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Pollutants Removal Performance of Modified Constructed Rapid Infiltration System at Low Temperature

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Abstract: The conventional Constructed Rapid Infiltration (CRI) system has a low removal rate for total nitrogen, although it has good removal effects on organic pollutants, ammonia nitrogen, suspended solid, etc. To improve the nitrogen removal performance of CRI system, two modified simulated columns were constructed in laboratory. The results in the domestic sewage treatment tests for these two modified systems was compared with conventional system. The system with the addition of an anaerobic saturated water layer only can increase the total nitrogen removal from 22.14% to 32.13% compared with the conventional system, however it contributes little to Chemical Oxygen Demand (COD) removal. Whereas in the system which is added with an anaerobic saturated water layer and extra carbon source entrance at the bottom, the average concentration of COD is decreased to 7.78 mg/l in the effluent wastewater, which is about 21 mg/l less than that of conventional column. The average removal rate of total nitrogen is increased to over 62%, which is almost three times that of the conventional system and two times that of the system with the addition of anaerobic saturated water layer only. Moreover, its average concentration of nitrate nitrogen is significantly decreased in the effluent wastewater. The improved pollutant removal of the system added with anaerobic saturated water layer and extra carbon source entrance resulted from the anaerobic environment, carbon sources and time for nitrate retention which are essential to denitrification.

Keywords: low temperature, modified constructed rapid infiltration system, pollutants removal, COD, nitrate nitrogen, total nitrogen

1 Introduction

Constructed Rapid Infiltration system (CRI) is a new type of wastewater ecological treatment method, which is developed from traditional sewage land treatment technology. It uses natural river sand, coal gangue, natural gravel, etc., to replace natural soil to greatly improve hydraulic load (He et al 2001). CRI system is widely used for the treatment of sewage in small towns (Liu et al 2013) and slightly polluted river water (Ma et al 2009), and has good removal for organic pollutants, ammonia nitrogen, suspended solid, etc. Moreover, compared with conventional treatment systems, it is less energy-intensive and more environment-friendly and has a remarkable economic benefit (4.95E + 05 em$/yr) (Ling et al 2017). However its removal efficiency of Total Nitrogen (TN) is low at 10%-30% only (Zhang 2002), which is unable to meet the first grade standard (TN ≤ 15 mg/l in effluent) of "*urban sewage treatment plant pollutant discharge standard*" (GB18918-2002). For the conventional CRI system, there are lack of the time for nitrate retention, the anaerobic environment and carbon sources, which are essential to denitrification. To improve the nitrogen removal performance of CRI system, Mark et al (2004) adjusted carbon-nitrogen ratio to 2:1 through adding extra carbon source in CRI system and found the denitrification effect was enhanced. Fan et al (2009) added sub-section intake and overflow pool in CRI system simulated columns, and the result showed these methods increased the total nitrogen removal efficiency to 64.8%. Shortcut nitrification was studied by Chen et al (2016). This method improved the nitrogen removal efficiency, and meanwhile had the advantage of saving oxygen and reducing the organic matter requirement in CRI system. But the concentrations of ammonia nitrogen in the influent wastewater of Mark et al (2004) and Fan et al (2009) were only about 20 mg/l, which were lower than the real wastewater. Moreover, the method (Chen et al 2016) needs to add the inhibitor to the influent wastewater to achieve shortcut nitrification-denitrification, which may cause secondary pollutions (Harmony 2017). Therefore, in this paper, a mixture of synthetic wastewater and domestic sewage with the ammonia nitrogen concentration of around 49 mg/l was adopted as the influent

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wastewater and the comprehensive effects of saturated water layer and extra carbon source added to CRI system on the TN removal performance were investigated. Two kinds modified CRI systems of enhanced nitrogen removal simulated columns and one conventional CRI system were used to conduct domestic sewage treatment tests to compare the pollutants removal performance.

2 Materials and Methods

2.1 Experimental devices

Three types of simulated columns of CRI system were constructed in laboratory. The first one was a conventional type, named Column 1; the second was added with saturated water layer at the bottom of the column, named Column 2; based on the Column 2, the third was added with both saturated water layer and extra carbon source entrance at the bottom of the column, named Column 3. Columns 1, 2 and 3 were all made of PVC. Their heights were 100 cm and inner diameters 22 cm. the packing medium with a height of 75 cm was made up with 90% natural river sand (0.25 - 0.30 mm), 5% marble sand (1.0 - 2.0 mm) and 5% zeolite sand (1.5 - 1.7 mm). A 5 cm high supporting layer at the bottom of the column was made up of pebbles and gravel. The sampling outlet of the column 1 was located in the place which was 2 cm far from the bottom of the column; while the sampling outlets of the columns 2 and 3 were in the place that was 20 cm far from the bottom of the columns. The influent wastewater was lifted by the water pump, flowed along the water distributing pipe at the top of the column and into packing medium vertically. The inflow rate and water distributing time were controlled by rotor flowmeter and relay, respectively. Fig. 1. is a schematic diagram of simulated columns of CRI system.

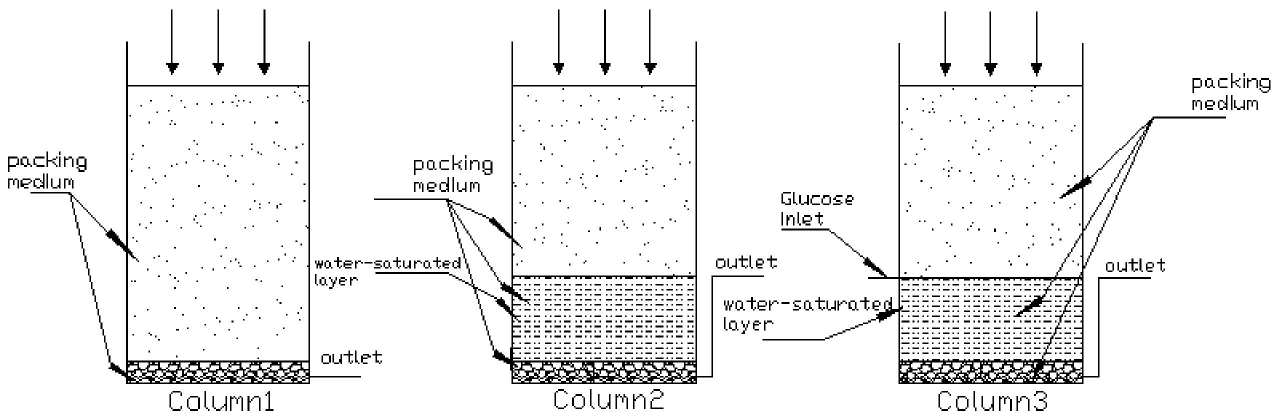

Fig. 1 Schematic diagram of simulated columns of CRI system

2.2 The influent parameters and operation conditions of simulated columns of CRI system

The influent wastewater in this experiment was a mixture of synthetic wastewater and domestic sewage. Water quality parameters are shown in Table 1. In terms of water distributing way of this experiment, the intermittent feeding and dry-wet alternate operation mode were adopted. The hydraulic load was 0.4 m^3 m^{-2} day^{-1}. The water was given every 5 hours, 4 times a day. The inflow for each distributing time was 0.1 m^3 m^{-2} day^{-1} and the hydraulic retention time was 1 h. The test was started on October 16, 2016. Water quality was measured every 2 days. After 42 days, the removal rates of chemical oxygen demand (COD) and ammonia nitrogen (NH_4-N) in the effluent water of the three columns all reached at 85% stably, indicating that CRI system tended to stabilize and biofilm was formed successfully (Chen 2016).

2.3 Monitoring methods

To study the pollutant removal performance of CRI system at low temperature, the main monitoring parameters of this experiment were COD concentration, NH_3-N concentration, NO_3-N concentration, TN, pH and temperature (monitored only, no controlled). Test methods for each parameter (Wei 2002) are shown in Table 2.

Table 1 Water quality parameters of influent in CRI

Water Quality Parameters	Concentration (mg/l)
Chemical oxygen demand (COD)	231.01
NH_3-N	49.04
NO_3-N	0.20
Total nitrogen (TN)	53.31
pH	7.5
Temperature (ºC)	10±1

3 Results and Discussion

3.1 COD removal

The average COD concentration in the influent/effluent wastewater and the removal rate of are shown in Table 3.

Table 2 Test methods of the monitoring parameters

Number	Item	Determination Method
1	Chemical Oxygen Demand (COD)	Potassium Dichromate Method
2	pH	pH Meter
3	ammonia nitrogen (NH_3-N)	Nessler's Reagent Colorimetric Method
4	Nitrate nitrogen (NO_3-N)	Thymol UV-Vis Spectrophotometry
5	Total Nitrogen (TN)	Alkaline potassium persulphate digestion-UV spectrophotometry
6	Temperature	Thermometer

Table 3 COD concentration in the influent/effluent wastewater and removal rate

Type	Mean concentration in the influent wastewater (mg/l)	Concentration of extra COD added (mg/l)	Mean concentration in the effluent wastewater (mg/l)	Average removal rate (%)
Column 1	231.01	-	29.15	87.50
Column 2	231.01	-	26.82	88.52
Column 3	231.01	56.91	7.78	-

Table 4 Ammonia nitrogen concentration in the influent/effluent wastewater and removal rate

Type	Mean concentration in the influent water (mg/l)	Mean concentration in the effluent water (mg/l)	Average removal rate (%)
Column 1	49.04	1.74	96.48
Column 2	49.04	1.22	97.46
Column 3	49.04	1.06	97.83

Table 5 Nitrate nitrogen concentration in the influent/effluent wastewater

Type	Mean concentration in the influent wastewater (mg/l)	Mean concentration in the effluent wastewater (mg/l)
Column 1	0.20	21.88
Column 2	0.20	17.38
Column 3	0.20	9.89

The average removal rates of COD of both Columns 1 and 2 are over 87.50%. The average concentration of COD in the effluent water of Column 3 is 7.78 mg/l only, and their COD concentrations in the effluent water all meet the requirement of the first grade A standard (COD $\leq$ 50 mg/l) in the GB18918-2002 (*urban sewage treatment plant pollutant discharge standard*). In addition, the concentration of COD in the effluent water and the removal rate have little difference between Column 2 and Column 1, indicating that the addition of anaerobic saturated water layer contributes little to COD removal. The reason may be that the removal of organic matter mainly depends on aerobic biodegradation of aerobic-anaerobic alternating zone (Sun et al 2007). However, the average concentration of COD in the effluent water decreases obviously in Column 3. It is 7.78 mg/l only, which is about 19 mg/l less than that of Column 2. It suggests that the addition of carbon source (glucose) in anaerobic saturated water layer has helped remove COD. The rate of anaerobic reaction is related to the concentration of nutrients. The higher the concentration of organic matter is, the faster the anaerobic decomposition reaction is (Liu 2006). Accordingly, the addition of glucose could enhance the activity of anaerobic microorganism and promote anaerobic reaction, achieving the purpose of decreasing COD concentration in the wastewater ultimately.

3.2 Ammonia nitrogen and nitrate nitrogen removal

Tables 4 and 5 list the average concentration of ammonia nitrogen and nitrate nitrogen in the influent/effluent wastewater and their removal rates, respectively. It can be seen from Table 4, Columns 1, 2 and 3 all show a good removal performance of ammonia nitrogen. The average removal rates are all above 96%, and the average concentrations in the effluent water is less than 2 mg/l, which meets the first grade A standard (≤ 5 mg/l) in GB18918-2002. Therefore, the addition of anaerobic saturated layer and extra carbon source (glucose) in the CRI system have little contribution to ammonia nitrogen removal. As can be seen from Table 5, the average concentration of nitrate nitrogen in the effluent water of Column 2 is decreased compared with that of Column 1. The reason is that the addition of anaerobic saturated water layer could provide a longer and stable anaerobic environment for denitrification. That is, in the absence of dissolved oxygen, denitrifying bacteria could use N^{5+} of nitrate and N^{3+} of nitrite as electron acceptor in energy metabolism, O^{2-} as hydrogen acceptor to produce H_2O and OH^-, and the organic matter as carbon source and electron donor to provide energy and oxidation stability (Wang 2009). All these are conducive to produce the gaseous nitrogen, and hence achieve the purpose of nitrogen removal. Compared with the results of Column 2, the average concentration of nitrate nitrogen in the effluent water of Column 3 is decreased by about 7 mg/l, showing that an anaerobic environment and sufficient organic carbon source are both essential to enhance the activity of denitrifying bacteria and make denitrification proceed smoothly (Xu 2011).

3.3 Total nitrogen removal

After CRI system works stably, the monitoring data of TN concentration in the influent/effluent water and the removal rate of TN are shown in Fig. 2.

The removal efficiency of TN is compared and analyzed for these three types of simulated columns. As shown in Fig. 2, the TN removal efficiency of Column 1 was low, the average concentration in the influent and effluent water is 53.31 mg/l and 41.51 mg/l, respectively, and the average removal rate is 22.14%.

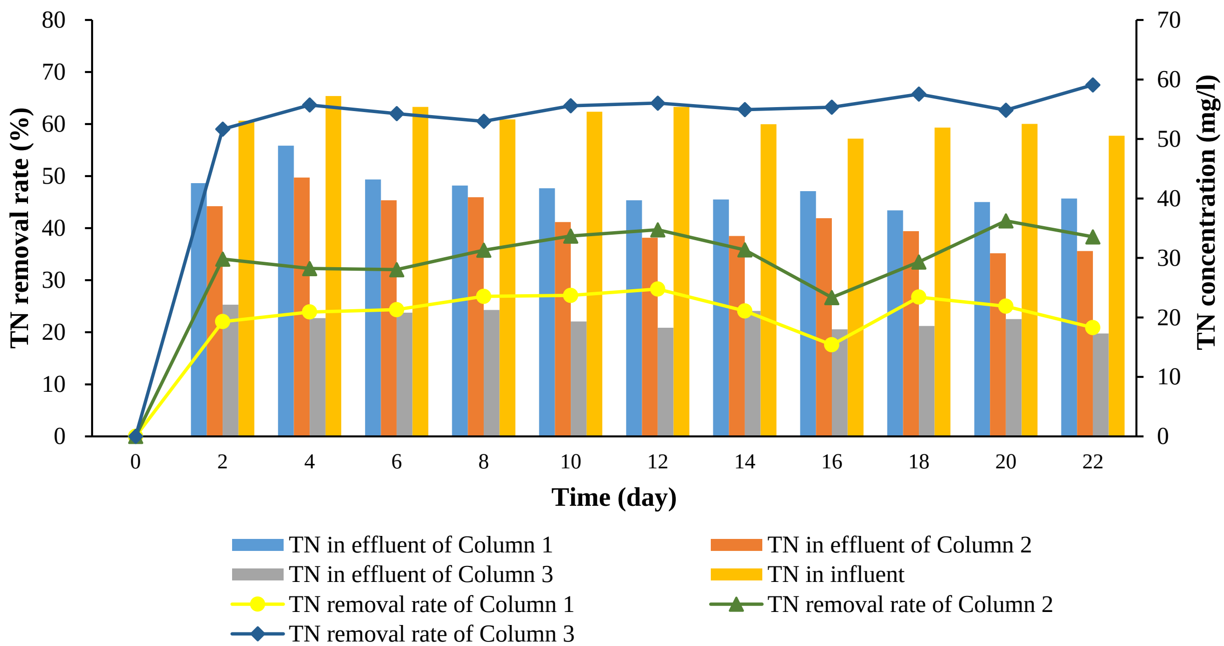

Fig. 2 TN concentration (the influent wastewater/the effluent wastewater) and removal rates of simulated columns of CRI system

Compared with Column 1, the average concentration of TN in the effluent water of Column 2 is reduced by 5.3 mg/l, and its average removal rate is increased by 9.9%, but its TN concentration was still too high to reach the standard (≤ 20 mg/l), the reason was that the ammonification and nitrification only change the forms of nitrogen, the final removal of nitrogen from the CRI system could not be achieved. At the same time, only through the microbial denitrification which converts the nitrate nitrogen into gaseous nitrogen, the nitrogen removal efficiency could not be increased significantly (Xu 2011). The Column 1 CRI system was operated by dry-wet alternating mode in which the drying time was longer than wetting time. This causes the lack of the anaerobic environment and inhibits the process of denitrification. The addition of saturated water layer could create the anaerobic environment at the bottom part (20-centimetre-long) of Column 2, which could provide time and place for denitrification. Therefore, the TN removal efficiency of Column 2 is better than that of Column 1 However, the average concentration of TN in the effluent water of Column 2 is still high and could not meet the requirement of the first grade B standard (≤ 20 mg/l) in GB18918-2002. There are two reasons: 1) during the period of water distribution, the ammonia nitrogen is adsorbed and entrapped in the non-saturated water layer and then the nitrate nitrogen is produced through nitration reaction. However due to the same negative charge, the dielectric particles have no adsorption capacity to NO_3^- (Zhang et al

2002), the nitrate nitrogen is easy to move out from the system along with water flow, resulting in high concentration of TN in effluent water (Wang et al 2006). It can be found in Table 2, the average concentration of nitrate nitrogen is about 17.38 mg/l, which accounts for more than 47% TN concentration in the effluent water; and 2) the aerobic reaction produced by the non-saturated layer of Column 2 consumes a large amount of organic matter, causing the lack of organic carbon source in the anaerobic saturated layer This inhibits the activity of denitrifying bacteria and produces the adverse effects on denitrification.

The average concentration of TN in the effluent water of Column 3 is 19.67 mg/l and meets the requirement of the first grade B standard (≤ 20 mg/l) in GB18918-2002, and the removal rate of TN reaches 63.09%, which is increased significantly compared with that of Columns 1 and 2. In addition, the average concentration of nitrate nitrogen in the effluent water of Column 3 is also reduced obviously, was 9.89 mg/l.

4 Conclusions

1) Through setting anaerobic saturated water layer and carbon source entrance at the bottom of the conventional simulated columns of CRI system, the average removal rate of TN is increased to more than 60% and its average concentration in the effluent wastewater is decreased to below 20 mg/l at a low temperature (10 ± 1^{o}C) environment. This is because the two conditions, an anaerobic environment and sufficient organic carbon source, have helped denitrification proceed smoothly.

2) The modified simulated column of CRI system contributes little to the ammonia nitrogen removal, however it has promoted the removal of COD and nitrate nitrogen in the effluent wastewater. Due to the fact that nitrate nitrogen is a kind of non-adsorbing ion, which is easy to move out from the CRI system along with water flow, the concentration ratio of nitrate nitrogen to total nitrogen in the effluent wastewater is still relatively high.

3) Although the average TN concentration in the effluent wastewater was decreased to below 20 mg/l, it is still too high to meet the first grade A standard (TN ≤ 15 mg/l in effluent) of "*urban sewage treatment plant pollutant discharge standard*" (GB18918-2002). To improve the TN removal rate in the effluent wastewater of CRI system, the hydraulic retention time of denitrification phase needs to be extended. In addition, the dynamics and microbiology of CRI system also need to be further studied to provide the basis for the efficient nitrogen removal.

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