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Simultaneous Nitrogen and Phosphorus Removal by Denitrifying Dephosphatation in a $(AO)_2$ Sequencing Batch Reactor

ZHANG Yan-ping (张艳萍), PENG Yong-zhen (彭永臻), WANG Shu-ying (王淑莹), WANG Shao-po(王少坡)

(Key Laboratory of Beijing for Water Quality Science and Water Environment Recovery Engineering, Beijing University of Technology, Beijing 100022, China)

Abstract: A 24 L working volume reactor was used for the research on simultaneous phosphorus (P) and nitrogen (N) removal by denitrifying dephosphatation in an anaerobic-oxid-anoxic-oxid sequencing batch reactor ($(AO)_2SBR$) system. The durations of each phase are: anaerobic 1.5 h, aerobic 2.5 h, anoxic 1.5 h, post-aerobic 0.5 h, settling 1.0 h, fill 0.5 h. The successful removal of nitrogen and phosphorus is achieved in a stable $(AO)_2SBR$. The effluent P concentrations is below 1 mg/L, and the COD, TN and P average removal efficiency is 88.9%, 77.5% and 88.7%, respectively. The batch experiment results show that the durations of aerobic and anoxic phase influence the P removal efficiency. Some feature points are found on the DO, ORP and pH curves to demonstrate the complete of phosphate release and phosphate uptake. These feature points can be used for the control of $(AO)_2$ SBR.

Key words: domestic wastewater; sequencing batch reactor; denitrifying dephosphatation; nitrogen removal

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Nitrogen (N) and phosphorus (P) can be simultaneously removed from wastewater in the biological nutrient removal (BNR) process[1]. A number of BNR processes have been developed in the past decade. Nevertheless, the biological mechanisms are not completely understood. In the convenient opitions, nitrate is an inhibiting factor on P removal[2]. It reduces P release in anaerobic stage and diminishes P uptake in aerobic stage. However, based on recent studies[3,4], it is apparent that some denitrifying phosphorus removal bacteria (DPB) can utilize nitrate as electron acceptor instead of oxygen. As a result, both P uptake and denitrification can be achieved in the same reactor. The energy and carbon resource requirement are reduced accordingly.

$(AO)_2SBR$ is a newly develop process. An anoxic phase is introduced into the middle of aerobic phase of anaerobic-aerobic sequencing batch reactor, because it is a single sludge system, successful removal of N and P require making the condition favorable for DPB[5].

The character of N and P removal in $(AO)_2SBR$ is investigated by means of varied aerobic/anoxic durations. The dissolved oxygen (DO), pH and oxidation-reduction potential (ORP) are also monitored to find the control point of SBR system.

1 Material and Methods

1.1 SBR System

A cylindrical vessel with 24 L working volume was used for the SBR reactor, which was operated in a fill-and-draw mode shown as Fig. 1. Each cycle consisted of 0.5 h feed, 1.5 h anaerobic, 2.5 h

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Biographies ZHANG Yan-ping(1971 -), doctoral student, zyp@emails.bjut.edu.cn; PENG Yong-zhen(1949 -), professor, doctoral adviser.

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aerobic, 2.0 h anoxic, 0.5 h aerobic and 1.0 h settling stages. There were two cycles each day.

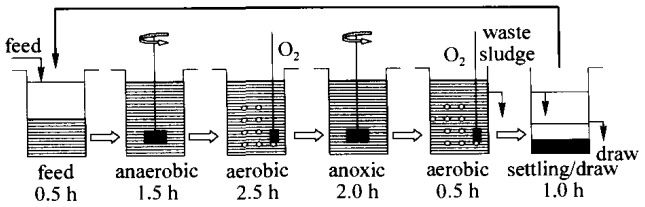

Fig. 1 Schematic chart of the $(AO)_2$ SBR system

The clarified supernatant was withdrawn from the reactor at the end of settling stage and the fresh wastewater was pumped into the reactor during the filling stage. The solid retention time (SRT) was maintained 16 d by wasting 0.75 L mixed liquor at the end of post-aerobic stage. DO, ORP and pH were continuously monitored through the experiment.

1.2 Sludge and Wastewater

The actual domestic sewage from the district in Beijing University of Technology was used for the operation. The characteristics of the wastewater were shown in Tab. 1. The activated sludge was seeded by the sludge from a Waste Water Treatment Plant (WWTP) in Beijing. The sludge had been cultivated for two months before this research.

Tab. 1 The characteristics of actual domestic wastewater

parameter	$\rho(COD)/(mg\cdot L^{-1})$	$\rho(NH_4^+)/(mg\cdot L^{-1})$	$\rho(TN)/(mg\cdot L^{-1})$	$\rho(TP)/(mg\cdot L^{-1})$	pH	alkalinity
range	172 – 456	43.8 – 65.2	55.2 – 76.8	4.2 – 9.8	6.8 – 7.4	310 – 405
mean	236	48.6	63.4	6.1	7.2	356

Sodium acetate was added into wastewater to make $\rho(COD):\rho(TN)=7-8:1$, just as that of the common municipal wastewater. NH_4Cl, KH_2PO_4 were used to adjust the NH_4-N and P content in the wastewater, respectively. The PO_4^{3-} concentration of influent was maintained to about 10 mg/L.

1.3 Batch Experiment

Three 4 L working volume glass vessels were used as reactors in the batch experiment. The activated sludge in the $(AO)_2$SBR was transferred and operated in parallel. Operation conditions of these three vessels were shown in Fig. 2.

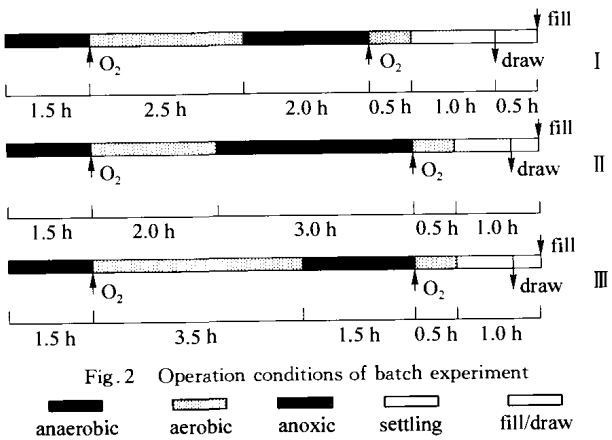

Fig. 2 Operation conditions of batch experiment

1.4 Analytical Methods

The DO and temperature were measured continuously with a WTW oxygen probe. PH and ORP were continuously monitored by using two WTW inolab pH meters with ORP electrode and pH probe, respectively. All analyses (COD, PO_4^{3-}, NO_3^-, TN, TP) were performed in accordance with standard methods[6].

2 Results and Discussion

2.1 Performance of $(AO)_2$SBR

Fig. 3 shows the change of PO_4^{3-} concentration in the effluent and the P removal efficiency during 20 cycles of SBR operation. PO_4^{3-} concentration at the end of the anaerobic phase is also shown in Fig. 3. The PO_4^{3-} concentration at the end of anaerobic phase is about 20 – 25 mg/L, and that in effluent is usually below 1 mg/L. The average P removal efficiency is

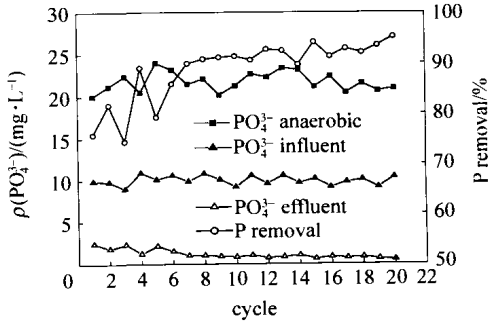

Fig. 3 Phosphate removal of $(AO)_2$ SBR

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88.7%. The significant P uptake is observed in the anoxic phase, and this high activity of anoxic phosphate uptake maintains for over two months. The changes of TN, COD in the influent and effluent including their removal efficiency are shown in Fig.4.

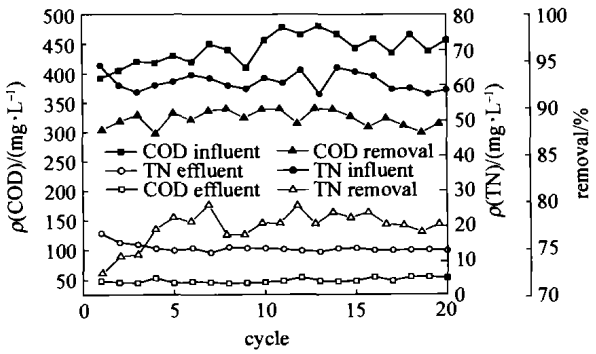

Fig.4 TN and COD removal of $(AO)_2$ SBR

Fig. 4 shows that the removal of COD in $(AO)_2$SBR system is quite stable. The average COD of influent is 441 mg/L throughout the 20 cycles operation. The average COD of effluent is maintained at 44 mg/L, and the average COD removal efficiency reaches 88.9%. The condition in anoxic phase might be favorable for the DPB in $(AO)_2$SBR system, and nitrogen could be successfully removed by denitrifying dephosphatation. The average TN concentration in effluent is 13.8 mg/L, and the removal efficiency of TN is 77.5%.

2.2 The Effect of Aerobic/Anoxic Duration on Phosphorus Removal

The durations of aerobic and anoxic phase in batch I are the same as that in the $(AO)_2$SBR reactor. It is used as a control reactor. In the batch Ⅱ, the aerobic phase is shortened to 2 h and the anoxic phase is extended to 3 h. The main purpose is to investigate if the anoxic phosphorus uptake will be enhanced by extending anoxic time. The P, N and COD variation in a cycle of batch experiment are shown in Fig. 5. The results show that the anoxic phosphate removal is 6.4 mg/L in anoxic phase, it is more than the anoxic phosphorus uptake in the batch Ⅰ (3.9 mg/L).

In the batch Ⅲ, the aerobic phase is lengthen to 3.5 h. The change of COD, PO_4^{3-}-P and NO_3^--N in one cycle is shown in Fig.6. The TN concentration does not decrease but increases in anoxic phase. The reason might be: the time of aerobic phase is too long and most of the carbon resourse is exhausted, there is not enough carbon resource to supply energy for anoxic phosphorus uptake. In order to obtain the necessary energy for metabolization, the polyphosphate particles is hydrolyzed by PAO. So P release occurs in the anoxic phase.

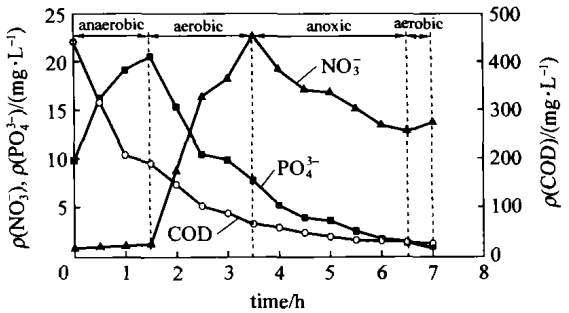

Fig.5 P, N and COD variation in batch Ⅱ reactor

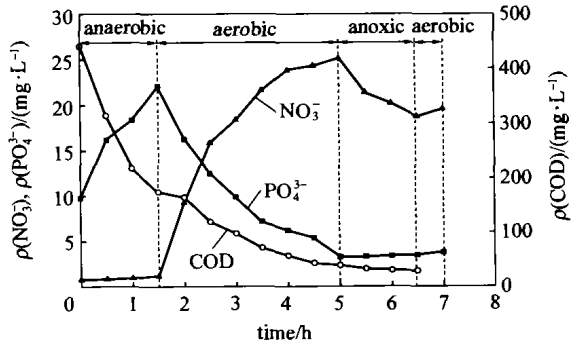

Fig.6 P, N and COD variation in batch Ⅲ reactor

The batch experiment results show that the durations of aerobic and anoxic phase relate to the N and P removal efficiency. The moderately long duration of anoxic phase can enhance the denitrifying P uptake, and improve the N and P removal. But considering the insufficient carbon resource in wastewater, the aerobic phase duration cannot be too long. The effect of N and P removal gets worse in the subsequent anoxic phase when the duration of aerobic phase exceeds 3 h.

2.3 DO, pH and ORP Curves

Typical curves of COD, PO_4^{3-}, NH_4^+ and NO_3^- concentrations and the corresponding DO, ORP and pH curves of the $(AO)_2$SBR are shown in Fig.7 and Fig.8, respectively. Fig.7 exhibits the P removal characteristics in different phases of $(AO)_2$SBR:

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① Anaerobic phase: the COD is removed quickly in 1.5 h anaerobic phase. With the removal of COD, P is released in the mixed liquor. The rate of P release is corresponding to the COD removal.

② Aerobic phase: the P uptake occurs when aeration begins. The uptake rate decreases with the increase of DO. The COD is decomposed throughout the aerobic phase. But the removal rate is lower than that in anaerobic phase.

③ Anoxic phase: The P uptake rate decreases slightly. The PO_4^{3-} concentration still decreases slowly.

④ Post-aerobic phase: The P uptake rate increases because of aeration. And the PO_4^{3-} concentration decreases to below 1 mg/L.

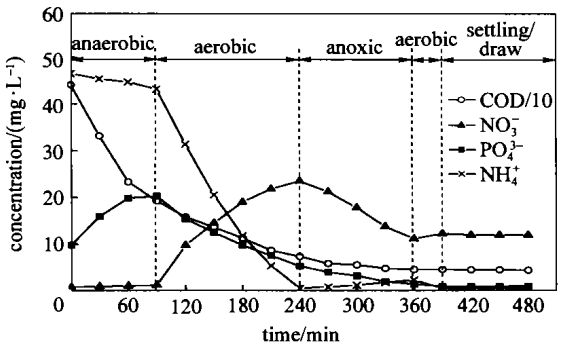

Fig. 7 Typical curves of COD, PO_4^{3-}, NH_4^+ and NO_3^- in the $(AO)_2$ SBR

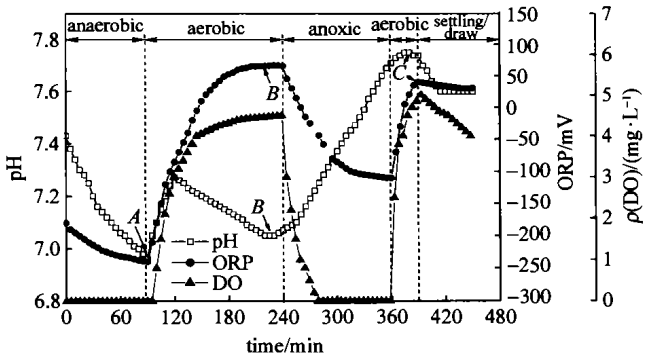

Fig. 8 Curves of pH, ORP and DO in the $(AO)_2$ SBR

Fig. 7 shows that there is P uptake in both aerobic and anoxic phases in $(AO)_2$SBR system. The condition in anoxic phase might be favorable for DPB, which utilize nitrate as an electron acceptor to take up P. N and P can be simultaneously removed by denitrifying dephosphatation.

The real time control of SBR system used for nutrient removal has been considered difficult because on-line measurements of nutrient concentrations are often difficult and costly. However, it has been reported that these nutrient concentrations are somehow related with the on-line sensor values such as pH and ORP in the SBR operations[7,8].

Fig. 8 represents typical DO, ORP and pH curves in one cycle of $(AO)_2$SBR. A number of features of ORP and pH are illustrated. These features are response to the changes within the reaction in the system. ORP continuously decreases during anaerobic stage mainly due to the P release. The ORP decreases at a slower pace until the P release ceased at point *A*. There is the same bend point on the pH curve.

Feature point *B* is the plateau of the ORP value during the first aerated period. This plateau indicates that the system has reached a fully oxidized state. By contrasting Fig. 8 with Fig. 7, it is found that point *B* coincided with the end of NH_4^+ conversion to NO_3^-. This point is very useful to adjust the duration of the first aerobic phase. Since NO_3^- can be used as an electron acceptor in the subsequent anoxic phase, the high concentrations of nitrate would be favorable for DPB and increasing the anoxic phosphate uptake.

Feature point *B* is obvious on the pH curve too. After the initial increase caused by the stripping of CO_2, pH decreases continuously in the aerobic stage and eventually reaches a valley at point *B*. The decrease of pH is mainly due to the release of H^+ from nitrification.

Feature point *C* is another plateau of ORP during the post-aerobic period. The sharp increase of pH is observed in the anoxic phase because the anoxic phosphate uptake consumes H^+ in the reactor. In the post-aerobic phase, pH increases continuously and reaches a relatively constant value as the P uptake ends.

The point *A* corresponding to the end of P release can be determined by the second derivative of the pH and ORP curves ($d^2pH/d^2t=0$, $d^2ORP/d^2t=0$), points *B* and *C* are the minimum and maximum of pH curve, and can also be identified by the first derivative of the pH curve ($dpH/dt=0$). Therefore, the on-line curves of pH and ORP can detect the ends

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of P release, ammonia conversion and P uptake, and be used as a real time control parameters for $(AO)_2SBR$.

3 Conclusions

The durations of aerobic and anoxic phase influence the P removal efficiency. In this experiment, when we extend anoxic phase to 3 h, the anoxic phosphorus uptake is enhanced. When the duration of aerobic phase exceeds 3 h, most of the carbon resource is exhausted in the aerobic phase. The P release occurs in the subsequent anoxic phase, and the effect of P removal gets worse accordingly.

The stabilized $(AO)_2SBR$ system has the good capability to remove N and P. The effluent P concentrations is below 1 mg/L. The COD, TN and P average removal efficiency are 88.9%, 77.5% and 88.7%, respectively.

ORP and pH can be used as control parameters for $(AO)_2SBR$ system. There are some feature points on the ORP and pH curves. These features can demonstrate the complete of P release and P uptake. The point coinciding with the end of NH_4^+ converting to NO_3^- is very useful for determining the start of anoxic phase.

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