Evaluation of different structures of moving bed biofilm reactors (MBBR) for synthetic wastewater treatment

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Abstract. Performance of three different structures of moving bed biofilm reactors (MBBR) treating synthetic wastewater was evaluated. The three systems were operated under the same conditions of dissolved oxygen (DO) 3 mg/L at 26°C. The effluent of chemical oxygen demand (COD) decreased from 111.6 mg/L in reactor 1 (R1), 128.8 mg/L in reactor 2 (R2), and 154.5 mg/L in reactor 3 (R3), to less than 100 mg/L, respectively, with concentration of influent NH₄⁺-N rising from 30 mg/L to 50 mg/L. The concentration of effluent NH₄⁺-N for R1, R2 and R3 were close to 2 mg/L, 4 mg/L and 5 mg/L, respectively. The highest TN removal rate in R1 achieved average 84.4 %, which was 6.0 % and 9.7 % higher than those of R2 and R3, respectively. R1 with two baffles in it exhibited well fluidization and abundant microbes growing on carrier.

1. Introduction

In recent years, water eutrophication has aroused widespread concern. Nitrogen and phosphorus are the main factors that cause water eutrophication. Therefore, the emission standards of nitrogen and phosphorus are becoming more and more stringent at home and abroad. Ammonia removal is often achieved using nitrification/denitrification system. In the processes, nitrifying bacteria oxidize ammonia to nitrate under oxic conditions, and then denitrification occurred under anoxic conditions [1]. However, the operational control of aerobic and anaerobic conditions needed for nitrification and denitrification is hard to implement. To resolve these problems, various kinds of bioreactors have been studied for promoting the efficiency of nitrogen removal [2]. A biofilm reactor can accumulate high concentrations of biomass by way of microorganism immobilization on carriers compared to activated sludge reactors, which are comprised of bacterial suspensions [3]. Biological processes based on biofilms have been proved to be a better pathway for the removal of organic components and nitrogen from wastewater, avoiding some of the problems regarding activated sludge process such as large reactor size, require for settling tank, and biomass recycling [4]-[6]. Microbes with slow specific growth rates can attach to the carriers and circumvent being easily washed out [3], [7].

Moving Bed Biofilm Reactors (MBBR) was developed and applied in the 1990s and is an efficient wastewater treatment method that combines the advantages of both conventional fluidized bed and biological contact oxidation processes. МРРRs rely on biofilms that are grown on small (1-4 cm diameter) plastic carriers which are suspended and mixed in a reactor [8]. Microorganisms attached to the carriers are in fluidized state by aeration (aerobic) or agitation (anoxic or anaerobic), and the aerobic/anoxic conditions of the biofilm enable nitrification and denitrification to take place simultaneously in MBBR [9]. MBBRs which possess high resistance of load fluctuation, high nitrogen removal efficiency, and high effluent quality have been widely used to treat both urban and industrial
wastewaters for its. This technology allows biochemical oxygen demand (BOD₅) and N removal rates similar to those of activated sludge-based processes, with the advantage of a smaller tank volume [4], [10]. The effect of different structures of MBBR on the removal efficiency of pollutants is rarely reported. In the present study, MBBRs with different structures were developed, the systems included two parts: a major reactor and a settle tank. We evaluated the effect of structure of MBBR on synthetic wastewater treatment and to nitrogen removal under different NH₄⁺-N concentrations.

2. Materials and methods

2.1. Reactor and operational strategy

This experiment was carried out in three plastic Plexiglas MBBR (Figure 1), each one had a working volume of 8.1 L and a settle tank with a volume of 3 L. The first reactor (R1) had two baffles in the reactor, the second one (R2) had one baffle, and the last one had no baffle in the reactor as the control reactor. Plastic carrier was used as the biomass carrier and the packing rate was 30% (V/V). The carrier was 10 mm tall with diameter of 10 mm. The temperature was fixed at 26 °C during the whole experiment by means of a resistance wire heating. Mixing inside the reactor was performed using an aerator at the bottom of the reactor. The MBBR was running with dissolved oxygen (DO) concentration controlled at about 3.0 mg/L by adjusting the air flow rate. After the starting up of the MBBRs, MBBRs were operated for about 70 days. In phase I (1-39 d), the reactors operated at NH₄⁺-N concentration of 30 mg/L, and the residual days (II) at 50 mg/L, with the same HRT of 14 h, respectively.

2.2. Inoculation

The reactor was inoculated with activated sludge from a domestic wastewater treatment plant in Chengdu, China. The initial MLVSS (mixed liquor volatile suspended solid) concentration of the sludge was approximately 20,500 mg/L.

2.3. Feed composition

The MBBRs were fed with synthetic wastewater containing glucose as substrate. The composition of the synthetic wastewater was as follows: glucose, 1000 mg/L; NH₄Cl, 125-191 mg/L; K₂HPO₄, 44 mg/L; and 1 mL/L of a trace element solution. One liter of trace element solution contained 1.5 mg/L CaCl₂, 10 mg/L EDTA, 1.1 mg/L CuCl₂·2H₂O, 0.003 mg/L H₃BO₃, 0.003 mg/L Na₂SeO₃, 1.2 mg/L MgSO₄·7H₂O, 0.28 mg/L FeSO₄·7H₂O, 0.2 mg/L ZnSO₄·7H₂O, 0.11 mg/L MnSO₄·H₂O, 0.06 mg/L CoSO₄·7H₂O. NaHCO₃ with 100 mg/L was added to the influent to maintain the pH of the MBBRs suspension between 6.5 and 7.5.

Figure 1. Schematic diagram of experiment equipment
2.4. Analytical method
The influent and effluent samples were collected on daily basis and were immediately analyzed. The determination of ammonium, nitrite, nitrate, COD, TN, TSS and VSS were measured were analysed according to Standard Methods [11].

3. Results and Discussion

3.1. Organic removal
The COD removal efficiency of the MBBRs at the same conditions was summarized in Figure 2. In the first 39 days (I), the average COD removal efficiency were about 89%, 87.1%, and 84.7%, and effluent COD concentration were about 111.6 mg/L, 128.8 mg/L and 154.5 mg/L, respectively. In phase II, the NH$_4^+$-N rose to 50 mg/L, the COD of effluent quickly decreased to less than 100 mg / L of the three MBBRs accordingly, and the optimal effluent quality was obtained in R1 with about 50 mg/L. The efficiency trend of reactors was R1>R2>R3. On one hand, MLVSS concentration was increased from 847 mg/L to 1474 mg/L in R1, from 565 mg/L to 1416 mg/L in R2, and from 443 to 1039 g/L in R3, respectively. This phenomenon indicated that the enrichment of microbes on the carriers, which caused the further decreasing of COD. On the other hand, denitrification enhances the COD removal rate. Therefore, it was concluded that the baffle in the reactor could promote the removal efficiency of organic because of the highest COD removal efficiency and the substantial microbes that had been obtained in R1.

![Figure 2. COD concentrations in influent and effluent.](image)

3.2. Nitrogen removal
Figure 3 illustrates the NH$_4^+$-N (A) and total nitrogen (TN) removal efficiency (B) of different MBBRs during the whole operation. In phase I, DO concentration was about 3.0 mg/L, the effluent ammonia concentration was below 1.0 mg/L, and the average removal rate of NH$_4^+$-N was more than 96%. When concentration of influent NH$_4^+$-N was switched to 50 mg/L in phase II, the removal rate of NH$_4^+$-N decreased and then increased until the biomass gradually adapted to the imposed conditions. The concentration of effluent NH$_4^+$-N for R1, R2 and R3 were close to 2 mg/L, 4 mg/L and 5 mg/L, respectively. The DO content is a limiting variable in biological nitrification-denitrification treatment processes. R1 with two baffles promoted sufficient carrier movement and obtained high oxygen transfer co-efficient, which favored the oxidation of ammonia.
Figure 3. Typical concentration profiles of NH$_4^+$-N (A) and TN removal efficient of the MBBRs (B).

4. Conclusion
Comparison among different structures of MBBRs, higher effluent quality was obtained for R1 with two baffles. R1 exhibited well fluidization and abundant microbes on carriers. The result further indicated that MBBR structure had a significant effect on the pollution removal; structural optimization by adding baffles could enhance the mass transfer efficiency leading to MBBR performance improvement. Finally, we can further reduce energy consumption by adding baffles in practice.

5. References
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