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# Optimization of a cyclic activated sludge system for norfloxacin wastewater treatment under low-load conditions

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**ABSTRACT**

A sewage treatment station was used to treat the pharmaceutical intermediate wastewater of norfloxacin. The designed influent was 480 $m^3$ $d^{-1}$, but the actual influent was only 100 $m^3$ $d^{-1}$. Thus, the cyclic activated sludge system (CASS) was under low-load conditions, which demonstrated poor operation. In this experiment, the optimal operating parameters of the CASS under low-load conditions were studied by adjusting the inflow duration, return sludge ratio, aeration time, dissolved oxygen (DO) concentration, and mixed liquid volatile suspended solids (MLVSS) concentration to improve pollutant removal. The results showed that the optimal inflow duration was 4 h, the return sludge ratio was adjusted from 100% to 133%, the aeration time was 6 h, the DO concentration was adjusted from the designed parameter of 2.0 mg $L^{-1}$ to the range of 2.8~3.0 mg $L^{-1}$, and the MLVSS concentration was adjusted from the designed parameter of 2,500 mg $L^{-1}$ to the range of 2,300~2,500 mg $L^{-1}$. Under these optimal operating conditions, the entire effluent could meet the local indirect discharge standard of Henan Province. Furthermore, the guaranteed rate of the effluent reaching the standard exceeded 95%.

*Keywords:* Cyclic activated sludge system; Effluent water quality; Guarantee rate; Low-load conditions; Operation parameters; Pharmaceutical wastewater

## 1. Introduction

The pharmaceutical industry produces 250 million tons of wastewater every year in China. Pharmaceutical wastewater generally contains many drug residues and antibiotics, which have a certain degree of biological toxicity and are difficult to degrade. Wastewater pretreatment before sewage treatment increases the burden of the biological treatment system [1,2]. Due to the difference in molecular structure and content of different antibiotics, the removal effects of sewage treatment on antibiotics are also different. Therefore, some antibiotics can leak out and contaminate natural waters [3,4].

Fine Chemical Co., Ltd., produces 3,000 tons of fluorine-containing fine chemical intermediates per year. In the synthesis process of ethyl 7-chloro-6-fluoro-1-ethyl-1 and 4-dihydro-4-oxo-quinoline-3-carboxylic acid borate, a large amount of highly concentrated organic wastewater is discharged through condensation, cyclization, ethylation, and chelation. In the synthesis process of 2-chloro-5-trifluoromethylpyridine and trifluoromethylphenol, the hydrogenation wastewater, phenol-containing wastewater, fluorine-containing wastewater, and rectification residue are discharged. This organic wastewater contains a large number of toxic, carcinogenic and teratogenic organic pollutants (such as nitrobenzene, aniline, volatile phenol, organic fluoride, etc.) [5]. Additionally, low concentrations of flushing wastewater, desalting water, cooling circulating water, and factory sewage are discharged. A coupled metal reduction-oxidation (CMRO) reactor is used in the pretreatment

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step at the station. After pretreatment, some quinolones that are difficult to biotreat are further removed by anaerobic hydrolysis acidification. Moreover, the color of the water becomes lighter, showing improved water quality due to a larger decrease in the chemical oxygen demand (COD, more than 40%). The treated wastewater flows into a cyclic activated sludge system (CASS) and is drained out after meeting the design standard. The process is shown in Fig. 1.

Previous results have shown that the CASS used to treat wastewater from the Fine Chemical Co., Ltd., is not effective, especially in regard to the COD. There are two main problems: (1) the designed wastewater capacity of the sewage station is 480 $m^3\ d^{-1}$, but the operation of the sewage station is not up to full load. This situation occurs because the actual wastewater treatment capacity of the sewage station is 100 $m^3\ d^{-1}$, but the operation scheme is designed according to a full load. Therefore, there are problems, such as the excess aeration capacity of the blowers, less settling of the sludge and a large fluctuation in the return sludge flow. (2) The CASS is running under low-load conditions, and the sludge activity is low due to the lack of a carbon source. Therefore, it is difficult to run stably according to the designed operation scheme.

In this experiment, the actual CASS operation is debugged by adjusting the operating parameters, such as the aeration time, mixed liquid volatile suspended solids (MLVSS) concentration, return sludge ratio, inflow duration, and dissolved oxygen (DO) concentration. Suitable operation conditions of the process were determined with pharmaceutical wastewater containing norfloxacin intermediates treated under low-load operation conditions. Finally, the discharged effluent reaches the standard.

Stable operation of norfloxacin wastewater under low-load conditions by a CASS has not been reported. This study can provide a reference for the biological treatment of refractory antibiotic wastewater under low-load conditions.

## 2. Materials and methods

### *2.1. CASS reactor*

There were two CASS reactors in the sewage station, and the total designed flow was 480 $m^3\ d^{-1}$. That is, the single-designed flow was 240 $m^3\ d^{-1}$. However, the actual average inflow was only 100 $m^3\ d^{-1}$, so only one CASS reactor was run. The schematic diagram is shown in Fig. 2. The length of the pond was 20.0 m, the width was 4.0 m, the depth was 6.0 m, the maximum water depth was 5.0 m, and the total effective volume was 400 $m^3$. The main body of the reactor was divided into three parts: the volume of the bioselective area was 16 $m^3$, the volume of the prereaction area was 64 $m^3$, and the volume of the main reaction area was 320 $m^3$. A submersible mixer was installed in the prereaction area. Two return sludge pumps (one of which contained frequency conversion technology), one jet tube aerator, two circulating water pumps and one decanter were installed in the main reaction area.

The cyclic period of the CASS was 8 h, in which the aeration time was 6 h, the inflow duration was 4 h, the return sludge time was 6 h, the sedimentation time was 0.5 h,

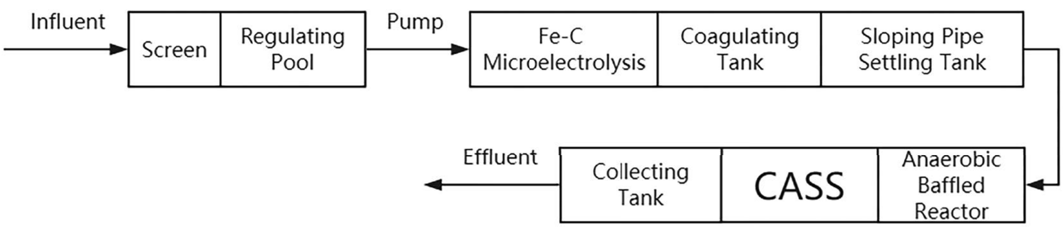


Fig. 1. Flow diagram of the wastewater treatment process.

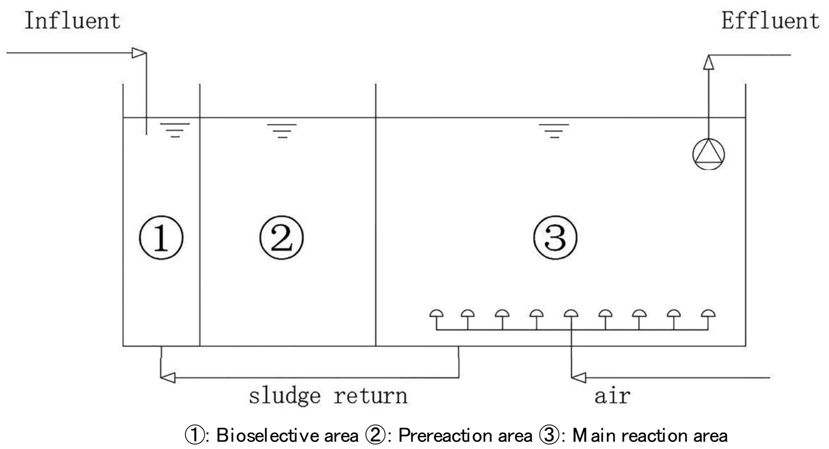


Fig. 2. Schematics of the CASS reactor.

the decanting time was 1.5 h, and the cyclic period was 3 cycles per day. The design included a 1/5 drainage ratio, 2,500 mg $L^{-1}$ MLVSS, 100% return sludge, 20 d of sludge retention time and 2 mg $L^{-1}$ DO.

### 2.2. Wastewater quality

After being treated at a sewage treatment station, the effluent discharge standard based on the local indirect discharge standard of Henan Province, the "Chemical synthetic pharmaceutical industry water pollutants indirect discharge standard" (DB41/756-2012 in Henan Province), was implemented into the limits of the regional wastewater treatment plant. Among these limits, the COD could not exceed 220 mg $L^{-1}$, $NH_3$–N could not exceed 35 mg $L^{-1}$, and total nitrogen (TN) could not exceed 50 mg $L^{-1}$. The quality of influent and effluent wastewater in the CASS design and actual influent water quality are shown in Table 1.

From Table 1 it can be seen that the actual influent wastewater quantity and water quality of the CASS were far lower than the designed wastewater, showing a low-load operation state.

### 2.3. Methods

The experiment was divided into two parts. First, the effects of aeration time, MLVSS concentration, return sludge ratio, inflow duration, and DO concentration on the treatment of COD and $NH_3$–N in the CASS were analyzed. Each group was measured for 30 d, and the optimized operation parameters of the CASS under low-load conditions were determined. Then, according to the optimized results, the operating parameters of the CASS have adjusted accordingly, and the removal of COD and $NH_3$–N by the CASS before and after the adjustments was compared and analyzed.

### 2.4. Analytical methods

The water quality analysis methods used in the experiment were all determined according to the "Determination methods for the examination of water and wastewater" (China). The COD, $NH_3$–N concentration, suspended solids (SS) concentration and MLVSS concentration were measured once a day, and the DO and pH values were measured twice a day. The apparatus was a UV photometer (Model LH-AA9626) and a portable DO meter (Model JPB-607).

### 2.5. Statistical analysis

The statistical analysis was performed using SPSS (IBM SPSS Statistics Version 20). To test whether the effects of different groups of the same independent variables on the CASS removal rate were statistically significant, a one-way analysis of variance (ANOVA) was used. To test whether there was any difference in the pollutant removal effects of the CASS before and after optimization of the operational parameters, a *T*-test was adopted, and the confidence interval was 95%.

## 3. Results and analysis

### 3.1. Effect of the aeration time

The aeration time was changed to 5 h (sedimentation 0.5 h, decanting 1.5 h, and idling 1 h), 6 h (sedimentation 0.5 h and decanting 1.5 h) and 7 h (sedimentation 0.5 h and decanting 0.5 h). The effect of these aeration times on the performance is shown in Fig. 3.

It can be seen from the graph that the average COD removal rate was 80.60% when the aeration time was 5 h and 83.83% when the aeration time was 6 h. There was a significant difference between the two ($P < 0.05$). The average COD removal rate was 84.36% when the aeration time was 7 h, and there was no significant difference between the two when the aeration time was 6 h ($P > 0.05$); thus, the reaction time of 6 h was suitable.

The CASS, in the case of constant water intake per cycle, shortens the reaction time, helping to improve its treatment load. However, the experimental results show that when the reaction time was reduced to 5 h, the COD removal rate was significantly lower than that at 6 h. The treated norfloxacin wastewater contained antibiotics that were difficult to biodegrade. When the reaction time was short, activated sludge had no time to oxidize organic matter containing antibiotics, and the degradation effects of COD were poor [6]. Moreover, a high antibiotics concentration could inhibit the growth and reproduction of activated sludge and prolong the reproduction cycle of activated sludge. An aeration time that was too short was not conducive to the reproduction of activated sludge and the formation of good flocculation. Therefore, the removal effects of COD with an aeration time of 6 h were better than those with an aeration time of 5 h. However, when the aeration time was further increased, the change in the COD removal rate was small, which may lead to the self-oxidative decomposition of activated sludge flocs, the proliferation of filmlike bacteria, and the sedimentation performance of the activated sludge floc became worse [7–9]. Therefore, the optimum aeration time was 6 h.

As shown in Fig. 3, when the aeration time of the CASS was 5, 6 and 7 h, the $NH_3$–N removal rate was over 88%, and there was no significant difference ($P > 0.05$). The results showed that aeration time had less of an effect on $NH_3$–N

Table 1
Designed and actual quality of influent and effluent wastewater in the CASS

| Project | COD (mg $L^{-1}$) | TN (mg $L^{-1}$) | $NH_3$–N (mg $L^{-1}$) | SS (mg $L^{-1}$) |
|---|---|---|---|---|
| Designed influent quality | 1,770 | 100 | 80 | 50 |
| Actual influent quality | 1,000~1,600 | 50~70 | 15~40 | 50~200 |
| Designed effluent quality | 200 | 40 | 25 | 50 |

than COD. In the CASS, the $NH_3$–N concentration in the designed influent was 80 mg $L^{-1}$, but the actual influent concentration was only 15~40 mg $L^{-1}$; furthermore, the amount of wastewater was less than 60% of the designed amount of wastewater. Therefore, the limited ammonia nitrogen was less affected by the reaction time, and the effluent $NH_3$–N concentration reached the discharge standard with aeration times of 5, 6 and 7 h. Finally, the CASS was selected for an aeration time of 6 h. Under this condition, COD and ammonia nitrogen had higher removal rates.

### *3.2. Effect of the MLVSS concentration*

At the end of the aeration time optimization experiment, the MLVSS concentration in the CASS was 3,109 mg $L^{-1}$, and the MLVSS concentration was reduced by gradually discharging sludge. The effects of different MLVSS concentrations (1,600–3,000 mg $L^{-1}$) on the treatment were studied. The results are shown in Fig. 4.

The results show that with increasing MLVSS concentration, the COD removal rate in the effluent of the CASS reactor first increased and then decreased. The optimal MLVSS concentrations were between 2,300~2,500 mg $L^{-1}$, and the average COD removal rate was 84.28%. There was a significant difference between the MLVSS concentrations of 2,300~2,500 mg $L^{-1}$ and the MLVSS concentrations of 1,600~2,300 mg $L^{-1}$ (average removal rate of 79.96%) and 2,500~3,600 mg $L^{-1}$ (average removal rate of 81.57%) ($P < 0.05$), which indicated that the COD removal rate was sensitive to changes in the MLVSS concentration. With increasing MLVSS concentration, the $NH_3$–N removal rate in the CASS reactor first increased and then decreased. The best removal rate occurred for MLVSS concentrations of 2,200~2,500 mg $L^{-1}$, and the average removal rate was

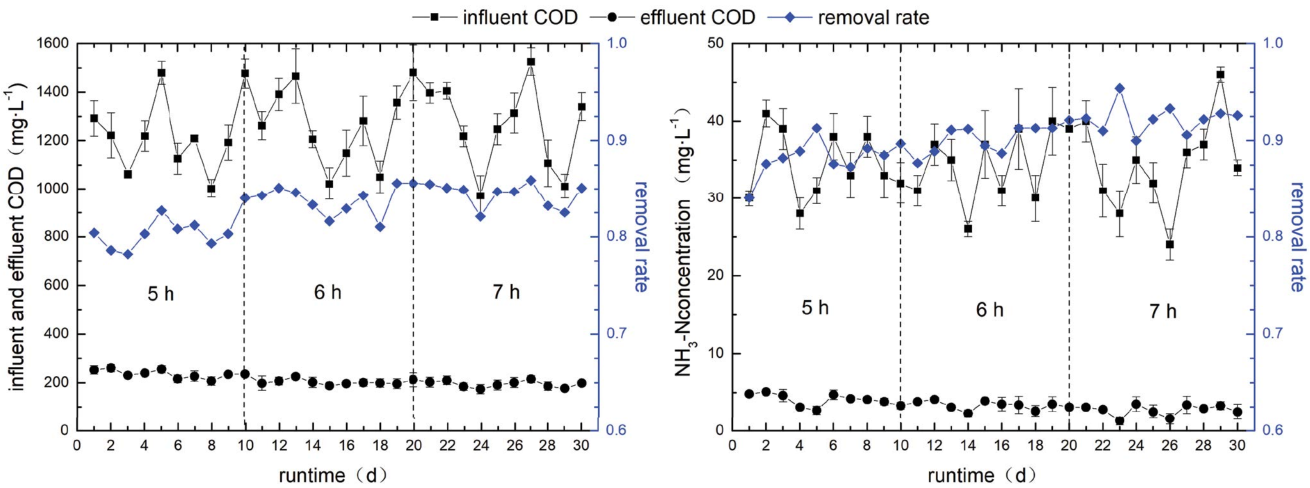


Fig. 3. Effect of the aeration time on the treatment efficiency (MLVSS: 2,500 mg $L^{-1}$, return sludge ratio: 100%, inflow duration: 4 h, DO: 2.0 mg $L^{-1}$).

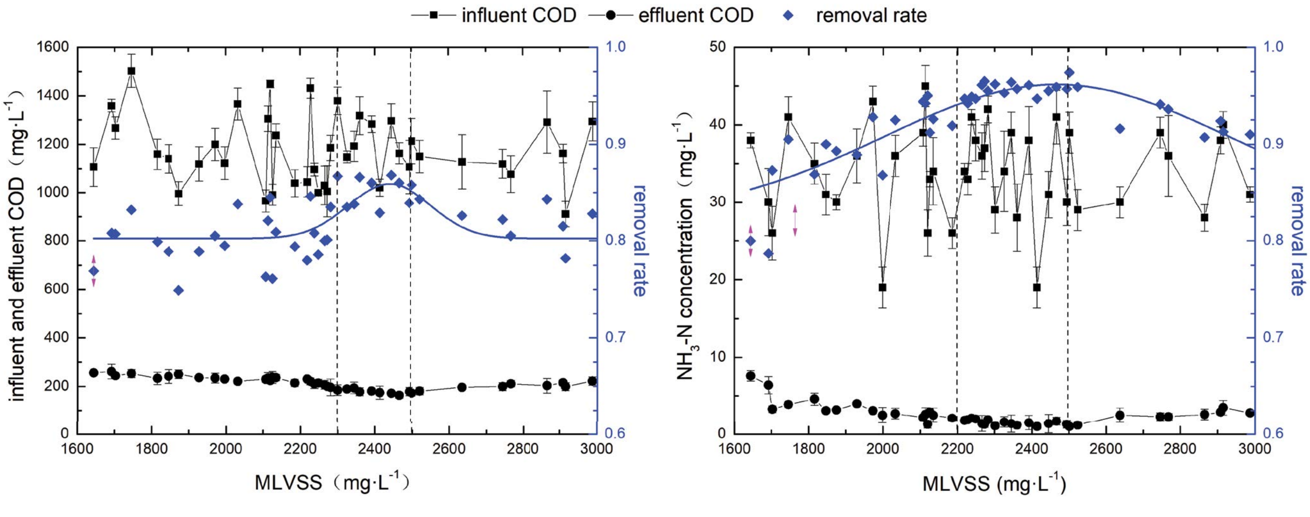


Fig. 4. Effects of the MLVSS concentration on the treatment efficiency (inflow duration: 4 h, return sludge ratio: 100%, aeration time: 6 h, DO: 2.0 mg $L^{-1}$).

95.63%. There was a significant difference between the MLVSS concentrations of 2,200~2,500 mg $L^{-1}$ and the MLVSS concentrations of 1,600~2,200 mg $L^{-1}$ (average removal rate of 89.95%) and 2,500~3,600 mg $L^{-1}$ (average removal rate of 89.38%) ($P$ < 0.05). This result indicates that changes in the volatile sludge concentration also had a significant effect on the removal of $NH_3$–N in the CASS reactor.

The influent wastewater quantity and concentration were lower than the designed value, resulting in a low sludge load and the slow growth of activated sludge. The proper reduction of the MLVSS concentration can increase the sludge load, increase the sludge activity, and improve the removal efficiency of pollutants [10,11]. However, when the MLVSS concentration was too low, the pollutant removal rate decreased. The MLVSS concentration was too low when the number of microorganisms in the CASS was insufficient, and the activated sludge formed fewer flocculants and had poor adsorption and coagulation performance for organic matter, which was not conducive to the adsorption and oxidation of organic matter in wastewater by activated sludge. The slow degradation of organic matter led to an increase in the $BOD_5$/TKN (Total Kjeldahl Nitrogen) ratio in wastewater, which was not conducive to nitrification, and the wastewater treated with norfloxacin contained more antibiotics, making it not conducive to the growth of microorganisms, such as nitrifying bacteria [12–14]. Therefore, the degradation of organic matter and $NH_3$–N was not enough, which affected the treatment effect. The use of MLVSS concentrations from 2,300 to 2,500 mg $L^{-1}$ was very effective for the removal of COD and $NH_3$–N.

### 3.3. Effect of the return sludge ratio

In this study, a return sludge pump was used to recirculate the low-concentration mixed liquid from the main reaction area to the bioselective area, and the return sludge ratio was adjusted to 100%, 133% and 200%. The results are shown in Fig. 5.

The results show that the removal efficiency of COD was 81.48% when the return sludge ratio was 133%, which was significantly different from that when the return sludge ratio was 100% (the average removal rate was 79.56%) ($P$ < 0.05), and there was no significant difference when the return sludge ratio was 200% (average removal rate of 81.25%) ($P$ > 0.05). With an increase in the return sludge ratio, the removal efficiency of $NH_3$–N increased slightly. When the return sludge ratio was 200%, the removal efficiency was the best, and the average removal rate was 91.24%, which was significantly different from the return sludge ratio of 100% (the average removal rate was 88.23%) ($P$ < 0.05). There was no significant difference with a return sludge ratio of 133% (average removal rate of 89.70%) ($P$ > 0.05), so a return sludge ratio of 133% was suitable.

The method of return sludge with aeration was used in this experiment. Increasing the return sludge ratio could buffer the inhibitory effect of antibiotics and other substances in the influent on the growth of activated sludge, shorten the sludge residence time in the main reaction area and increase the sludge load to some extent. Therefore, with increasing sludge activity, the removal efficiency of COD and $NH_3$–N also increased. Although increasing the return sludge ratio was beneficial to increase the operating load, when the return sludge ratio was too large, it was easy to dilute the influent organic matter concentration, resulting in negative effects, such as malnutrition of microorganism in activated sludge, growth of filamentous bacteria, poor flocculation and sedimentation of activated sludge. Moreover, the improvement effect was not obvious, and the energy consumption of the equipment increased. Therefore, the optimal sludge recirculation ratio was 133%, which demonstrated good removal of COD and $NH_3$–N.

### 3.4. Effect of the inflow duration

The design value of the inflow duration was 4 h. The inflow duration was adjusted to 6, 4 and 3 h, and the removal of pollutants under these conditions was tested. The results are shown in Fig. 6.

The experimental results show that changing the inflow duration had a large influence on the COD removal

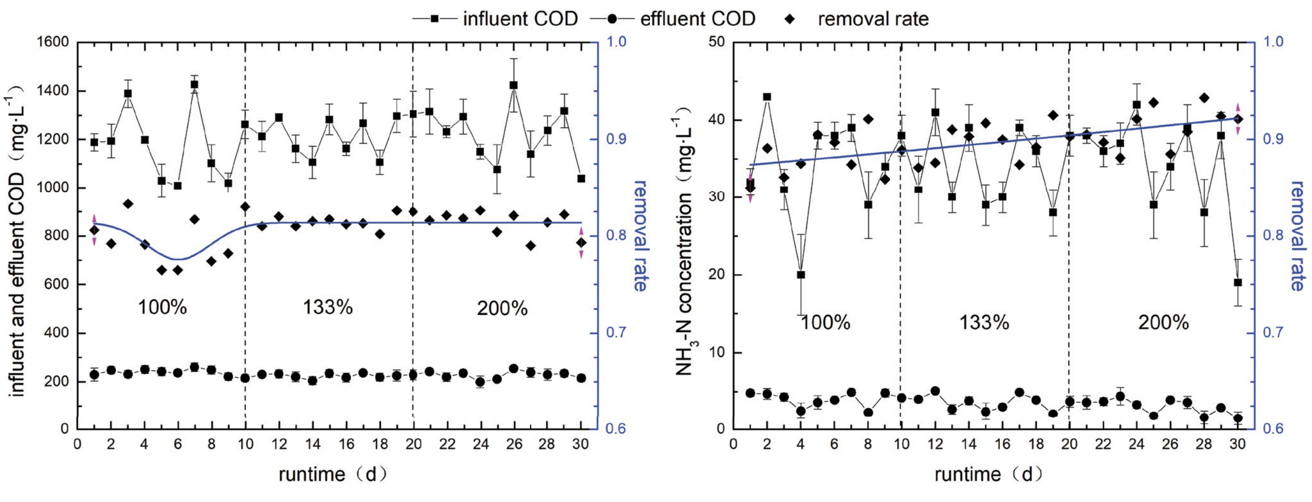


Fig. 5. Effect of the return sludge ratio on the treatment efficiency (MLVSS: 2,300~2,500 mg $L^{-1}$, inflow duration: 4 h, aeration time: 6 h, DO: 2.0 mg $L^{-1}$).

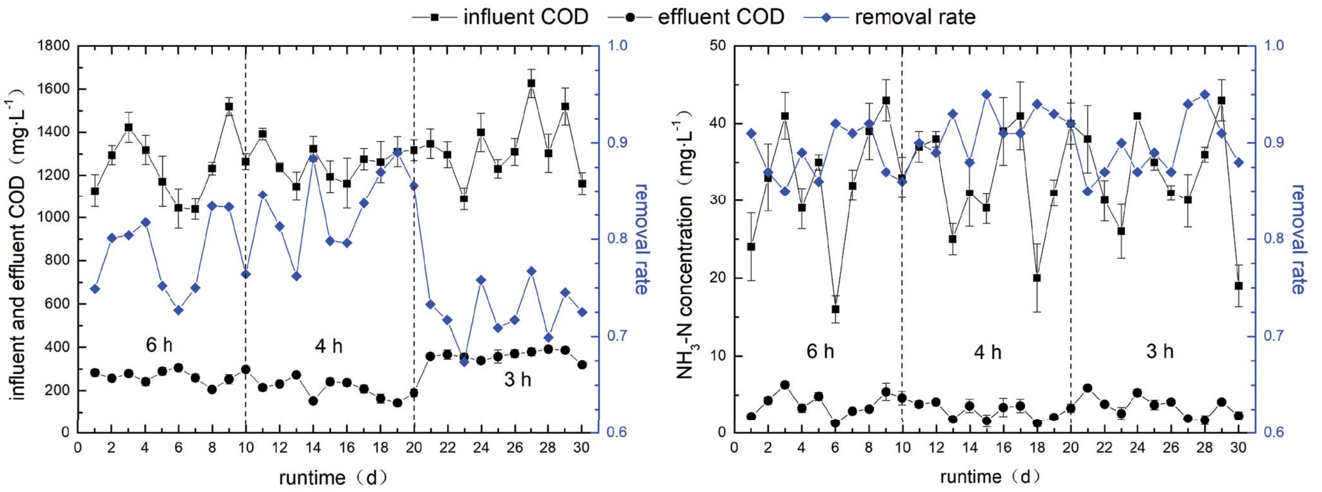


Fig. 6. Effect of the inflow duration on the treatment efficiency (MLVSS: 2,300~2,500 mg L$^{-1}$, return sludge ratio: 133%, aeration time: 6 h, DO: 2.0 mg L$^{-1}$).

rate ($P < 0.05$). With a decreased inflow duration, the COD removal rate first increased and then decreased. When the inflow duration was 4 h, the COD removal rate was the best, and the average removal rate reached 83.52%. When the inflow duration was further reduced to 3 h, the COD removal rate decreased to 72.44%. The inflow duration had little effect on $NH_3$–N, and the average $NH_3$–N removal rate was more than 88% with each influent duration.

Low influent loading usually leads to sludge bulking, and decreasing the inflow duration could increase the F/M ratio in the bioselective area and avoid the growth of filamentous bacteria due to the deficiency of microbial nutrition [15]. In this study, the inflow duration was reduced from 4 to 3 h, but the COD removal rate decreased substantially because this process was used to treat norfloxacin wastewater. Norfloxacin wastewater contained more antibiotics. However, with a short duration, a large amount of water would increase the water load, relieving the CASS under the condition of low-load operation, although this could lead to reactor influx of norfloxacin containing antibiotic pharmaceutical wastewater. The antibiotic concentration was too high, which could affect the growth of activated sludge. As a result, the flocculation and sedimentation capacity of activated sludge was poor, the adsorption and oxidation capacity of organic matter in water was reduced, and even a large number of microorganisms in activated sludge died, thus affecting the treatment effect. High influent loading was unfavorable to the growth of activated sludge. When adjusted to 4 h, the COD removal rate recovered to more than 80%. When the inflow duration was extended to 6 h, the COD removal rate decreased slightly, but the filamentous bacteria did not swell. Therefore, the suitable inflow duration was determined to be 4 h.

### 3.5. Effect of the DO concentration

The effect of DO concentrations from 1.0 to 5.5 mg L$^{-1}$ on the removal of COD and $NH_3$–N was investigated in the CASS reactor, which was designed to contain 2 mg L$^{-1}$ DO. The results are shown in Fig. 7.

As shown in the graph, with an increasing DO concentration, the COD removal rate first increased and then decreased. When the dissolved oxygen was in the range of 2.8 to 3.5 mg L$^{-1}$, the COD removal rate was the best, and the average COD removal rate was 84.2%. The COD removal efficiencies at different concentrations of DO were significantly different ($P < 0.05$), which indicated that the COD removal rate could be significantly affected by properly increasing the DO concentration; additionally, further increasing the aeration rate would lead to a decrease in the COD removal rate. The reason may be that the CASS was in a low-load operation state, the influent organic matter content was low, and nutrition was deficient. Moreover, too much DO led to the self-oxidative decomposition of activated sludge flocs, and the self-oxidation of aerobic sludge led to a loose structure of activated sludge flocs and a decline in flocculation and sedimentation performance. In addition, high DO may also lead to a large amount of filamentous bacteria growth, further affecting the sedimentation performance of activated sludge and resulting in an increase in effluent COD and SS [16,17], and some studies have shown that too much DO can have a negative effect on the decomposition of COD by microorganisms. For example, Sun et al. [18] studied the effect of the DO concentration on nitrogen and phosphorus removal by a multistage biological contact oxidation method. They concluded that a high DO concentration and the strong activity of heterotrophic bacteria in the aerobic layer consumed a large amount of easily degraded fatty acids and reduced the biodegradability of wastewater. Thus, the above mechanism affected the degradation of COD by microorganisms. According to the test results, the treatment effect was best when the DO concentration was 2.8~3.5 mg L$^{-1}$. When aeration was stopped, the sludge could continue to be oxidized and decomposed, and the biochemical reaction could be fully carried out.

Regarding $NH_3$–N, the removal efficiency of $NH_3$–N was significantly different among the different DO concentrations ($P \approx 0$). It was found that changes in the DO concentration could also affect the removal efficiency of

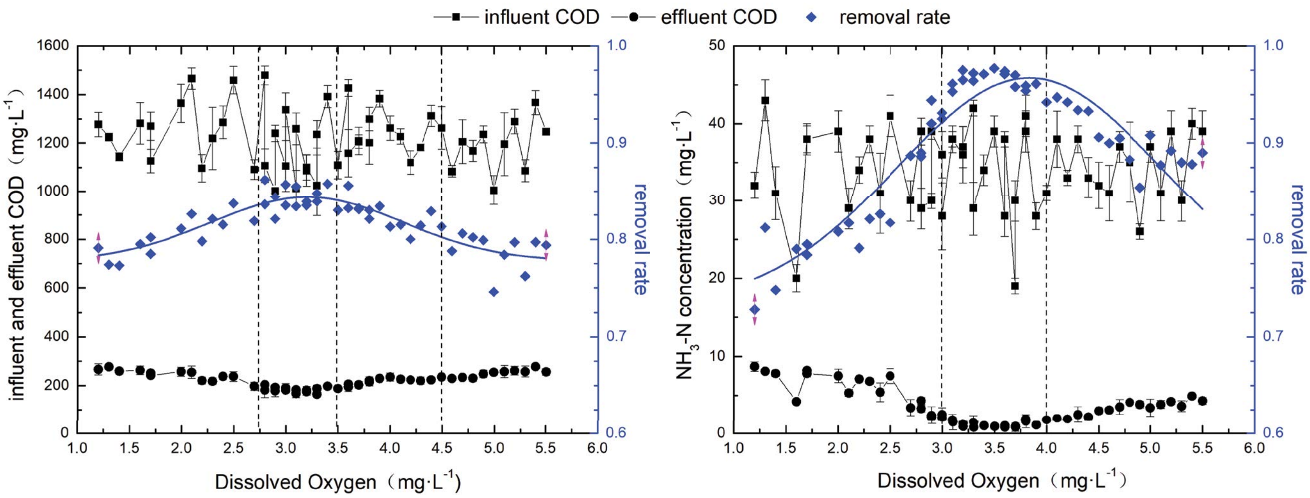


Fig. 7. Effect of the DO concentration on the treatment efficiency (MLVSS: 2,300~2,500 mg L$^{-1}$, inflow duration: 4 h, return sludge ratio: 133%, aeration time: 6 h).

$NH_3$–N. The $NH_3$–N removal rate first increased and then decreased. The $NH_3$–N removal rate was the best when the DO concentration was 3.0~4.0 mg L$^{-1}$, and the average removal rate was 96.01%. Because $NH_3$–N needed to be removed under aerobic conditions, the degree of aeration directly affected the growth of nitrifying bacteria. When the DO concentration in the main reaction area was too high, it could cause an imbalance in the number of flora. Moreover, aerobic bacterial growth affected the growth of nitrifying bacteria, which affected the nitration reaction of the main reaction area, and the mixed solution containing high DO was recirculated to the bioselective area by the return sludge, which increased the oxygen content in the bioselective area. This increase in DO inhibited the denitrification process and made the nitrate content in the CASS too high [11,19,20]. Therefore, the subsequent nitrification was inhibited, and the $NH_3$–N removal rate decreased.

In summary, when the DO concentration was 2.8 to 3.5 mg L$^{-1}$, the CASS had the best COD removal. When the DO concentration was 3.0 to 4.0 mg L$^{-1}$, the CASS process showed the best removal of $NH_3$–N. The optimum DO concentration was 2.8~3.0 mg L$^{-1}$.

## 4. Actual production performance and optimization

According to the experimental results, the optimized operating conditions were applied to the studied CASS, that is, inflow duration: 4 h, return sludge ratio: 133%, aeration time: 6 h, DO: 2.8~3.0 mg L$^{-1}$, and MLVSS: 2,300~2,500 mg L$^{-1}$. Changes in the COD and $NH_3$–N concentration before and after the adjustment was observed. The results are as follows.

### 4.1. COD removal

After the sewage treatment process of the sewage station was adjusted, the quality of the wastewater in and out of the CASS was tested, and the COD of the effluent before and after the adjustment was graphed and analyzed. The results are shown in Fig. 8.

According to the analysis of the test results, the influent COD concentration of the CASS showed little change before and after the adjustment. Before adjustment, the COD concentration in the influent was 1,200~1,400 mg L$^{-1}$, the COD concentration in the effluent was 165~278 mg L$^{-1}$, the average concentration was 223.5 mg L$^{-1}$, and the average COD removal rate was 81.7%. The guaranteed rate of an effluent COD concentration <220 mg L$^{-1}$ was 40%, and the rate of reaching the standard was low. The effluent COD concentration adjusted by the CASS was 155~192 mg L$^{-1}$. The average concentration was 169.2 mg L$^{-1}$, and the average removal rate was 86.57%. The removal effects of COD after the adjustment were clearly improved, and the difference between the data before the adjustment was obvious ($P \approx 0$), which demonstrated that the optimized parameters were better. The guaranteed rate of effluent with a COD concentration less than 220 mg L$^{-1}$ after the adjustment was more than 95%. Thus, almost all of the discharge could achieve the local indirect discharge standard of Henan Province, "Discharge standards of water pollutants for pharmaceutical industry; Chemical synthesis products category" (DB41/756-2012 in Henan Province), showing that the CASS had good COD removal effects after optimization.

### 4.2. $NH_3$–N removal

The removal effects of $NH_3$–N before and after the process adjustment of sewage stations are shown in Fig. 9.

According to Fig. 9. Before adjustment, the $NH_3$–N concentration in the influent was 30~40 mg L$^{-1}$, the $NH_3$–N concentration in the effluent was 2.6~6 mg L$^{-1}$, the average concentration was 4.53 mg L$^{-1}$, and the average removal rate was 86.79%. After adjustment, the $NH_3$–N concentration in the influent was between 26 and 41 mg L$^{-1}$, the average concentration was 34.7, the $NH_3$–N concentration in the effluent was between 0.8 and 1.6 mg L$^{-1}$, the average concentration was 1.31 mg L$^{-1}$, and the average removal rate was 96.21%. After the *T*-test, the difference between the data before and after optimization of the CASS was obvious ($P \approx 0$).

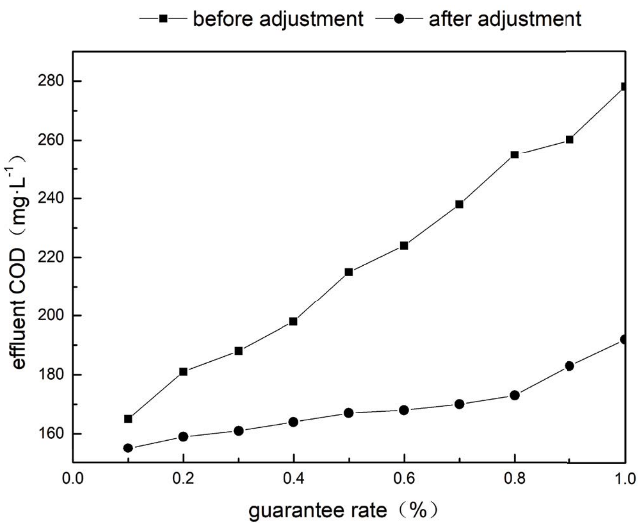


Fig. 8. Comparison of the COD removal before and after optimization.

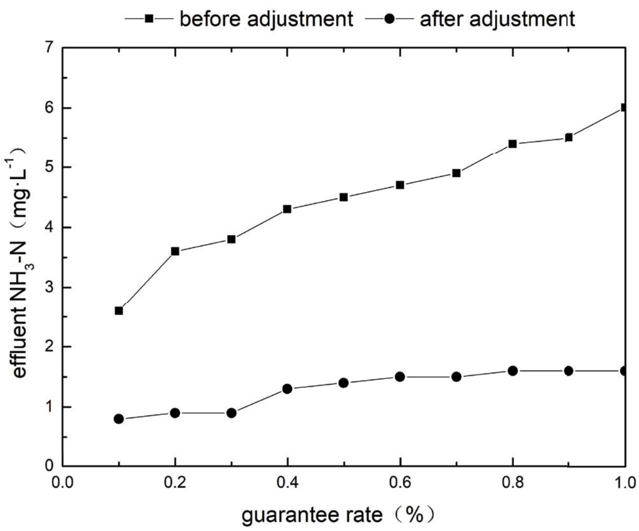


Fig. 9. Comparison of $NH_3$–N removal before and after optimization.

Before and after the adjustment, the $NH_3$–N concentration in the effluent was lower (<35 mg $L^{-1}$), which met the local indirect discharge standard of Henan Province, "Discharge standards of water pollutants for the pharmaceutical industry; Chemical synthesis products category" (DB41/756-2012 in Henan Province). The removal efficiency of $NH_3$–N by the CASS was better than 85% under different operating conditions, and the $NH_3$–N concentration in the effluent was less than 6 mg $L^{-1}$. Additionally, the $NH_3$–N removal rate was improved by adjusting the CASS, which showed that the optimized CASS could further improve $NH_3$–N removal.

## 5. Conclusion

A CASS was used to treat pharmaceutical intermediate wastewater under low-load conditions, and the optimal operating parameters were as follows: an aeration time of 6 h and inflow duration of 4 h. The MLVSS concentration was adjusted from 2,500 mg $L^{-1}$ to 2,300~2,500 mg $L^{-1}$, the return sludge ratio was adjusted from 100% to 133%, and the DO concentration was adjusted from 2 to 2.8~3.0 mg $L^{-1}$, effectively improving the removal efficiency of COD and $NH_3$–N. The average COD concentration in the effluent decreased from 290.7 to 169.2 mg $L^{-1}$, and $NH_3$–N decreased from 4.53 to 1.31 mg $L^{-1}$. Regarding the local indirect discharge standard of Henan Province, "Discharge standards of water pollutants for pharmaceutical industry; Chemical synthesis products category" (DB41/756-2012 in Henan Province), the guaranteed rate of COD effluent meeting the standard increased from 40% to 95%.

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