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Organic matter removal performance and mechanism in the constructed rapid infiltration system

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The Constructed Rapid Infiltration System (CRI system) finds application in engineering, however, the pollutant removal mechanism is still not clear, which limits its further promotion and application. The experiment of processing wastewater by building a CRI simulation column while studying the pollutant removal mechanism and performance showed: after the CRI system operated steadily, under operation mode 1, that the CRI system had a higher removal rate of Chemical Oxygen Demand (COD) and COD had been removed effectively in a CRI filter tank 0-100cm segment, with a removal rate of up to 77.8%, under operation mode 2, the CRI system has a relatively low removal rate of COD, with an average removal rate of only 59.1%. Filtration and adsorption was the first step in the removal of organic pollutants by the CRI system; organic matter was accumulated during the flooding period and oxidized and decomposed during the drying period in the CRI system, degradation of aerobe mater played an important role in the removal of organic matter by the CRI system; alternation of the wetting and drying operation mode facilitated COD removal. The study results enrich our theoretical knowledge of the CRI system and promote the application of the CRI system.

Key words: Organic matter; Removal performance; Mechanism; Constructed rapid infiltration system

INTRODUCTION

The Constructed Rapid Infiltration system (CRI system) employs a new biological wastewater treatment method, which is now becoming a hot spot of research and application in China. The CRI system finds application in engineering, however, its pollutant removal capacity and fundamentals are still insufficiently studied and limit further promotion. Therefore it is necessary to further study the migration, transformation and degradation rules and master the degradation mechanism of various pollutants in the CRI system [1-4]. This study will provide a theoretical basis to further promote and apply the CRI system by conducting the experimental processing of domestic wastewater by building a CRI simulation column in the laboratory as well as by analysis of the organic matter and removal performance.

MATERIALS AND METHODS

Building a CRI Simulation Column

A CRI simulation column was built in the laboratory. The main part of the CRI simulation column reactor consists of an organic glass column, the column height is 200cm, the internal diameter is 21cm, the filtering material consists of 90% of natural sand + 5% of sand marble + 5% of zeolite sand, with at a height of 150cm, the 7 sampling ports are set 25cm from the top filtering material layer to the bottom filtering material layer: 1# sampling port, 2# sampling port, 3# sampling port, 4# sampling port, 5# sampling port, 6# sampling port and 7# sampling port were set at 0cm, 25cm, 50cm, 75cm, 100cm, 125cm and 150cm from the top filtering material layer, respectively. A water distribution pipe was fixed on the top of the filtering material of the CRI system, the wastewater enters the water distribution pipe and feeds the water to the CRI system after extraction by a water pump, the wastewater quantity is controlled with a flowmeter and the wastewater flows straight down in the CRI system where it is purified by trickling through the filtering material from top to bottom. Fig.1 shows the schematic diagram of the filter tank of the CRI simulation column.

Operation and Management of the CRI Simulation Column

The CRI simulation column was operated on July 10, 2009, the experimental water was domestic wastewater from the sewer of a student apartment. The experimental design hydraulic load was 1m/d; two intermittent water distribution modes were adopted, an operational mode 1: 4 times of waterdistribution per day, 0.5h for each time, every time the water distribution quantity was 0.25m, the water was distributed once every 6h; the

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operational mode was 2: the water was distributed once every day, for 2h every time, every time the water distribution quantity was 1m, the water was distributed once every 24h. The CRI simulation column was started with fresh water and the COD test yielded effluent every 3d.

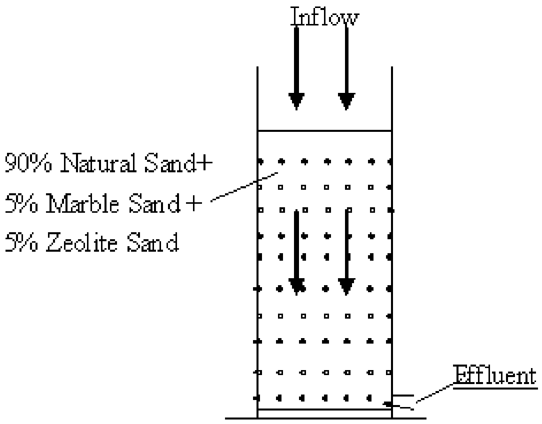

Fig.1. CRI simulation column.

Experimental Monitoring Items

The experimental monitoring items included CODCr, NH3-N, NO3-N, TN and TP. Table 1 shows the experimental monitoring method [5].

EXPERIMENTAL RESULTS AND ANALYSES

Experimental Results of COD Removal by the Cri System

Table 2 shows the COD concentration and removal rate of influent and effluent by the CRI simulation column under operational mode 1 (Notes: sampling times 1-13 are the natural bio-film colonization stage of the CRI system, and the sampling time 14 is the stable operational stage of the CRI system, Table 2 starts from sampling time 14) and Table 3 shows the COD concentration and removal rate of influent and effluent of the CRI simulation column under operational mode 2. Table 4 shows the removal effect of COD by filtering materials of different heights in the CRI simulation column under operational mode 1.

To investigate the degradation rule of COD along with flow in the CRI simulation column, a wastewater sample at each sampling port along the flow in the CRI simulation column under operational mode 1 was taken, Table 4 displays the specific experimental results.

Rule Analyses of COD Removal by the Cri System

It can be seen from Table 2 that after the CRI system was operated steadily following successful natural bio-film colonization, the CRI system manifest a high COD removal rate under operational mode 1 (the hydraulic load cycle was 6h): after 19 sampling tests (sampling numbers 14-32), after 7 tests the effluent COD concentration in the CRI system was less than 20mg/L, after 12 tests the effluent COD concentration in the CRI system was less than 30mg/L, after 19 tests the effluent COD concentration in the CRI system was less than 20.39 mg/L, in terms of the COD index, the effluent COD concentration in the CRI system under operational mode 1 reached the A-level standard or the first class standard of the Pollutant Discharge Standard for the Town and Country Sewage Treatment Project (GB18918-2002).

The influent COD concentration in the CRI system had a larger fluctuation range, whose minimum COD concentration was 90.36 mg/L and the maximum COD concentration was 189.61 mg/L, however, the effluent COD concentration in the CRI system had a small fluctuation range, which was maintained at 14-25 mg/L, suggesting that the CRI system had a stronger capacity for resisting the impact load for COD.

Table 1. Experimental methods of pollutant indexes.

Index	Experimental method
Water temperature	Thermometer method
Ph	Glass-electrodes method
COD	Potassium dichromate method
NH3-N	Nessler's reagent colorimetry
TN	Alkaline potassium per sulfate digestion-uv spectrophotometric method
TP	Ammonium molybdate spectrophotometric method

Table 2. COD Concentration and Removal Rate of Influent and Effluent of the CRI Simulation Column under Operational Mode 1.

Sampling times	Influent concentration (mg/L)	Effluent concentration (mg/L)	Removal rate (%)
14.	159.64	23.31	85.4
15	136.48	20.47	85
16	126.31	19.33	84.7
17	104.34	14.50	86.1
18	97.34	15.67	83.9
19	112.32	17.18	84.7
20	159.69	24.59	84.6
21	178.34	22.47	87.4
22	189.61	21.05	88.9
23	104.35	18.57	82.2
24	90.36	15.45	82.9
25	94.58	17.59	81.4
26	147.35	21.07	85.7
27	163.24	22.69	86.1
28	158.31	22.64	85.7
29	146.36	23.56	83.9
30	165.65	23.36	85.9
31	115.43	20.66	82.1
32	151.23	23.29	84.6

It can be seen from Table 3 that the removal effect of COD when the hydraulic load cycle was 24h declined dramatically compared with that when the hydraulic load cycle was 6h, with an average removal rate of only 59.1%, after 10 sampling tests (sampling numbers 33-42), after 7 sampling tests the final effluent COD concentration in the CRI system was greater than 60mg/L, after 3 tests the effluent COD concentration in the CRI system was greater than 50mg/L, after 10 tests the effluent average COD concentration in the CRI system was 60.77 mg/L, in terms of COD index, the effluent COD concentration in the CRI system exceeded the A-level standard of the first class standard of the Pollutant Discharge Standard of the Town and Country Sewage Treatment Project (GB18918-2002).

Table 4 shows the change in COD concentration along the flow in the CRI system under operational mode 1 (the hydraulic load cycle is 6h). The average removal rate of COD by the CRI system in the 5 experiments was 84.9%, the removal rate of COD in the CRI filter tank 0-75cm segment reached 71.9%, accounting for 84.6% out of the total removal rate of COD by the CRI system, the removal rate of COD in the CRI filter tank 0-100cm segment reached 77.8%, accounting for 91.6% out of the total COD removal rate by the CRI system, suggesting that COD had been effectively removed in the CRI filter tank 0-100cm segment and removed less effectively (only about 6%) in the CRI filter tank 0-100cm below the segment.

Mechanism Analyses of COD Removal by the Cri System

The following conclusions can be reached from the analysis of the COD removal mechanism by the laboratory simulation column[6-10]:

(1) Filtration and adsorption was the first step of organic pollutant removal by the CRI system.

It took a long time for the organic matter in the wastewater to be decomposed completely in the CRI system, more especially, some of the macromolecular organic matter can continue to be decompose aided by the microorganisms surrounding the filtering material in the CRI system only by being first decomposed into a dissolved state through hydrolytic processes, which needed to take a relatively long period of time, in the CRI system, the filtering material and bio-film first managed the interception and adsorption of organic matter to allow sufficient contact time with the microorganisms, during which they started the biochemical reaction to let the organic matter to be completely decomposed, absorbed and utilized by the microorganisms. The filtration and adsorption was the first step of organic pollutant removal by the CRI system, providing a basis for further degradation and removal of the organic matter.

(2) The organic matter accumulates during the flooding period and is oxidized and decomposed during the drying period in the CRI system.

When the wastewater flows through the filtering material of the CRI system, the organic matter becomes detached from the aqueous phase due to adsorption, interception and flocculation. By filtering the material and bio-film, among which a portion of low molecular weight and dissolved organic matter can be quickly decomposed, absorbed and utilized by the microorganisms in the CRI system and wastewater, but the macromolecular or granular organic matter can continue to be completely decomposed by the microorganisms in the CRI system only by first being decomposed by the hydrolytic process. This involves a process where the macromolecular and granular organic matter is decomposed and dissolved to organic matter that can be absorbed and utilized by the microorganisms following the action of the hydrolytic enzyme released by the microorganisms. This process needs a relatively long period of time, so the macromolecular organic matter absorbed by the filtering material of the CRI system cannot be decomposed by the microorganisms in a timely fashion. The matter accumulates in the CRI system, if the CRI system is fed with water all the time, then more and more organic matter accumulates in the CRI system and this will easily result in a blockage of the CRI system. In order to operate normally, the CRI system adopted an alternate wetting and drying operational mode, during the flooding period, the organic mater accumulates in the CRI system, only a small portion of low molecular weight and dissolved organic matter can be decomposed by the microorganisms, in the drying period, because no new organic matter enters the CRI system, so the microorganisms in the CRI system have plenty of time to conduct biodegradation of organic matter accumulated during the flooding period, the assimilative capacity of the CRI system was restored in the drying period, allowing continued effective adsorption and accumulation of organic matter during the next wastewater feed. The alternate wetting and drying operational modes were the safeguard for a normal operation of the CRI system, while limiting the hydraulic load of the CRI system because it took a certain time for the macromolecular organic matter to be hydrolyzed, absorbed and utilized by the microorganisms, so the drying period should not be too short. Therefore, such alternate wetting and drying operational modes limit the increase of the hydraulic load of the CRI system.

(3) The aerobic degradation played an important role in the removal of organic matter by the CRI system.

The study showed that because the CRI system adopted the alternate wetting and drying operational mode and characteristics of the CRI system itself, the CRI filter tank upper segment (0-100cm) belongs to the aerobic/anaerobic alternating segment, which has a wide range of microorganisms, very complex, including obligate aerobes, facultative microorganisms and obligate anaerobes, a relatively rich content. The obligate anaerobes required a much stricter living environment than the bligate aerobes, since the CRI system had a longer drying period and shorter flooding period, which means that the aerobic/anaerobic alternating segment had a longer aerobic state and a shorter anaerobic state, thus this segment was advantageous to the growth and reproduction of aerobes and inhibits the growth of anaerobes. Therefore, the degradation of aerobes played an important role in organic matter removal by the CRI system in the aerobic/anaerobic alternating segment (CRI filter tank 0-100cm segment).

Table 3. COD Concentration and Removal Rate of Influent and Effluent of the CRI Simulation Column under Operational Mode 2.

Sampling times	Influent concentration (mg/L)	Effluent concentration (mg/L)	Removal rate (%)
33	163.4	47.39	71.4
34	158.6	65.03	59.6
35	148.3	63.32	57.3
36	167.5	68.34	59.2
37	159.1	61.73	61.2
38	146.8	64.45	56.1
39	152.4	59.89	60.7
40	154.7	65.75	57.5
41	146.2	58.77	59.8
42	136.7	53.04	61.2

Table 4. COD Concentration (mg/L) along the Flow in the CRI Simulation Column under Operation Mode 1.

Sampling times	CRI filter tank depth (cm)						
	0	25	50	75	100	125	150
43	168.6	105.8	66.6	46.6	34.6	28.2	25.3
44	171.3	105.6	63.9	44.0	37.6	26.3	25.1
45	159.6	103.7	66	48.3	39.7	28.7	25.1
46	163.2	103.9	65.5	47.2	35.1	27.0	24.2
47	160.8	101.7	63.7	45.2	35.7	26.8	24.2.
Average removal rate (%)	0	37.2	60.4	72.4	79.5	83.3	85

The CRI filter tank lower segment (100-150cm) was in an anaerobic state, but it made a small contribution to organic matter removal, there were two main reasons:

1. The decomposition capacity of anaerobes was far less than that of aerobes and the decomposition of organic matter was not complete.

2. The anaerobic reaction rate of the microorganisms related to the initial concentration of nutrients, the higher the initial concentration of organic pollutants, the faster the anaerobic decomposition reaction, which is otherwise slower.

3. Because the CRI filter tank 0-100cm segment had a high removal rate of the organic matter, with an average removal rate of around 80%, by producing a small quantity of organic matter entering the anaerobic zone of the CRI filter tank the lower segment had a low anaerobic biodegradation rate of organic matter.

In conclusion, the organic matter removal by the CRI system depended mainly on aerobic biodegradation.

4. The alternation of wetting and drying operational mode facilitated COD removal.

It can be seen from Table 2 and Table 3 that under the conditions of different wet-to-dry rates, the CRI system had a remarkably different removal efficiency for organic matter, which was mainly caused by a change in the hydraulic load cycle of the CRI system due to a different wet-to-dry rate. The organic matter removal by the CRI system depended mainly on aerobic biodegradation, so the reaeration state and hydraulic retention time of the CRI system will have a great influence on organic matter removal. The main reasons for the large difference in the removal rate of COD under the conditions of two different wet-to-dry rates in this experiment are mainly as follows:

1) Differences of the reaeration effect of the CRI system.

The CRI system is a technology for wastewater treatment using a natural system without the need for aeration and its reaeration process relies mainly on air convection and diffusion. At the time of infiltration of the residual water on the surface layer of the CRI system, the air inside and outside the CRI system initiates air convection due to infiltration and inhalation by the water and air convection carried through once within one hydraulic load cycle, the volume of air convected is equal to the volume of all the water coming out of the CRI system during the time from drying of the residual water on the surface layer of the CRI system to the next wastewater feeding of the CRI system. When the CRI system was in the drying period, its reaeration mainly relied on the air diffusion. The study conducted by Zhang Jinbing [7] suggests that even when the CRI system is in the drying period, the amount of reaeration through air diffusion is still low and it is difficult for oxygen to reach deeper into the CRI system. To allow for better reaeration of the CRI system, the hydraulic load cycle of the CRI system needed to be shortened, the wastewater feeding and drying frequencies needed to be increased, and air the convection times of the air inside and outside the CRI system needed to be increased, thus allowing for an increase of the reaeration efficiency of the CRI system, which will be favorable for the decomposition of organic matter by the aerobes inside the CRI system.

The operational mode for sampling numbers 14-32 required a one time wastewater dosing every 6h, 4 times per day and the CRI system completed the whole process of one time drying and flooding every 6h. Under such an operational mode, the CRI system had a higher drying frequency and less time and it conducted air convection 4 times every day, such an operational mode strengthened the reaeration of the CRI system, while for sampling numbers 33-42, the infiltration column only conducted air convection once every day. Thus it can be seen that the hydraulic load cycle will directly affect the reaeration way and reaeration efficiency of the CRI system. Under these experimental conditions, the reaeration way of sampling numbers 14-32 relied mainly on the air convection, while the reaeration way of sampling numbers 33-42 relied mainly relied on the air diffusion. Therefore, the reaeration efficiency of sampling numbers 14-32 was much higher than that of sampling numbers 33-42, it was more favorable for the decomposition of organic pollutants by aerobes under the conditions of sampling numbers 14-32, so the CRI system had better removal efficiency for organic pollutants under the operational mode of 4 times of wastewater dosing per day and one time every 6h.

2) Hydraulic retention time.

The organic matter removal by the CRI system mainly relied on the degradation by aerobes, so the length of time of contact between the organic pollutants with the bio-film in the CRI system will have a great influence on the removal effect of the organic pollutants. Because the hydraulic load of the CRI system was relatively high in the CRI system, the hydraulic retention time (HRT) had a much greater influence on the removal effect of organic pollutants [8,9].

This experiment adopted two obviously different hydraulic load cycles and the HRT had a major difference under the conditions for two different hydraulic load cycles [10-13]. When the sampling numbers 14-32 adopted 4 times of wastewater dosing per day, once every 6h and the sampling numbers 33-42 adopted the hydraulic load cycle of 24h, under such different conditions the hydraulic load was the same, however, the wastewater quantity flowing through the CRI system of each time of wastewater distribution of sampling numbers 33-42 was equal to the total wastewater quantity flowing through the CRI system of 4 times of wastewater distribution for sampling numbers 14-32, so the actual flow rate of wastewater for sampling numbers 33-42 was significantly greater than that for sampling numbers 14-32. Therefore, the wastewater had longer HRT for sampling numbers 14-32, such an operational mode was more favorable for the degradation and removal of organic matter by microorganisms in the CRI system [14, 15].

CONCLUSIONS

The following conclusions were reached through the wastewater processing experiment by building a CRI simulation column:

(1) After the CRI system operated stably following the successful natural bio-film colonization, the CRI system had a high COD removal rate under operational mode 1: COD had been effectively removed in the CRI filter tank 0-100cm segment, with a removal rate reaching 77.8%, the effluent COD concentration in the CRI system under operational mode 1 reached the A-level standard for the first class standard of the Pollutant Discharge Standard of the Town and Country Sewage Treatment Project (GB18918-2002). The CRI system had a stronger capacity of resisting impact load for COD. The CRI system had a relatively ineffective removal effect of COD under operational mode 2, with an average removal rate of only 59.1%.

(2) Filtration and adsorption were the first steps in organic pollutant removal by the CRI system; organic matter in the CRI system was accumulated during the flooding period and oxidized and decomposed during the drying period; the aerobe degradation played an important role in organic matter removal by the CRI system; the alternate wetting and drying operational mode facilitated COD removal.

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ОТСТРАНЯВАНЕ НА ОРГАНИЧНА МАТЕРИЯ И МЕХАНИЗЪМ НА ДЕЙСТВИЕ НА СИСТЕМАТА ЗА БЪРЗА ИНФИЛТРАЦИЯ

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(Резюме)

Конструирана е бърза инфилтрационна система (CRI), която намира приложение в отстраняването на замърсители от водите. Механизмът на този процес още не е ясен, което препятства на неговото разпространение и приложение. Експериментите по третиране на води в колона на базата на CRI-системата показват следното. При стационарен режим по способ 1 се постига висока степен на отстраняване на ХПК (до 77%) в слой от 0 до 100 cm. При способ 2 се постига средно само 59,1 % отстраняване на ХПК. При CRI-системата първите степени са филтруването и адсорбцията. Органичната материя се натрупва през периода на омокряне, а се окислява и се разлага в периода на сушене. Деградацията на аеробната материя изграе важна роля за отстраняване на органиката. Редуването на заливане и сушене благоприятства отстраняването на ХПК. Тези резултати обогатяват теоретичните знания за CRI-системата и насърчават приложението ѝ.