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Combined process of sequencing batch reactor activated sludge process and constructed wetland for domestic wastewater treatment *

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Abstract: By combining sequencing batch reactor (SBR) activated sludge process and constructed wetland (CW), this study is to achieve the domestic wastewater treatment. Our purpose was to determine the optimum operating parameters of the combined process. The process involved advantages and shortages of SBR and CW. Under normal temperature, the 3rd cycle (SBR's operation cycle is 8 h: inflow for 1 h, limited aeration for 3 h, sediment for 1 h, outflow for 1 h, and idling for 2 h; CW's hydraulic retention time (HRT) is 24.8 h and hydraulic loading is 24.5 m^3/m^2 d) was the best cyclic mode. The effluents can meet the standard GB/T18921-2002: "The reuse of urban recycling water: water quality standard for scenic environment use". In the 3rd cycle, the efficiency of CW was the maximum, and energy consumption of SBR was the minimum. Under the condition of low dissolved oxygen, the removing efficiency of chemical oxygen demand (COD) and ammonia was not affected obviously. Simultaneously, nitrification and denitrification phenomena occured and phosphorus was absorbed obviously.

Keywords: sequencing batch reactor activated sludge process ; constructed wetland; energy consumption; low dissolved oxygen

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1 Introduction

As water consumption increases sharply, many areas face water shortage now or in the near future. To overcome the crisis, many measures have been introduced for the effective use of this valuable natural resource. In this situation, wastewater could be considered as a water resource. However, conventional treatment systems focus on treatment rather than reuse. Thus the related issues of what kind of wastewater should be treated, how to treat, and how to transport them should be concerned [1].

By combining sequencing batch reactor (SBR) activated sludge process and constructed wetland (CW), the domestic wastewater treatment can benefit from both SBR and CW, such as resistance to shock loading, sludge bulking prevention, flexible automatic control, simple operation, easy maintenance, lower energy consumption, lower total investment, more green areas, and other advantages [2]. The two technologies can make up deficiencies for each other, such as high energy consumption of SBR, and covering too large area and easy blocking of CW. Our purpose was to determine the optimum operating parameters of the combined process.

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2 Experiment procedure

2.1 *Characteristics of influent wastewater*

The quality of wastewater, resulting from the various daily uses in students' dormitory of B campus, Chongqing University, fluctuated and is influenced largely by climate changes. For example, during the summer, temperature and humidity in Chongqing city is very high, which lead to increasing consumption of water used by students for various daily purposes. The quantity of wastewater would also increase, therefore. However, the quantity of water consumed by students decreased in winter because of the low temperature. Table 1 shows the wastewater quality of influent used in the experiment. The effluents should meet standard GB/T18921-2002: "The reuse of urban recycling water-water quality standard for scenic environment use"[3].

Table 1 Wastewater quality of influent used in the experiment

Index	Range	Requirement
Chemical oxygen demand/(mg/L)	245 to 357	≤20
BOD_5	114 to 208	≤6
NH_3-N/(mg/L)	42.4 to 50.2	≤5
Total nitrogen/(mg/L)	58.6 to 69.3	≤15
Total phosphorus/(mg/L)	4.85 to 6.03	≤0.5
pH	6.4 to 7.6	6 to 9
Turbidity	52 to 64	≤5.0

2.2 *Experiment process*

Fig. 1 shows the experiment process.

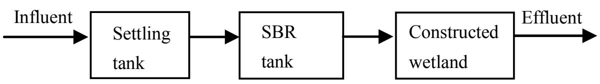

Fig. 1 Experiment process

2.2.1 *SBR system*

SBR reactor consists of SBR tank, intake (influent) system, aeration system, and decant (discharge) system (Fig. 2). SBR tank was made of Polyvinylchlorid. The shape of base is square with each side of 1.0 m and the effective depth of 1.2 m. In each cycle, the wastewater was fed to the reactor. The volumetric exchange ratio in the reactor was 1/2. Discharge volume of each cycle is equal to 0.5 m³. By using intake pump can carry influent (wastewater) from primary sedimentation tank (equalization tank) to SBR tank. Flow capacity was 35 L/min. The wastewater pump start-up and shut down by the water level sensor control in the SBR tank. Aeration was achieved by an aquarium-type air pump (the model is ACO-010, and its largest aeration capacity is 170 L/min) connected with sintered-sand diffusers at the bottom of the SBR tank. The sand diffusers firstly were fixed at the height of 0.3 m from the bottom of the tank, but this height was not benefit for the sludge aeration. Therefore, we changed it to 0.1 m from the bottom of the SBR tank. It ensured a good aeration for the sludge and wastewater treatment.

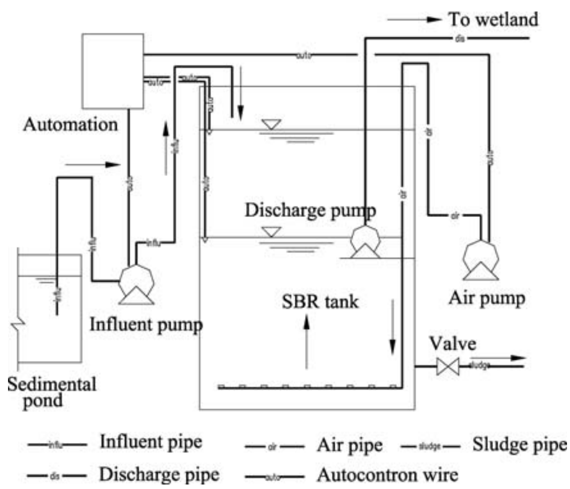

Fig. 2 Sequencing batch reactor (SBR) system

2.2.2 *CW system*

CW consists of three lateral wetlands bed, natural aeration chutes, and stabilization pond. The parallel diversion walls divide the CW into S-shaped flow gallery. The slope of gallery (corridor) bottom is 1% along the flow direction. The nature aeration chutes in the wetland can improve the dissolved oxygen in domestic wastewater. The CW layout is like a right triangle (Fig. 3). The three lateral beds are like S-shape. Of the first lateral bed (cell), the gallery wide is 0.4 m, effective area is 2.5 m², depth is 0.6 m, volume is 1.5 m³, and aeration slot width is 0.4 m. Of the second lateral bed (cell), the gallery wide is 0.4 m, effective area is 2 m², depth is 0.55 m, volume is 1.1 m³, and aeration slot width is 0.4 m. Of the third lateral bed (cell), the gallery wide is 0.4 m, effective area is 4 m², depth is 0.5 m, volume is 2 m³, and aeration slot width is 0.4 m. The last part of CW is a stabilization pond which is also in S-shape. Its gallery wide is 0.4 m, effective area is 9.3 m², depth is 0.45 m, and volume is 4.2 m³. Table 2 lists the measurement of CW.

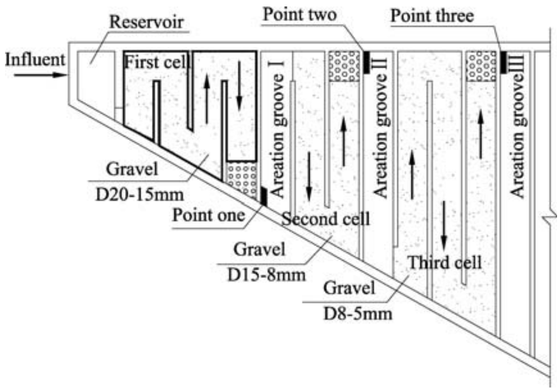

Fig. 3 Constructed wetland plan view

Table 2 Constructed wetland's measurement

Index	Area/m^2	Depth/m	Volume/m^3	Filter volume /m^3	Valid volume /m^3
First cell	2.6	0.65	1.690	1.56	0.55
Aeration groove I	0.9				
Second cell	2.2	0.60	1.320	1.21	0.39
Aeration groove II	1.2				
Third cell	4.5	0.55	2.475	2.25	0.61
Aeration groove III	1.6				
Summation	9.3			5.02	1.55

We used filler in three areas in CW as shown in Fig. 3.

Taking all the factors into consideration, we chose local windmill grass in Chongqing (climate conditions of the Three Gorges reservoir area), Cyperus alternifolius, and aquatic canna as the experimental plants. The wetland plants were used in the experiment.

3 Experiment design

The experiment was started from March to September in 2007. The temperature is above 15 °C, suitable for living sludge organism. In these conditions, SBR operated as 4 cyclic modes as shown in Fig. 4. In each cycle, the volume of treated wastewater is 0.5 m^3.

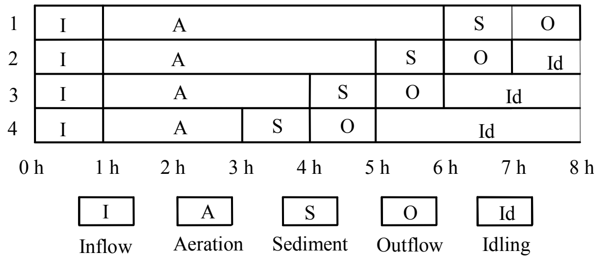

Fig. 4 Sequencing batch reactor operate cycle

Aeration intensity and aeration time are very important for SBR system, so the dissolved oxygen (DO) concentration of SBR is controlled from 0.5 mg/L to 1.0 mg/L [4]. Limited low DO can reduce the energy of SBR.

The wastewater volume treated by CW is 1.5 m^3/d, the valid volume of CW is 1.55 m^3, the HRT (hydraulic retention time) is 24.8 h, and the hydraulic load rate is 24.5 cm/d.

4 Results and discussion

4.1 COD removal under normal temperature

The effect of aeration time on the COD removal was studied at different operation cycle modes under low dissolved oxygen (0.5 mg/L to 1.0 mg/L) as shown in Fig. 4.

The COD oxidization is not affected under low DO. COD removal in each SBR operation cyclic mode is over 75% (Fig. 5), and COD concentration of the effluent is reduced to a lower concentration. The removal of COD mainly occurred in the first hour because of the dilution reactor and the biological activated sludge adsorption.

Because the SBR performance for COD degradation is high (SBR removal efficiency is high), CW for COD removal will not performed fully (CW removal efficiency is low). It means that the performance of CW for COD degradation rate depends on the quality of COD influent which comes from SBR. When the COD of the effluent from SBR is in a high concentration, CW for COD removal efficiency will increase correspondingly. On the contrary, when the COD of the effluent SBR is in a low concentration, the removal efficiency of CW will reduced accordingly.

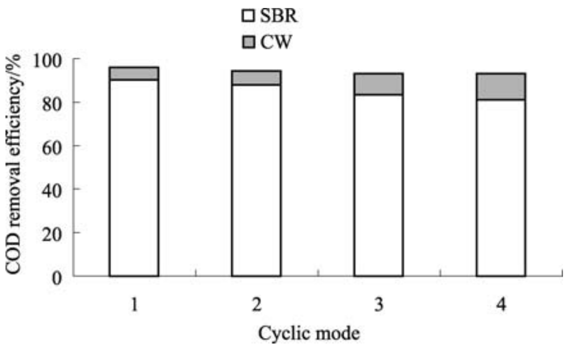

Fig. 5 Chemical oxygen demand (COD) removal efficiency by combination process of different cyclic modes 1 to 4

The COD concentration of different operation cyclic modes 1 to 4 can meet the standard. In the 4th operation cyclic mode, the COD concentration is 17 mg/L, which satisfies the urban landscape water standards. And energy consumption is the minimum, so that the 4th operation cyclic mode will be recommended as the best cyclic mode.

4.2 Ammonia removal under normal temperature

SBR reactor operated under limited aeration (0.5 mg/L to 1.0 mg/L), and the ammonia oxidation was not significantly affected. The ammonia degradation process was effected by the COD concentration. The COD removal started firstly, and after that the ammonia removal began. In the first hour of aeration, the COD concentration was high and the rate of heterotrophic bacteria quickly increased, so that COD degradation was fast, which made self-support type of nitrifying bacteria inhibited. Therefore, the denitrification rate was slow, and the speed of reducing ammonia concentration was slower.

After 1 h aeration, the COD degradation accomplished, and the ammonia degradation rate increased. The ammonia degradation has not been completed in the SBR to meet standards, so that more treatment needs to be accomplish by CW. After CW treatment, the concentration of ammonia nitrogen in the effluent fell beyond 5 mg/L. The reason is that oxygen supplied by roots and DO of the natural anaerobic bed made the wetland bed become consecutively aerobic, anoxic and anaerobic in the CW system. It was equivalent to a lot of series-wound or shunt-wound A^2/O unit, which made nitrification and denitrification occur simultaneously in the wetland system.

Under normal temperature, the combined process made the removal of ammonia nitrogen efficiently. The density of COD in the effluent was less than 5 mg/L. The water can meet effluent standards.

CW treatment efficiency of ammonia nitrogen removal is as shown in Fig. 6. It can be seen from Fig. 6 that the 4th operation cyclic mode is the best cyclic mode to meet the standard and it is a cost-effective mode.

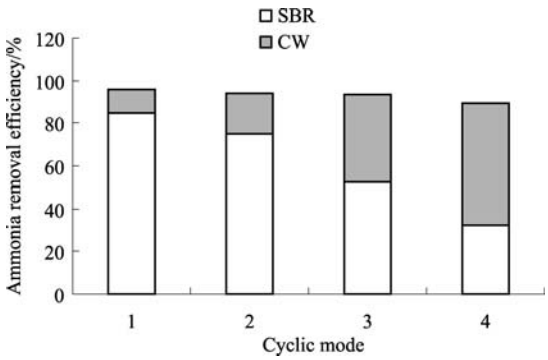

Fig. 6 Ammonia removal efficiency by combine process of different cyclic modes 1 to 4

4.3 Total nitrogen (TN) removal under normal temperature

Under normal temperature and limited aeration circumstances, TN removal in SBR appeared by nitrification and denitrification simultaneously.

In the process of influent water, TN in the sewage sharply decreased due to dilution. Because of synchronic nitrification and denitrification, TN always demonstrated the tendency of descent. After dilution, TN was degraded to 15 mg/L to 20 mg/L by the nitrification and denitrification.

In the CW system, the removal of TN was due to the capacity of oxygen supplied by the plants. The plants in CW flourished heavily, and the developed roots had lots of fibrous roots [5]. The vascular species of roots absorbed the oxygen in the air and transported it into the wetland bed matrix.

Except the oxygen supplied by the roots, the DO concentration of the CW was enhanced by the natural reoxygenation bed in the experiment. The DO concentration of the reoxygenation bed raised along with the increase of reoxygenation bed length, and the effects of DO mainly depended on the length of the bed. The relationship between DO and length of reoxygenation bed is positive and linear as shown in Fig. 7.

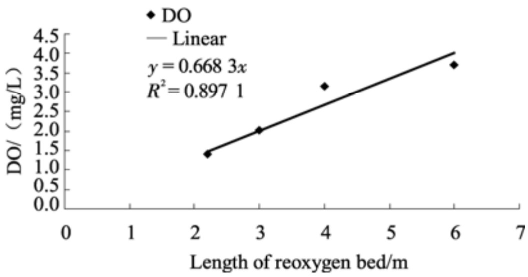

Fig. 7 Relationship between dissolved oxygen (DO) and length of reoxygenation bed

Due to the degradation of ammonia nitrogen and TN by the SBR, the density of TN was almost less than 30 mg/L before the CW process.

When the nitrogen compounds went to the CW, its degradation process was similar to the sewage treatment of A^2/O because of the oxygen supplied by the roots and DO supplied by the natural reoxygenation bed. CW change ammonia nitrogen in the sewage into nitrate nitrogen in the oxidation zone, and the nitrate was deoxidated into NO_2^- by the denitrifying bacteria in the anaerobic zone, finally it was removed by deoxidated into N_2 [6]. The nitrate nitrogen was removed in the denitrifying process by the oxidation zone and anaerobic zone of the CW. Under the circumstances, there was no oxygen but nitrate which was used by the denitrifying bacteria to breathe. The oxygen decomposed organic compound so that the nitrate would be deoxidated into N_2 or N_2O [7].

After the action by the deposition, volatile, adsorption, and microbes of the CW, the plants absorbed the descend concentration of TN which was between 15 mg/L and 20 mg/L. Except the 4th operation cyclic mode, other modes can make the content of TN in the effluent water meet the standards. The removal efficiency of TN in the combined process is as shown in Fig. 8.

On the premise that the effluent water reached the standards, CW treatment was effective for TN removal and gave high removal efficiency in the combined process operation. The 3rd operation cyclic mode was the best cyclic mode because it can meet the standard and was a cost-effective mode.

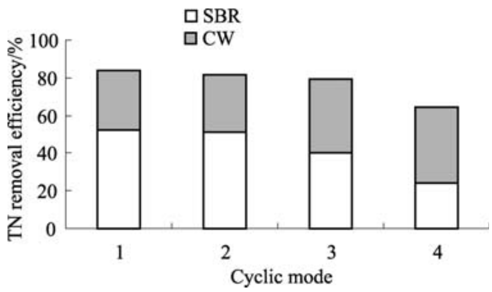

Fig. 8 Total nitrogen (TN) removal efficiency by combine process of different cyclic modes 1 to 4

4.4 *Total phosphorus (TP) removal under normal temperature*

After 1 h, SBR reactor settling, the percentage of sludge contained in the SBR reactor was between 30% and 35%. The sludge was drained 15 L a day in volume from the bottom sludge pipe of SBR. The sludge age was about 20 d.

In conditions of low oxygen aeration in the whole process, the SBR system obviously appeared a phenomenon that the phosphorus was released and absorbed. The phenomenon of phosphorus releasing appeared in the early stage under the circumstance of continuous low oxygen aeration. The average concentration of TP under normal temperature was 5.84 mg/L. After 1 h low oxygen aeration, the average concentration of TP in the reactor increased to 6.73 mg/L. The time of low oxygen aeration lasted from 3 h to 5 h, and the concentration of phosphorus in the effluent water decreased to 2.34 mg/L to 3.52 mg/L. The percentage of removal efficiency was between 42% and 56%.

The removal efficiency of phosphorus in the CW system was stable. The phosphorus removal mainly depended on microorganisms, plant absorption and packed bed physical chemistry of matrix [8]. The plant growth needed inorganic phosphorus. On one hand, because of the impact of absorption and assimilation by plants, the inorganic phosphorus in the sewage was synthesized into adenosine triphosphate (ATP), deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), and the phosphorus was removed by reaping plants. On the other hand, the phosphorus was normally assimilated by the microorganism and accumulated by the polyphosphoric bacteria. Therefore, the phosphorus removal in the system depended on regularly changing of the wetland bed. The photosynthesis and respiration of plants alternated in the CW. The quantity of oxygen supplied by the roots correspondingly varied with the alternation of the light intensity, and the wetland bed was different. Aerobic and anaerobic conditions appeared in the system owing to different rate of oxygen in the region, which facilitated the release and excessive accumulation of phosphorus by the microorganism. During the dephosphorization process in the CW, the phosphorus was removed by the plant and the microorganism. Although they were not the main methods, they affected the cycle of phosphorus in the CW [9].

Except in the 4th operation cyclic mode, the TP concentration of the effluent water in other three modes was below 0.5 mg/L, which meet the standard. The removal efficiency of TP in the combined process is as shown in Fig. 9.

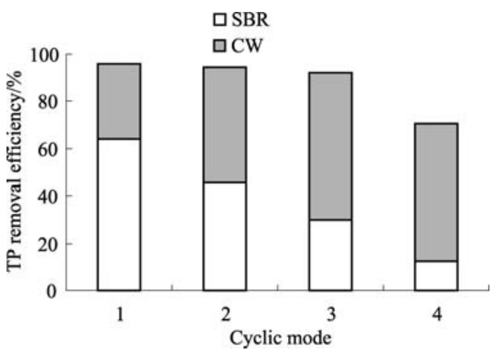

Fig. 9 Total phosphorous (TP) removal efficiency by combining process of different cyclic modes 1 to 4

On the premise that the effluent water reached the standard, CW treatment was effective for TP removal and gave high removal efficiency in the combined process operation. The 3rd operation cyclic mode was the best cyclic mode and it was a cost-effective mode.

4.5 Optimum operation under normal temperature

By statistically analyzing the removal efficiency of COD, ammonia nitrogen, TN, and TP in the combined process (Fig. 10), it can be found that COD and ammonia nitrogen were mainly removed by the SBR, and TN and TP were effectually removed by the CW [9].

Under normal temperature, the 3rd cycle (SBR's operation cycle is 8 h: inflow for 1 h, limited aeration for 3 h, sediment for 1 h, outflow for 1 h, and idling for 2 h; CW's HRT is 24.8 h and hydraulic loading is 24.5 m^3/m^2 d) is the best cyclic mode. The effluents can meet the standard GB/T18921-2002: "The reuse of urban recycling water: water quality standard for scenic environment use". In the 3rd cycle, the efficiency of CW is the maximum, and energy consumption of SBR is the minimum.

Fig. 11 shows the relationship of COD, ammonia, TN, and TP in the 3rd cycle of SBR.

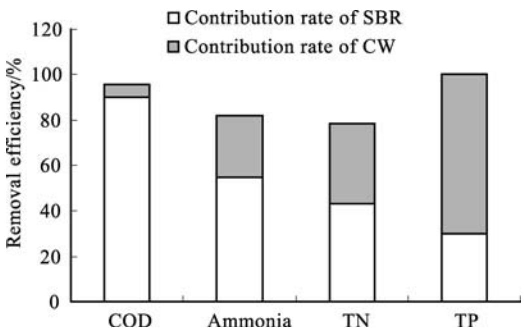

Fig. 10 Removal efficiency of chemical oxygen demand (COD), ammonia, total nitrogen (TN), and total phosphorous (TP) in combined process

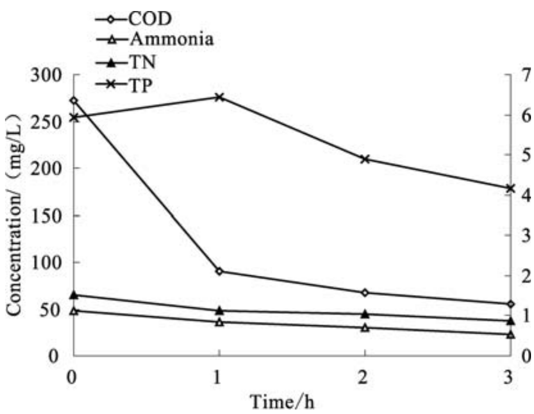

Fig. 11 Relationship of COD (chemical oxygen demand), ammonia, TN (total nitrogen), TP (total phosphorus) in the 3rd cycle of sequencing batch reactor

5 Conclusions

1) Under normal temperature, the 3rd cycle (SBR's operation cycle is 8 h: inflow for 1 h, limited aeration for 3 h, sediment for 1 h, outflow for 1 h, and idling for 2 h; CW's HRT is 24.8 h and hydraulic loading is 24.5 m^3/m^2 d) is the best cyclic mode. The effluents can meet the standard GB/T18921-2002: "The reuse of

urban recycling water: water quality standard for scenic environment use". In the 3rd cycle, the efficiency of CW is the maximum, and energy consumption of SBR is the minimum.

2) To control the DO concentration between 0.5 mg/L and 1.0 mg/L, the aeration concentration should be from 1 m^3/h to 2 m^3/h. Under low oxygen condition, the removal efficiency of COD and ammonia was not affected obviously. Simultaneously, nitrification and denitrification phenomena occured and phosphorus was absorbed obviously in SBR.

3) The removal of TN and TP was not affected obviously by influent and temperature in CW. The removal efficiency of TN was 2.2 mg/m^2d, and the 2nd and 3rd cells in CW were important for TN removal.

4) Under normal temperature, removal of COD and ammonia largely depended on SBR, and removal of TN and TP largely depended on CW.

5) Reoxygenation bed in the CW was available for enhancing the dissolved oxygen. The dissolved oxygen amount and the length of reoxygenation bed follow the normal-phase linear relationship.

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