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Study on Nitrification Characteristics of Livestock Wastewater Treated With SBR

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Abstract. By coupling intermittent characteristics of livestock wastewater and intermittent operation of SBR, the feasibility of using intermittent aeration to reduce energy consumption of livestock wastewater treatment facilities was studied. SBR was utilized to treat livestock wastewater pretreated by the anaerobic process. A systematic study of the start-up of nitrification in SBR using the novel aeration method and the influence of aeration rate and aeration time on nitrification performance was carried out. The results showed that the removal of NH₄⁺-N could be achieved under different operating conditions. DO concentration was the dominant factor affecting the nitrification process. Under the operation condition of stage 3 (i.e., aeration rate 0.8 L/min, temperature 25℃, aeration time 12 h). Because of the lack of carbon source, the removal rate of TN decreased, and a certain degree of accumulation of NO₃⁻-N occurred. Through monitoring the DO, pH and Eh, the results indicated that the Eh curves varied irregularly. However, DO and pH in one operating cycle showed obvious patterns and corresponded well with the nitrification process, so they could be used as real-time control parameters to control the nitrification aeration process.

1. Introduction

With the development of economy and society, livestock breeding has become a pillar industry of agriculture and rural economy in China [1], and the pollution of livestock and poultry has become more and more serious. Livestock breeding pollution has become the third major pollution source after industrial pollution and domestic pollution.

Livestock wastewaters usually feature high concentrations of organic matter, ammonia, phosphate, and suspended solids, and are one of the key sources of water pollution in Chinese rural area [2]. It is usually discharged into public waters without treatment in Chinese rural area due to lack of funds and technology. Thus, in order to preserve the water quality, there is a need for cost-effective approaches to treat livestock wastewaters before being discharged into public waters.

Nitrification is divided into two steps: the first step is to oxidize NH₄⁺-N to NO₂⁻-N under the catalysis of AOB [3] (ammonia oxidizing bacteria) or AOA [4] (ammonia oxidizing archaea). The second step is to generate the NO₂⁻-N in NOB (nitrite oxidizing bacteria) under the catalysis of
oxidation of NO$_3^-$-N. AOB, AOA and NOB are autotrophic bacteria and heterotrophic bacteria, at a disadvantage in competition, in order to maintain the stability of nitrification, that DO concentration in the aeration tank should be more than 2 mg/L is required [5]. In addition, when the 1 g NH$_4^+$-N is completely oxidized to NO$_3^-$-N, the 4.57 g O$_2$ are need theoretically.

2. Materials and methods

2.1. Experimental equipment
The reactor (Figure 1) was made of organic glass, 500 mm high, 150 mm in diameter, with an effective volume of 5 L. The reactor adopted intermittent operation, operated during the day and stopped at night. The reactor was divided into 3 operation modes (Table 1), and the operating parameters at each operation mode was shown in Table 2.

![Figure 1 The schematic of SBR](image)

| Table 1. The Operating mode of SBR |
|-----------------------------------|
| Item | Influent | Reaction | Sedimentation | Effluent | idle |
|------|----------|----------|---------------|----------|------|
| mode (1) and (3) | 6:45~7:00 | 7:00~19:00 | 19:00~20:00 | 20:00~20:15 | 20:15~6:45 (The next day) |
| mode (2) | 6:45~7:00 | 7:00~17:00 | 17:00~18:00 | 18:00~18:15 | 18:15~6:45 (The next day) |

| Table 2. The operating parameters of SBR |
|------------------------------------------|
| Operating parameters | Operation mode |
|-----------------------|---------------|
|                        | (1) | (2) | (3) |
| Aeration rate/(L/min)  | 0.6 | 1.0 | 0.8 |
| Aeration time/h        | 12  | 10  | 12  |
| Aeration intensity/(m$^3$ (m$^2$·h)) | 2.03| 3.40| 2.72|
| Temperature/℃          | 25  | 25  | 25  |
| Water exchange ratio/%  | 0.4 | 0.4 | 0.4 |

2.2. Influent water quality and inoculated sludge
The influent of SBR reactor (Table 3) was from UASB anaerobic digestion wastewater.
Table 3. The influent water quality of SBR

| Figure | COD Cr (mg/L) | NH₄⁺-N (mg/L) | TN (mg/L) | NO₃⁻-N (mg/L) | NO₂⁻-N (mg/L) |
|--------|---------------|----------------|-----------|----------------|---------------|
| Range  | 1055~1600     | 122~250        | 165~260   | 2~15           | 0.02~0.2      |
| Average| 1328          | 186            | 213       | 9              | 0.11          |

The inoculated sludge was obtained from the secondary sedimentation tank of Gaobeidian wastewater treatment plant, and the initial sludge concentration was 2000 mg/L.

2.3. The test item and method

SBR intake and effluent were collected every two days, and ρ(COD Cr), ρ(NH₄⁺-N) ρ(NO₃⁻-N) and ρ(NO₂⁻-N) were measured, in addition, the ρ(DO) and pH were also determined. The rapid digested spectrophotometry method applied to detect COD Cr. Nessler’s reagent spectrometry was utilized to determine the concentration of NH₄⁺-N. UV spectrophotometric method was used to detect NO₃⁻-N. N-(1-naphthyl)-ethylenediamine spectrophotometric method was used to detect NO₂⁻-N. The absorbance was determined by HACH DR5000 UV-Vis spectrophotometer. The pH was measured by the HACH HQ30d water quality analyzer (HACH, USA). The ρ(DO) was determined by HACH HQ40d multi parameter water quality analyzer (HACH, USA).

3. Materials and methods Results and discussion

3.1. Nitrogen removal efficiency

The influence of the change of operation parameters on the nitrogen removal efficiency was shown in Figure 2. Figure 2 showed that under the operation of mode 1, while the average NH₄⁺-N concentration of the influent was up to 226 mg/L, but the NH₄⁺-N removal rate has been very stable (the average value was greater than 94%), NH₄⁺-N concentration of the effluent was at an average of 22 mg/L and met the emission standards of livestock and poultry breeding. The results showed that the nitrifying activity of inoculated sludge was higher, and nitrifying bacteria in sludge could adapt to larger fluctuation of DO and intermittent operation. At this stage, due to high aeration intensity, DO concentration in the reactor was more than 8 mg/L after the end of aeration, the endogenous denitrification was limited. The TN removal rate was not high and the average value was less than 65%. The NO₃⁻-N was the main form of nitrogen in effluent, and the NO₂⁻-N was lower in effluent.

Under the operation of mode 2, aeration rate increased to 1.0 L/min, the reaction temperature is maintained constant. The average NH₄⁺-N concentration of the influent was at 224 mg/L, the effluent was at an average of 11 mg/L. The removal rate of NH₄⁺-N was about 96%. The removal efficiency of the second stage was better than that in mode 1. This was because the aeration rate increased in mode 2, microorganisms resumed activity, and microorganisms have better adaptability to livestock and poultry wastewater. In addition, the aeration time was reduced from 12 h to 10 h, and there was no effect on the removal efficiency of NH₄⁺-N. This indicated that the aeration rate was the factor affecting the removal rate at this stage.

Under the operation of mode 3, the aeration was at 0.8 L/min and aeration time increased to 12 h, the reaction temperature is maintained constant. The removal efficiency of TN at this mode was 70%, lower than that in the second mode. The average NO₃⁻-N concentration of the effluent significantly increased, which was up to 50 mg/L. Compared with the first two modes, nitrate accumulation occurred in mode 3. This is because when the aeration rate was sufficient, the diffusion resistance of DO to the interior of the micelle decreased with the increase of aeration time, thus the utilization rate of nitrifying bacteria substrate increased. What was more, at this stage, exogenous denitrification was inhibited due to insufficient carbon sources. The removal rate of NH₄⁺-N was about 98%, which was higher than the first two stage. On the one hand, because of the high activity of nitrifying bacteria, on the other hand, because of the long aeration time, it has a stripping effect on NH₄⁺-N.
In the livestock wastewater treatment process, COD$_{Cr}$ is commonly used as organic matter concentration index. Effects of operation parameters on COD$_{Cr}$ removal efficiency as shown in Figure 3. The influent was the livestock wastewater that was through the anaerobic pretreatment, the organic matter content in livestock wastewater decreased, the further removal on COD$_{Cr}$ can achieve under 3 different modes. The effluent concentration of COD$_{Cr}$ was less than 400 mg/L, which met the requirements of livestock and poultry breeding. It showed that the aerobic livestock wastewater had good biodegradability. In mode 2 and 3, the average influent and effluent concentration of COD$_{Cr}$ were 1465 mg/L and 1376 mg/L, 90 mg/L and 98 mg/L, respectively, and the average removal rates were 93.8% and 93.4%, respectively. In operation of mode 1, the effluent COD$_{Cr}$ was slightly higher than the latter two modes, the average effluent concentration was 274 mg/L, and the average removal rate was 86.3%. This was due to low aeration rate resulting in low microbial activity and microbial utilization of organic matter decreased.
3.3. **DO and pH variation in one single cycle**

DO and pH are important factors affecting nitrification, at the same time, the nitrification reaction consumes alkalinity, resulting in mixed liquid pH decreased. But when the nitrification reaction is over, the pH will rise as a result of aeration, and the pH curve will appear "ammonia Valley"\(^6\). At this point, the DO curve will appear "sudden jump".

The curves of DO and pH under 3 different operating modes were shown in Figure 4. The \(E_h\) curve was irregular and even serrated. The reason was that microorganisms attach to the surface of the \(E_h\) electrode and polluted the \(E_h\) electrode. In addition, the \(E_h\) was susceptible to interference by external electrons such as \(SO_4^{2-}\)\(^7\) when indicating nitrification reactions, thus not shown in Figure 4.

As can be seen from Figure 4, the regularity and reproducibility of the DO and pH curves were good. Under the condition that \(NH_4^+\)-N was completely removed, obvious feature points appeared on the DO and pH curves, and the larger the aeration rate, the earlier the feature points appeared. At the end of nitrification, with the increase of aeration rate, the stripping effect increased, and the pH curve increased faster.

Figure 4 (a) and (c) showed that the aeration rate rose from 0.6 L/min to 0.8 L/min, the pH mutation point was slightly ahead of time and the mutation was obvious. At the beginning of aeration, the DO curve fluctuated due to long idle time, and this stage was the stage of microbial recovery. Then DO began to rise, indicating that the rate of aeration at this time was balanced with the rate of oxygen consumption by microorganisms. When the nitrification was over, the microbial oxygen consumption rate decreased and DO increased rapidly. It should be noted that when the aeration rate was 0.8 L/min, the starting point of DO rising was obviously higher than that under the condition of 0.6 L/min at the beginning of aeration. This was mainly because when the aeration rate was too high, the oxygen in the mixed liquid exceeds the demand of microbial metabolic reaction, so that some of the oxygen in the mixed liquid was not effectively utilized, and the residual DO in the mixed liquid was more.

As illustrated in Figure 4 (a) and (b), when the aeration time was reduced from 12 h to 10 h, the aeration rate increased from 0.6 L/min to 1.0 L/min. During the reaction period, the DO of mixed liquor increased linearly, and at the stage of operation two (aeration rate was 1.0 L/min, aeration time was 10 h), the microbial recovery period was the shortest, and there was no obvious limit at the end of the reaction period and the end period, this was because aeration was the main controlling factor of nitrification.

In summary, under the aeration rate of 0.6 L/min, the extended aeration time has little influence on the nitrification process. But at the aeration rate of 0.8 L/min, the end time of nitrification process was obviously advanced. The amount of aeration and the length of aeration directly determine the level of energy consumption. DO and pH were used as the control parameters of nitrification process. At higher aeration rate, aeration could be stopped immediately after the appearance of the characteristic points, so as to prevent excessive aeration and reduce energy consumption.
4. Conclusion

This paper utilized 3 different modes of SBR to analyze nitrification characteristics of livestock wastewater. The following conclusions can be drawn:

1. In the intermittent aeration nitrifying SBR system, under the condition of different aeration rate and aeration time, NH$_4^+$-N and COD$_{Cr}$ can be effectively removed. The result shown that it is feasible to use intermittent aeration to treat livestock wastewater with high concentration and reduce the energy consumption of sewage treatment facilities.

2. When the aeration rate was 0.6 L/min, the aeration time was 12 h and the temperature was 25 °C, the influent COD$_{Cr}$ concentration ranged from 1055 mg/L to 1600 mg/L, and the influent NH$_4^+$-N was in the range of 122 mg/L to 250 mg/L, the efficient removal of NH$_4^+$-N could be achieved. The average effluent concentration was 22 mg/L, the average removal rate was 94%. In practice, the aeration rate was determined to be 0.6 L/min (aeration intensity was 2.03 m$^3$/ (m$^2·$h)), which was most economical and effective.

3. Under the condition of complete removal of NH$_4^+$-N, obvious characteristic points appeared on the DO and pH curves, and DO and pH could be considered as indirect control parameters for treating livestock wastewater with intermittent aeration SBR.

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