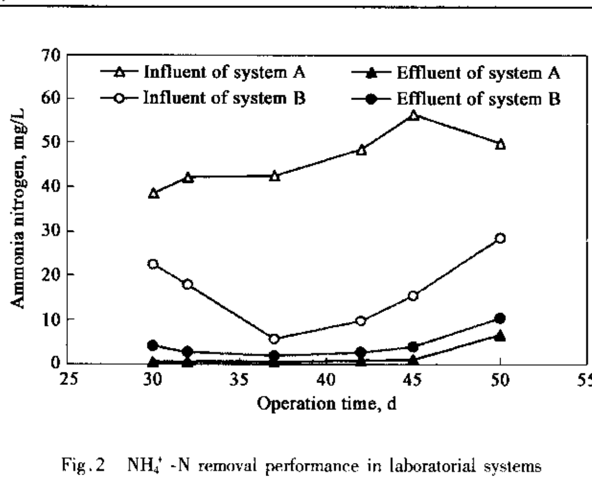

Fig.2 NH_4^+-N removal performance in laboratorial systems

The same excellent removal performances of COD and T-P could be achieved in both infiltration systems with removal rates about 85% and

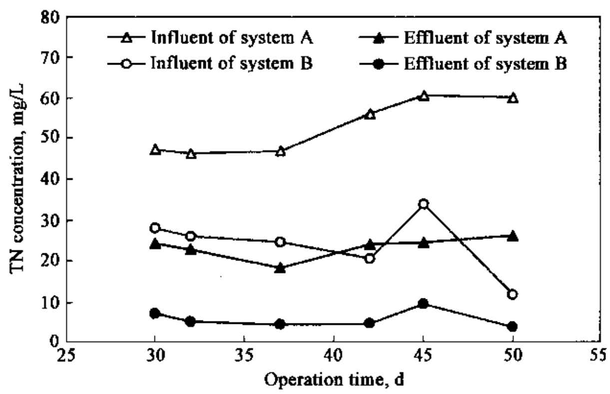

Fig.3 T-N removal performance in laboratorial systems

98%, respectively. However, there was great difference between T-N and NH_4^+-N removal performances. In system A, NH_4^+-N removal rate was as high as 96.5% and T-N removal rate was relatively much lower as 55.7%. In system B, NH_4^+-N removal rate was as low as 75.4% and T-N removal rate was relatively much higher as 75.5%. The negative correlation of T-N removal rate and NH_4^+-N removal rate showed that excellent NH_4^+-N removal performance was not always favorable to T-N removal in subsurface infiltration system.

Compositions of the influent and effluent T-N in both infiltration systems were analyzed (Fig. 4). NH_4^+-N was the main form of the influent sewage wastewater in both systems. However, the effluent T-N composition of system A was greatly different from that of system B. In system A, the main form of the effluent T-N was NO_3^--N that accounted for 98% of T-N, which showed that the nitrification was sufficient. In system B, NO_3^--N accounted for only 12% of the effluent T-N, which suggested that the denitrification was sufficient.

It was suggested that soil texture made great influence on nitrification and denitrification processes in subsurface infiltration system. Loamy soil in system A was favorable to nitrification process but disadvantageous to denitrification process. The result was just adverse to clay in system B. And the results suggested that clay was more preferable to T-N removal in the system.

2.2 Pollutants removal performance at intermittent operation mode in system B

An intermittent operation was adopted to system B to improve nitrogen removal. One cycle of intermittent operation included flooding period of 24 h and drying period of 24 h. It was expected that oxidative condition of soil could be improved through drying period of intermittent

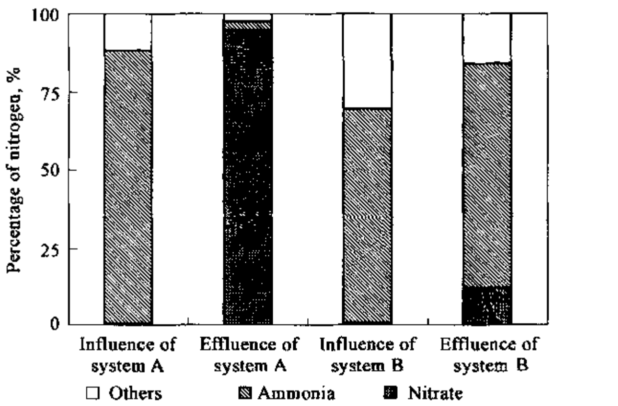

Fig.4 Analysis of T-N composition

operation, which was favorable to nitrification process in system B filled with red clay. The results are shown in Table 3.

Table 3 Average pollutants removal performance at intermittent operation mode in system B

Items	COD	T-P	T-N	NH_4^+-N
Average influent concentration, mg/L	132.1	3.35	19.1	14.3
Average effluent concentration, mg/L	12.9	0.06	1.7	0.7
Removal rate, %	90.2	98.3	91.0	95.1

The same removal performances of COD and T-P were achieved at intermittent operation mode in system B. At intermittent operation mode, NH_4^+-N removal rate was increased from 70% at continuous feeding mode to about 95%. This showed that nitrification process at intermittent operation mode was greatly enhanced. Correspondingly, T-N removal rate was increased from 77% to about 90%.

2.3 Analysis of nitrogen removal mechanisms

2.3.1 Analysis of nitrogen removal paths

Nitrogen removal mechanisms in subsurface infiltration system include soil fixation, ammonia volatilization, crop uptake and nitrification-denitrification. Volatilization loss of NH_4^+-N can be neglected since loamy soil filled in system A was neutral and clay filled in system B was acidic. T-N measurements of soil filled in the infiltration systems during operation period also showed that soil fixation of nitrogen was negligible.

During the operation period, quantity of T-N (M_1) that was assimilated by crop could be obtained by measuring weigh and T-N content of the plants in a reap cycle. As nitrogen(M_2) that entered the infiltration system with the influent and nitrogen(M_3) that was discharged with the effluent in the reap cycle were available, the quantity of nitrogen that was removed by nitrification-denitrification(M_4) could be calculated by the following Eq. (1). The results at continuous operation mode are given in Fig.5.

$$M_4 = M_2 - M_1 - M_3. \quad (1)$$

Fig. 5 indicated that nitrification-denitrification was the primary nitrogen removal path in both subsurface infiltration systems, which could remove 14.3 g nitrogen that accounted for 36% of the fed T-N in system A and 62.9 g nitrogen that accounted for 58% of the fed T-N in system B. Crop uptake was another important nitrogen removal way which could uptake about 19% of the fed T-N in system A and about 20% of the fed T-N in system B.

Since the analysis mentioned above was carried out in a crop growing period when crop had a maximum nitrogen assimilation quantity, there was few feasibility to enhance the nitrogen removal by promoting crop uptake. It was the key to improve the T-N removal performance that a favorable environment should be present for simultaneous nitrification and denitrification.

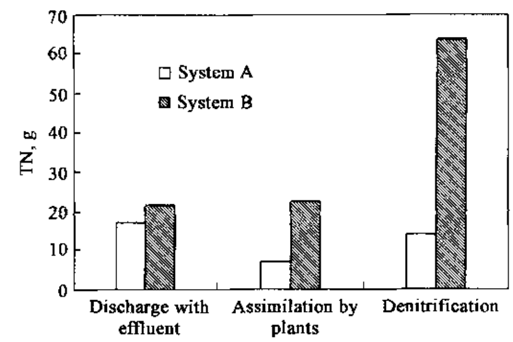

Fig.5 Analysis of nitrogen removal path

2.3.2 Soil ORP analysis

Soil oxidation-reduction potential (ORP) has been widely used to measure soil aeration condition which is a very important factor influencing nitrification-denitrification process(Meek, 1975). Pt electrodes were installed in advance in the different depths both in the infiltration trench and between the infiltration trench to investigate ORP changes of soil in both systems at continuous operation mode. ORP measurement results are shown in Fig.6.

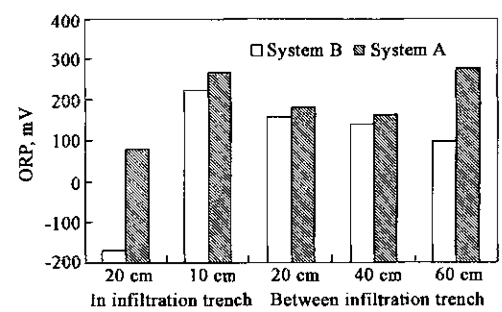

Fig.6 ORP measurement results

Soil ORP values of the different depths in system A were all higher than those in system B(Fig.6), which suggested that system A filled with loamy soil was in an relatively oxidative condition that was favorable to nitrification but disadvantageous to denitrification. And system B filled with clay was in a relatively reductive condition where nitrification reaction was inhibited and denitrification was favored. Nitrogen removal performance(Table 2 and Fig.3) coincided with the results.

The results suggested that soil texture determined soil oxidation-reduction condition that influenced nitrification and denitrification which was the main mechanism of nitrogen removal in subsurface infiltration system.

2.3.3 Discussion of soil nitrification potential

Substrate with NH_4^+-N was added to soils taken from the different positions of both infiltration systems. After short time of shaking, some ammonia nitrogen turned into nitrate nitrogen. According to measuring nitrate nitrogen generated by per unit soil sample per unit time, nitrification potential could be calculated. Nitrification potential was often used to indicate activity of nitrifying bacteria in soil(Hart, 1994). The results are shown in Fig.7.

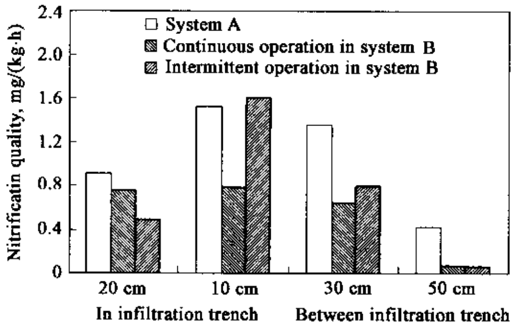

Fig.7 Soil nitrification potential in the two systems

Soil nitrification potentials of the different depths in system A were much higher than those in system B, especially in the infiltration trench. The results confirmed the conclusion that loamy soil was more advantageous to nitrification than clay and clay was more disadvantageous to nitrification. And intermittent operation mode was an effective method to promote nitrification reaction in system B filled with red clay.

3 Conclusions

At continuous operation mode, the same excellent removal performances of COD and T-P could be achieved in both infiltration systems with removal rates about 85% and 98%, respectively. In system A filled with loamy soil, NH_4^+-N removal rate was as high as 96.5% and T-N removal rate was relatively much lower as 55.7%. In system B filled with red clay, NH_4^+-N removal rate was as low as 75.4% and T-N removal rate was relatively much higher as 75.5%. The difference was attributed to different soil oxidation-reduction condition.

Intermittent operation mode was an effective method to promote nitrification reaction in system B filled with red clay. NH_4^+-N removal rate could be increased to about 95% and T-N removal rate could be increased to about 90% at intermittent operation mode in system B.

ORP measurements and nitrification potential analysis suggested that nitrification and denitrification processes were greatly influenced by soil texture in subsurface infiltration system. Loamy soil led to oxidative condition that was favorable to nitrification and disadvantageous to denitrification. The results were just adverse to the system filled with clay.

Analysis of the nitrogen removal mechanisms indicated that nitrification-denitrification was the primary nitrogen removal path in subsurface infiltration system and crop uptake was another important nitrogen removal way. It was the key to improve the total N removal performance that a suitable packing soil was available to present favorable oxidation-reduction condition for simultaneous nitrification and denitrification.

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