Experimental study on the effect of filler size on the denitrification of SBBR process in low temperature

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Abstract: In order to study the effect of filler size on the treatment of low temperature wastewater by SBBR process, three groups of SBBR reactors were established. They used cubic sponges with side lengths of 1, 1.5 and 2cm as filling fillers, respectively. The denitrification effect of the three fillers was compared under the conditions of stable water temperature of (10±1)°C, HRT of 10h and reactor filling rate of 16%. The results showed that the removal of NH₄⁺-N and TN in the reactor with the filling size of 1cm was the best, and the removal rates were 96% and 80%. The NH₄⁺-N and TN removal rates of the reactors filled with the other two sizes of fillers were all below 80% and 70%. The membrane biomass measurement of the reactor showed that the smaller size of the filler has a larger specific surface area, which was beneficial to mass transfer and microbial growth and enrichment, thereby promoting the denitrification of low temperature wastewater.

1. Introduction
Temperatures play a decisive role in the growth, reproduction, metabolism, population distribution and population of microorganisms, directly affecting the efficiency of winter sewage treatment. The main process of sewage treatment is the biological treatment process, which leads to consequence that the low temperature treatment of urban sewage is a major challenge in the sewage treatment industry[1]. The experimental results showed that the operation of the municipal sewage treatment plant was reduced by the sewage temperature, and the microbial metabolism and activity of the aeration tank were also reduced, which was in turn impressions the removal of organic matter and the effect of nitrogen removal. The low temperatures inhibit the activity of the functional flora, but the filamentous bacteria are relatively active due to their large contact area. These changes directly affect the effluent quality of the sewage treatment plant[2]. At the same time, with the effluent discharge standards of urban sewage treatment plants becoming more and more strict, most of China’s sewage plants face the problem of upgrading and upgrading[3]. The sewage plant is limited by the volume of the original biological pool in the upgrading and reconstruction project. The usual practice is to add suspended fillers to the biological pool[4]. Adding fillers, on the one hand, can increase the biomass of the system, prolong the residence time of the sludge, increase the oncentration of nitrifying bacteria, and then promote the nitrification. On the other hand, the inside of the bio-film attached to the surface of the filler is anaerobic or anoxic, and denitrification can be performed[5], thereby achieving the purpose of
enhancing biological nitrogen removal at low temperatures. In recent years, the research on fillers has the type, shape and color of fillers[6~8], and the research on the influence of filler size on the system at low temperatures is rarely reported.

In this experiment, the water temperature was controlled at (10±1)℃, and sponges of the same material and different sizes were used as the filler of the sequencing batch biofilm reactor (SBBR) to investigate the sewage treatment effect of different size fillers.

2. Materials and methods

2.1. Test materials and devices
As shown in Fig.1, the test apparatus used three columnar vessels having an effective volume of 2L as the reactors, numbered 1#, 2# and 3#. The filling rate of all three reactors was set to 16%(V/V). The sponge filler added to the reactor was a cube, and the corresponding side lengths were 1, 1.5 and 2cm, respectively. The parameters of the sponge filler used in the test were as follows: specific gravity 16~17kg/m$^3$; specific surface area 3.8×10$^5$m$^2$/m$^3$. The test was run in a temperature controlled room with a measured water temperature of 10±1℃. The air compressor was used for blast aeration, and the air rotameter was used to control the amount of aeration.

![Fig.1 Schematic diagram of test device.](image)

2.2. Test water
The test water was artificially prepared to simulated urban sewage. The agents used for water distribution were glucose (C$_6$H$_{12}$O$_6$), ammonium chloride (NH$_4$Cl), potassium nitrate(KNO$_3$), potassium dihydrogen phosphate (KH$_2$PO$_4$), and sodium hydrogencarbonate (NaHCO$_3$). The purity of the agents was analytically pure. The detailed water quality parameters of the water distribution during operation were shown in Table 1.

| Water quality index | COD   | TN   | NH$_4^+$-N | NO$_3^-$-N | pH       |
|---------------------|-------|------|------------|------------|----------|
| concentration (mg/L)| 245.3~350.6 | 18.22~34.56 | 17.82~24.6 | 1.67~3.45 | 6.92~7.53 |
| Average value (mg/L)| 349.4 | 26.64 | 21.5       | 2.8        | 7.25     |

2.3. Analytical testing methods
Conventional indicators: determination of COD, NH$_4^+$-N and TN were all referred to in the Water and Wastewater Analysis and Detection Methods (Fourth Edition) [9]. The pH was measured by a Phsj-4A acidity meter produced by Shanghai Lei Magnetic; the temperature and dissolved oxygen (DO) were detected by the Oxi3310 portable dissolved oxygen meter produced by WTW, Germany.

3. Results and analysis

3.1. Impact on COD removal
The average water quality of the COD influent during the official operation of the reactor was 349.4mg/L, and the fluctuation range was 245.3~350.6mg/L. The results of COD removal by the three reactors were shown in Figure 2. It can be seen from the figure that the three reactors were basically stable after 10 days of formal operation. Although the influent water quality fluctuate greatly in this interval, the COD removal rate of the three reactors was basically stable above 90%. Analysis reason: Most of the microorganisms in the reactor were attached to the surface of the carrier in the form of bio-film. The mud was long and not easy to be lost, so the removal of organic matter was better[10]. From the removal effect of organic matter, the filler size at low temperatures had no significant effect on the removal of organic matter in the SBBR system.

3.2. Effect on NH₄⁺-N removal
During the official operation of the test, the NH₄⁺-N influent concentration was 17.82~24.6mg/L, and the average influent concentration was 21.5mg/L. The effect of the three reactors on the removal of NH₄⁺-N were shown in Figure 3. It can be seen from the figure that in the stable period, the removal rate of the 1# reactor was basically maintained at about 98%. 2# and 3# fluctuate around 75% and 80%, respectively. Analysis reason: in the case of the same filler, the 1#-filled small-sized filler had the largest specific surface area, which provided a larger attachment environment for the nitrifying bacteria. At the same time, the number of fillers in the 1# system was obviously more than that in the 2# and 3# systems. The filler gap in the 1# system was more than that in other systems. The bubbles were tortuously passed through the packing, and the larger the contact area with water, the higher the efficiency of oxygen transfer from the gas phase to the liquid phase. From the results of NH₄⁺-N removal, 1# had the best removal effect, and it showed that the small size of the filler at low temperature was easier to remove NH₄⁺-N.

3.3. Impact on TN removal
The influent TN varied between 18.22 and 34.56mg/L, and the average TN was 26.64mg/L. The
removal effect of the three reactors on TN are shown in Fig.4. During the official operation, the removal efficiency of the 1#, 2# and 3# reactors was greatly affected by the influent water quality and ammonia nitrogen removal. 1#, 2#, 3# reactor removal rate fluctuated around 80%, 70% and 70%. The reason for the analysis was that under the conditions of this test, the mechanism of nitrogen removal was simultaneous nitrification and denitrification, and the external environment of the filler was an aerobic environment. The growth site of denitrifying bacteria was mainly the interior of the filler, and the proliferation of denitrifying bacteria was limited; On the one hand, the transfer substance of electrons inside and outside the membrane was limited, which limited its removal of TN; On the other hand, during stable operation, the TN removal rate was not as stable as NH$_4^+$-N. It was because the removal of TN was not only affected by the nitrate nitrogen yield, but also affected by various factors such as low temperature, carbon source and DO. From the above analysis, the filler size under low temperatures conditions will not only affect the internal transfer of nitrate, nitrite, and organic matter into the filler, but also affected the number of dnitrifying bacteria inside the filler, resulted in a huge difference in the system for nitrogen removal.

![Fig 4 Removal efficiency of TN by each reactor.](image)

### 3.4. Impact on system biofilm

|                | 1#       | 2#       | 3#       |
|----------------|----------|----------|----------|
| biomass (mg/L) | 5800     | 2500     | 4500     |
| EPS(mg/g MLVSS)| 66.64    | 77.10    | 109.29   |
| DHA(mg/gMLVSS) | 32.01    | 10.58    | 4.22     |

During the stable operation, the bio-films in the three reactors were tested for biomass and biological activity. The results were listed in Table 2. 1#, 2# and 3# system biomass were 5800mg/L, 2500mg/L and 4500mg/L. Dehydrogenase (DHA) was an intracellular enzyme involved in the oxidative phosphorylation of organic matter[11]. It could help microorganisms to catalyze the dehydrogenation of substrates, and its activity was large, which indirectly reflected the strength of sludge activity[12]. The DHA content of the 1# system was 32.01 mg/g MLVSS, which was significantly higher than the 2# and 3# systems. At the same time, the EPS content was 66.64, 77.10 and 109.29 mg/g MVSS, respectively, with obvious differences. The results showed that different filler sizes had a great influence on the biofilm of microorganisms, which in turn affected the effect of nitrogen removal.

### 4. Conclusion

The test used three different sizes of cubes as the filler for the SBBR process, the temperature was controlled at (10±1) °C, and other parameters were the same. It was found that the ratio of COD removal in the three SBBR systems exceeded 90%; the 1cm-filled system could remove NH$_4^+$-N and TN more effectively, with removal rates of 98% and 80%, respectively.
The large specific surface area of the 1cm filler system at low temperature could enrich more nitrifying bacteria, which made the nitrification ability better than the other two systems. In the case of denitrification, the 1cm filler length was more conducive to the transfer of substances, leading to 1cm filler system TN removal rate was higher than 10% of the other two systems. It could be seen that the different filler sizes at low temperatures would significantly affect the denitrification effect of SBBR.

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