

Modelling nitrogen removal performance of membrane aerated biofilm reactor by AQUASIM software

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Abstract. A biological nitrogen removal model was established by AQUASIM software to model the autotrophic nitrogen removal performance of membrane aerated biofilm (MAB). The effects of biofilm thickness, hydraulic retention time (HRT) and influent ammonia concentration on microbial community and total nitrogen (TN) removal efficiency were investigated. The results show that the large biofilm thickness of counter-diffusion MAB contributed to the small proportion of AOB and low TN removal efficiency. It is worth noting that the TN removal efficiency reached 84% when the membrane thickness was 500 μm . Regarding with the HRT and influent ammonia nitrogen concentration, the low influent ammonia nitrogen concentration and HRT resulted in the high TN removal efficiency. The influent ammonia nitrogen concentration of 450 mg/L and HRT of 5.5 days contributed to the highest TN removal efficiency of 87%.

1. Introduction

Nitrogen is an important constituent element of organic life, and the cycle of nitrogen in the natural environment is one of the most basic material cycles in the biosphere. With the rapid growth of industrial technology, the emissions of nitrogen-containing pollutants have increased rapidly, causing serious pollution to the environment, especially water bodies [1]. The wastewater with high ammonia nitrogen enters the water body, forming eutrophication pollution [2, 3].

The membrane aerated biofilm reactor (MABR) is a novel membrane bioreactor, composed of membrane module and biofilm on the membrane surface. By supplying oxygen to the membrane module and controlling the pressure below the bubble point, no bubble aeration is carried out. The membrane module is used as a carrier to support the growth of highly active biofilm to remove pollutants. It has the characteristics of high oxygen utilization rate, bubble-free aeration, few sludge and convenient operation and management [4, 5]. It is a noticeable method for treating wastewater with high ammonia nitrogen and volatile organic pollutants.

AQUASIM software is mainly used in the laboratory and sewage treatment field to simulate and analyze aquatic ecosystems. It can calculate the mathematical model of sewage treatment and the water



quality of rivers and lakes, which is designed to provide an important software tool for environmental science and engineering to simulate and analyze aquatic ecosystems.

The aim is to develop a nitrogen removal model of MAB by AQUASIM software. The effects of oxygen transfer direction, influent ammonia concentration, biofilm thickness and HRT on the microbial distribution and nitrogen removal were investigated.

2. Materials and Methods

2.1. Establishment of mathematical model

A one-dimensional multi-population biofilm model was constructed in AQUASIM 2.1 [6]. Both co-diffusion and counter-diffusion biofilm geometries were modeled to simulate performance and microbial community structure under various operational conditions. The models have the same structural dimensions and membrane surface areas as in the experimental biofilm reactors. Both modeled biofilm reactors have two linked compartments: a completely-mixed gas compartment and a biofilm compartment, the latter of which is further composed of a biofilm matrix and bulk liquid.

2.2. Model validation

The activated sludge model was extended by implementing a two-step nitrification process [7]. Bacterial growth and decay processes were considered for heterotrophic bacteria (HB), ammonia oxidation bacteria (AOB), anaerobic AOB (AMX) and nitrite oxidation bacteria (NOB). The dissolved oxygen (DO) was used as an electron acceptor for both autotrophic and heterotrophic growth, while denitrifying HB also use nitrite and nitrate as electron acceptors when oxygen is limited. Kinetic and stoichiometric parameters for AOB, AMX and NOB were derived from literature. According to the direction of oxygen diffusion, two kinds of MAB were compared: co-diffusion and counter-diffusion biofilms. The kinetic control of all microbial reaction rates is described by the Monod equation, and each reaction rate is modeled by an explicit function that takes into account all the substrates involved.

3. Results and Discussions

3.1. Microbial profile in co-diffusion and counter-diffusion MAB

The distribution of microorganisms in co-diffusion and counter-diffusion MAB is shown in Figure 1. In the co-diffusion MAB, because oxygen was supplied from the liquid phase to the biofilm in the main reactor compartment, the AOB bacteria content stayed highest at 500 μm on the membrane surface and decreased from 500 μm to the membrane surface. The content of AOB bacteria gradually decreased, while the content of anaerobic AOB gradually increased, and the highest content of anaerobic AOB appeared after 400 μm . In the counter-diffusion MAB, because oxygen was supplied from the membrane to the outside of biofilm, the AOB bacteria content was highest on the membrane surface. The content of AOB bacteria gradually decreased along with the increase of biofilm thickness from 0 μm to 500 μm . However, the content of anaerobic AOB gradually increased to be the highest at 500 μm . The proportion of inert microorganisms stayed lower than 30%. The growth of NOB bacteria was not observed in both two MAB systems.

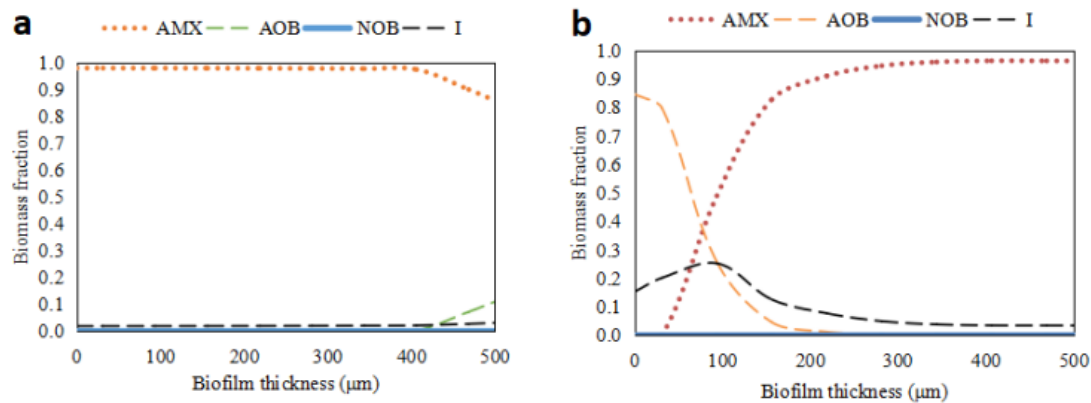


Figure 1. The biomass fraction of ammonia oxidation bacteria (AOB), anaerobic AOB (AMX), nitrite oxidation bacteria (NOB) and inert bacteria (I) inside biofilm thickness of co-diffusion MAB (a) and counter-diffusion MAB (b)

3.2. Effect of influent NH_4^+ concentration

In order to explore the effect of influent NH_4^+ concentration on the nitrogen removal performance and microbial community of counter-diffusion MAB, the $\text{NH}_4^+\text{-N}$ concentration varied from 150 mg/L to 500 mg/L and the TN removal efficiency as well as active biomass fraction of different bacteria were compared.

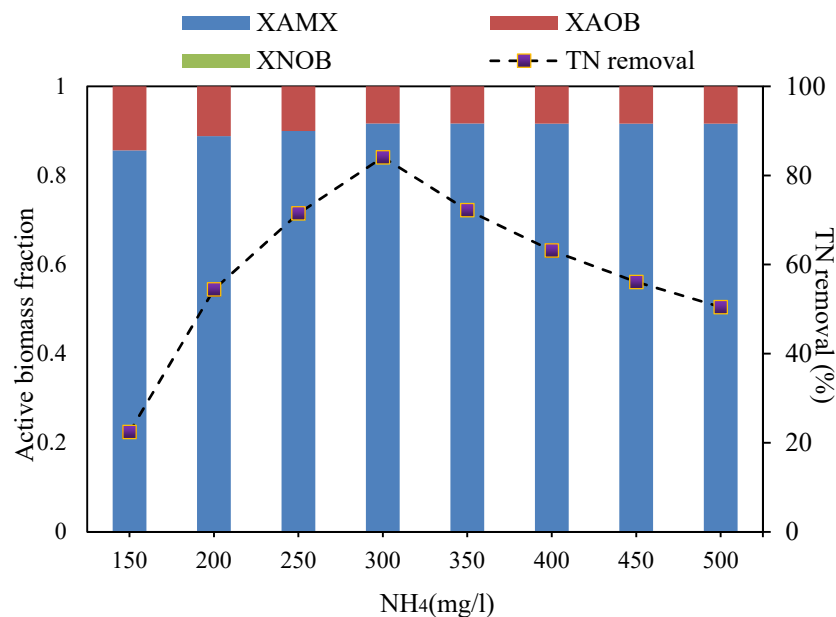


Figure 2. The active biomass fraction and TN removal efficiency under different influent NH_4^+ concentrations

As shown in Figure 2, the proportions of anaerobic AOB and AOB in the biofilm were 0.86 and 0.14 at the influent ammonia nitrogen of 150 mg/L, respectively. When the ammonia nitrogen load increased from 150 mg/L to 300 mg/L, the proportion of anaerobic AOB in the biofilm gradually increased, while the proportion of AOB decreased. However, the proportion of anaerobic AOB in the biofilm slowly decreased when the ammonia nitrogen load increased from 300 mg/L to 400 mg/L. Finally, when the

ammonia nitrogen load increased from 400 mg/L to 500 mg/L, the proportion of AOB and anaerobic AOB in the biofilm was basically unchanged. Regarding with TN removal, the increase of ammonia nitrogen concentration from 150 mg/L to 300 mg/L contributed to the increase of TN removal efficiency that increased from 22% to about 84%. The further increase of ammonia nitrogen load from 300 mg/L to 500 mg/L resulted in the reduction of the TN removal rate in the system from 84% to approximately 50%.

3.3. Effect of film thickness

In order to explore the influence of biofilm thickness on the nitrogen removal performance and microbial community of counter-diffusion MAB, the film thickness varied between 400 μm and 1000 μm and the TN removal efficiency as well as active biomass fraction of different bacteria were compared.

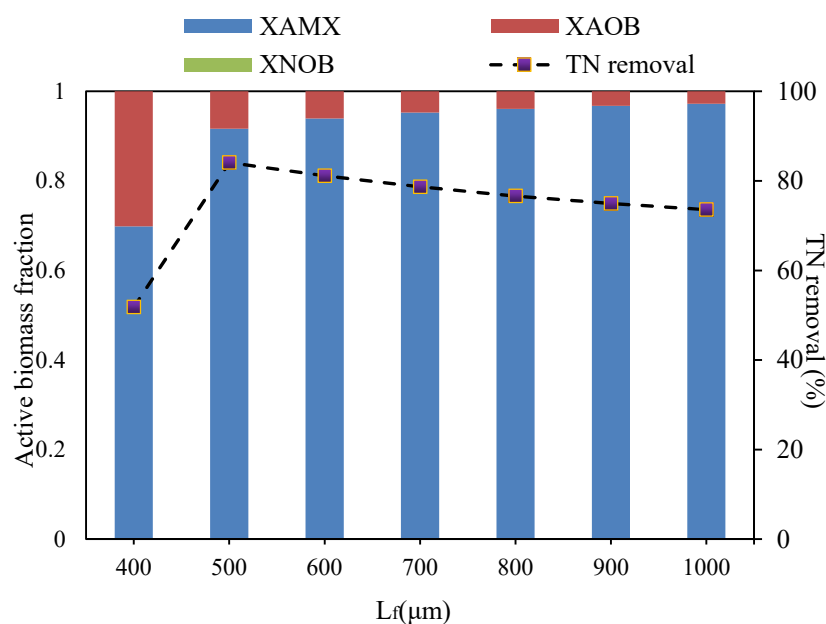


Figure 3. The active biomass fraction and TN removal efficiency under different biofilm thickness

As shown in Figure 3, the proportion of anaerobic AOB and AOB in the biofilm was 0.70 and 0.30 at the membrane thickness of 400 μm , respectively. When the membrane thickness increased from 400 μm to 1000 μm , the proportion of anaerobic AOB in the biofilm gradually increased, while the proportion of AOB decreased. Regarding with TN removal, the TN removal efficiency of the system increased rapidly from 52% to 84% along with the increase of film thickness from 400 μm to 500 μm . The further increase of biofilm thickness from 500 μm to 1000 μm reduced the TN removal efficiency of system from 84% to approximately 73%.

3.4. The comprehensive effect of HRT and ammonia nitrogen concentration

In order to further study the effect of HRT and ammonia nitrogen concentration on the nitrogen removal of counter-diffusion MAB, the HRT was changed between 1.5 and 5.5 days and ammonia nitrogen concentration changed from 150 mg/L to 500 mg/L at the same time. And the study on TN removal efficiency under different conditions was conducted.

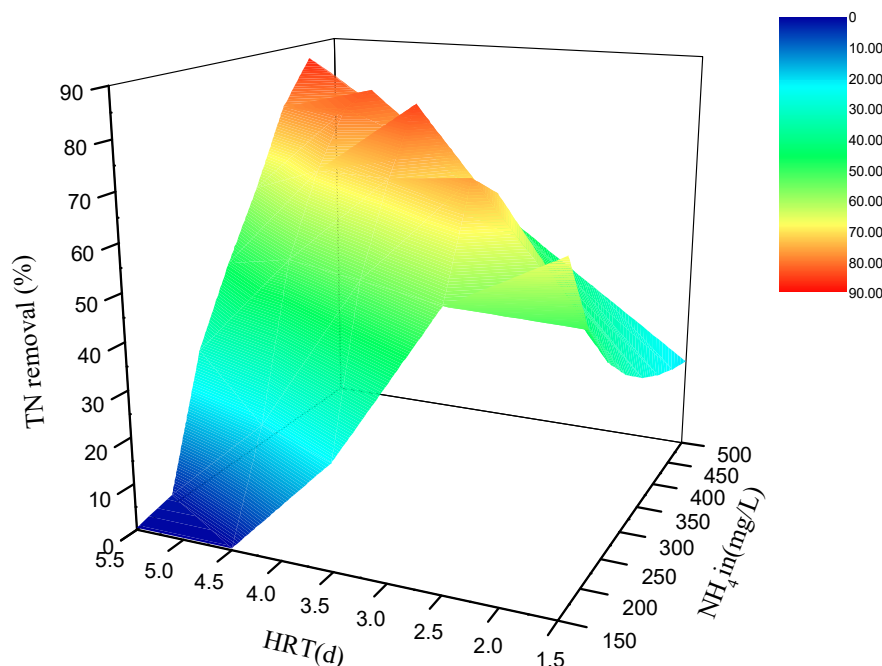


Figure 4. The TN removal efficiency under different HRT and influent ammonia nitrogen concentrations

As shown in Figure 4, the high TN removal efficiency of system under certain HRT corresponded to the different ammonia nitrogen concentrations. The highest TN removal efficiency under HRT of 1.5 days reached 67% when the ammonia nitrogen concentration was 150 mg/L. However, the highest TN removal efficiency under HRT of 4.5 days arrived at 82% when the ammonia nitrogen concentration was 400 mg/L. The high TN removal efficiencies were 76%, 84%, 82% under the HRT of 2.5, 3.5, 4.5 days and the ammonia nitrogen load of 200, 300, 400 mg/L, respectively. It can be seen that the highest TN removal efficiency reached 87%, when the HRT was 5.5 days and the ammonia nitrogen load was 450 mg/L.

4. Conclusion

The simulation results of pollutant degradation model by AQUASIM software showed that the large biofilm thickness of counter-diffusion MAB contributed to the small proportion of AOB and the low TN removal efficiency. It is worth noting that the TN removal efficiency reached 84% when the membrane thickness was 500 μm . Regarding with the HRT and influent ammonia nitrogen concentration, the low influent ammonia nitrogen concentration and HRT resulted in the high TN removal efficiency. The TN removal efficiency was the highest of 87%, when the influent ammonia nitrogen concentration and HRT were 450 mg/L and 5.5 days, respectively.

Acknowledgments

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