Effect of Sorting by a Hydrocyclone on Denitrification Performance of Activated Sludge

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Abstract: Denitrification performance is an important indicator of the denitrification process in wastewater treatment. A lateral experiment was carried out on the campus wastewater treatment plants (WWTPs) in East China University of Science and Technology (ECUST) by using a SBR process equipped with a hydrocyclone. The results showed that the hydrocyclone in the SBR process was able to break activated sludge (AS) flocs into smaller flocs because of the rotation and revolution. At the same time, organic carbon sources such as polysaccharides and proteins were released, which supplemented the carbon source of the biochemical pool and improved the denitrification performance. After hydrocyclone treatment, the denitrification performance of sludge flocs increased by more than 50%, and the denitrification rate increased by 20.39%. Under continuous operating conditions, the average denitrification performance increased by 6.43%.

1. Introduction
The activated sludge process is widely used in urban and industrial wastewater treatment. Since its development, it still has many problems. With the progress of urbanization, unprecedented eutrophication of water bodies, in the face of low C/N ratio sewage, the lack of denitrifying carbon source makes bio-nitrogen removal efficiency very low[1]. Effective measures must be taken to improve sludge settling and enhance biochemical efficiency. Due to strict regulatory requirements and increasingly stringent emission limits[2], many wastewater treatment plants have no choice but to increase retention time or add additional carbon sources (ie acetate, glucose, methanol and ethanol) as carbons sources to improve biochemical efficiency. However, additional carbon sources may incur additional costs and generate more excess sludge[3].

The main purpose of this paper is to use the hydrocyclone to sort out the excess sludge, using the high speed rotation in the hydrocyclone flow field, the centrifugal force and shear force to break the activated sludge floc. Body to improve sludge denitrification performance.

2. Materials and methods
2.1. Characteristics of AS and sewage
The AS was taken from WWTPs which using SBR process. The MLSS was 3450 ± 210mg/L, and the SVI was 94.9 ± 4.8mL/g.

The sewage was the sewage in ECUST campus. what’s shown in Table 1 are the water quality parameters.
Table 1. Sewage quality parameters in ECUST

| Index | COD     | TN      | NH_4-N  | SS     | pH     |
|-------|---------|---------|---------|--------|--------|
| Value (mg/L) | 153.4 ± 36.4 | 28.1 ± 4.2 | 24.9 ± 4.0 | 155 ± 62 | 7.0 ± 0.2 |

2.2. Technological methods

2.2.1. Appaeatus
The SBR reactor coupled with a hydrocyclone is shown in Fig. 1, its processing capacity was 8 tons/day. The reactor’s volume of was 2m³ (height of 1.7m, diameter of 1.26m). The hydrocyclone the key equipment, its diameter was 10mm, the taper angle was 8°, and the split ratio was controlled at 10%. The sewage was drawn into the reactor by a submersible pump, and was aerated by an air pump. Finally it was discharged by a small submersible pump, which fixed at a certain depth below liquid surface by a float.

Figure 1. Schematic diagram of the SBR reactor with hydrocyclone

2.3. Analytical methods
The polysaccharide and protein contents were determined by the sulfuric acid-anthrone method and the Lowery reagent method, respectively, and the EPS content was calculated by the sum of the polysaccharide and the protein. The test method for denitrification rate was as follows: After repeated washing three times, 100 mL sludge sample was put into an erlenmeyer flask. Then an appropriate amount of KNO_3 solid was added to make the initial nitrate concentration of 35-45 mg/L. We need to purge nitrogen gas into the reactor to discharge the air and then seal the reactor. Mix the sludge, and then start the timer. Get samples at 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, 70, 80, 100, 120 min, and test nitrate concentration. Plot the time-nitrate concentration curve to get the slope r. Measure the MLVSS of the sludge in the erlenmeyer flask, the denitrification rate is obtained by the equation (1).

\[ \rho_{NO_3-N} = -\frac{r}{MLVSS} \]  

(1)

3. Results and discussion

3.1. Instantaneous denitrification rate comparison
Figure 2 shows the concentration of NO_3-N as reaction time. Experimental samples were taken from SBR and WWTPs biochemical pools. The results showed that the denitrification rate in the first stage was larger, in SBR and WWTPs they were 5.424mg/(g·h) and 4.783 mg/(g·h), respectively. The reaction time at this stage was about 20 minutes. At this stage, the microorganisms used degradable soluble carbon sources in the wastewater as denitrifying nutrients. The reaction rate was only related to the amount of denitrifying bacteria and was independent of the concentration of nitrate in the
sewage. The denitrification rates of the second stage in SBR and WWTPs were 0.923 mg/(g·h) and 0.312 mg/(g·h), respectively, and the reaction time was about 40 min. This was because this stage mainly utilizes the remaining particulate state and slowly degradable organic matrix after the degradable organic matrix was depleted, it’s greatly reduced in response to the first stage reaction rate. In the third stage, the denitrification rate was lower, and the concentration of nitrogen in the stage was basically stable and did not decrease. This was because the degradable carbon source in the sewage had been substantially consumed.

From the denitrification rate in Figure 2, it could be clearly seen that the denitrification rate of activated sludge in the first two stages of SBR was significantly higher than that in WWTPs, indicating that the activity of activated sludge increased after hydrocyclone sorting.

| Process | NO$_3^-$-N (mg/gMLSS) | NO$_3^-$-N Removal rate | Denitrification rate (mg·g$^{-1}$·h$^{-1}$) |
|---------|------------------------|------------------------|-----------------------------------------|
|         | Start                  | End                    | First stage | Second stage | Third stage |
| SBR     | 3.553                  | 3.246                  | 0.962       | 1.541        | 72.92%      |
| WWTPs   | 3.246                  | 1.541                  | 52.53%      | 4.783        | 0.312       | 0.026       |

From the degree of denitrification in Table 2, the nitrogen removal rate in the SBR process and WWTPs was 72.92% and 52.53%, respectively. The nitrogen removal rate of the SBR was increased by 20.39% compared with the WWTPs. It can removal nitrogen deeply.

3.2. Denitrification rate test under continuous operating conditions

Figure 3 showed the changes in denitrification rate of activated sludge under continuous conditions. During the few days of testing, the overall denitrification rate did not change much. The denitrification
rate of the AS in SBR was higher than that in WWTPs except for occasional one day. The average denitrification rates of SBR and WWTPs sludge in the first stage were 5.46 mg·g⁻¹·h⁻¹ and 5.13 mg·g⁻¹·h⁻¹, respectively, and in the second stage those were 0.89 mg·g⁻¹·h⁻¹ and 0.41 mg·g⁻¹·h⁻¹.

3.3. EPS content and denitrification performance
The changes of EPS content in the sludge flocs before and after the hydrocyclone treatment were determined, and the contents of protein and polysaccharides in the mud phase and water phase were analyzed too. Figure 4 is the test results of mud phase. Compared with the original sludge, the content was basically unchanged In the inlet, while at the underflow and overflow they both reduced. The floc EPS, polysaccharide and protein content in the underflow was reduced from 313, 25 and 280 mg/L to 267, 17 and 251 mg/L, respectively. It indicated that after treated by the reflux pump, the EPS was not broken. The EPS was broken in the hydrocyclone due to the centrifugal force generated by the high-speed rotation and revolution in the flow field, so the encapsulated polysaccharide and protein in the floc channel and the EPS could be released.

Figure 4. EPS, polysaccharide and protein concentration change in the mud phase after treatment by hydrocyclone

Figure 5 is the results of the water phase test. After the hydrocyclone treatment, the SCOD, polysaccharide and protein in the water phase of the underflow increased from 103, 2.5 and 7.4 mg/L to 203, 7.5 and 11.8 mg/L, respectively. But in the overflow they were all decreased. This indicates that the released polysaccharide and protein dissolved into the water phase, and most of them flowed out from the underflow with the water phase and back to the biochemical pool. This may be because after flowed into the hydrocyclone, the floc firstly entered the outer circulation area. During the breaking process, a large amount of organic carbon sources was released, and was discharged from the
underflow with the external circulation, so in the underflow it contained more carbon sources to supply carbon sources for denitrification.

3.4. Influence mechanism

Figure 6 is a schematic diagram of the hypothesis of the cyclone carbon release mechanism. When the floc enters the inner cavity of the cyclone, it will be subjected to tensile stress and shearing force, and it will rotate at high speed and revolve around the central axis to generate centrifugal force. This part of the force causes the sludge flocs to break into smaller fragments, even individuals of microbial cells. This can greatly enhance the mass transfer effect. The centrifugal force generated by the high-speed rotation can "peel" the EPS structure of the floc layer by layer and dissolve in the liquid phase, among which there are a large amount of organic matter such as polysaccharides and proteins. These carbon sources are supplemented as denitrifying carbon sources, greatly improving denitrification performance[4].

![Figure 6. Schematic diagram of carbon release by hydrocyclone](image)

4. Conclusion

- The high-speed rotation of the sludge flocs in the hydrocyclone causes the EPS surface of the flocs to be cracked, releasing organic carbon source for use in the denitrification process.
- Most of the released carbon source flows out from the underflow of the hydrocyclone and flows back to the biochemical pool.
- After the hydrocyclone treatment, the denitrification performance of the sludge floc increased by more than 50%, and the nitrogen removal rate increased by 20.39%. Under continuous operating conditions, hydrocyclone sorting increased the average denitrification performance by 6.43%.
References

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