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Suppression of nitrite-oxidizing bacteria in intermittently aerated biofilm reactors: a model-based explanation

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Introduction

Membrane-aerated biofilm reactors (MABRs) are excellent candidates to perform autotrophic N removal. In counter-diffusion nitrifying biofilms, N oxidizing bacteria (ammonia oxidizers, AOB and nitrite oxidizers, NOB) dominate at the base of biofilm, efficiently utilizing the oxygen source provided from the membrane lumen. NOB presence at the biofilm base challenges the ability to reduce its abundance and activity, and the selective enrichment of AOB needed to maximize nitritation or short-cut ammonium (NH_4^+) removal via nitrite (NO_2^-). Pellicer-Nàcher et al. (2010) observed that MABRs immediately accumulated NO_2^- after switching from continuous to intermittent aeration. They suggested that the intermittency caused nitratation to lag behind nitritation, but the underlying mechanisms were not explored. Mathematical modelling can be useful to gain insights in the behaviour of systems that harbour multiple interacting processes. Nitrifying biofilms are such systems, and models may be useful to identify determinant effects as part multiple simultaneous processes across time and space. The main objective here is to develop and calibrate a multi-species nitrifying biofilm model to evaluate NOB suppression under intermittently aerated regimes. The model considers relevant physical, chemical, and biochemical processes and explores how the net growth kinetics of the N oxidizing groups change in different aeration strategies.

Material and Methods

The studied counter-diffusion MABR was equipped with tubular PDMS membranes (3100506, Labmarket, Germany), and was inoculated with enriched nitrifying biomass. In the intermittent aeration strategy, a 12-hour cycle was defined with a 6-hour O_2 period, followed a 6-hour N_2 period. After reaching stable state, N concentrations in the bulk and within the biofilm were measured. Commercially available DO microelectrodes (OX-10, Unisense, Denmark) were used to measure DO profiles within the biofilm. Lab-made potentiometric microelectrodes were used for NH_4^+, NO_2^- and nitrate (NO_3^-) measurements. The model used in this study is one-dimensional and dynamic, based on Terada et al. (2007), incorporating explicit pH calculation. The local pH within the biofilm was calculated based on the proton production via nitrification and consumption via denitrification, the equilibrium reaction with the bicarbonate buffer, and CO_2 stripping to the lumen. Three active microbial groups were considered: AOB, NOB, heterotrophic bacteria; in addition, decay resulted in accumulation of inert mass. For the 2-step nitrification process, free ammonia (FA) and free nitrous acid (FNA) were considered as true substrates. The effects of DO limitation, and a pH-kinetic effect as well as pH effect on substrate-speciation were taken into account. Default values for kinetic parameters were taken from ASMN model (Hiatt and Grady, 2008), and model was recalibrated and validated with experimental data.

Results and Conclusions

Sensitivity analysis showed that μ_{max}^{AOB} and μ_{max}^{NOB} were the most sensitive parameters governing ammonium removal and nitritation efficiency. The microprofile data (NH_4^+, NO_2^-, NO_3^-, DO) in the first aeration hour were used to estimate the most sensitive parameters (Figure 1a). The parameter values, including calibrated μ_{max}, were shown in Table 1. The model was evaluated with microprofile data during the last aeration hour (figure 1b) and N concentrations and pH in the bulk (data not shown).

Table 1 Kinetic parameter values in the model
* default growth rates from ASMN

Kinetic parameters	AOB	NOB	References
μ_{max}: the maximum specific growth rate (optimal pH)	3 0.78*	5.35 0.78*	this study
K_{O2}: half-saturation coefficient for O_2	0.6	1.2	
Y: autotrophic yield	0.18	0.06	
K_{FA}^{AOB}, K_{FNA}^{NOB}: half-saturation coefficient for substrate	0.0075	0.0001	(Hiatt and Grady, 2008)
$K_{I,FA}$: free ammonia inhibition coefficient	1	0.2	
$K_{I,FNA}$: free nitrous acid inhibition coefficient	0.1	0.04	
b_{max}: decay coefficient (aerobic condition)	0.17	0.073	(Hao et al., 2002)
$pH_{opt}(\omega)$: optimal pH	8.4(3.2)	7.7(2.4)	(Park et al., 2007)

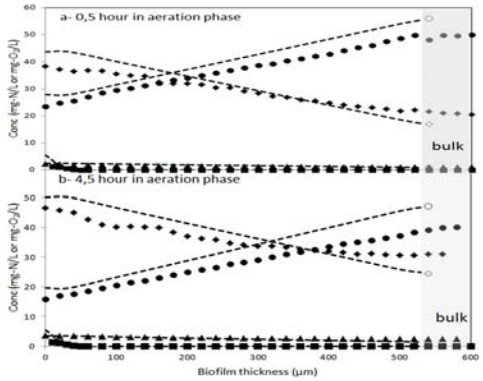

Figure 1 Experimental (marker) and predicted (line) profiles (NH_4^+/NO_2^-/NO_3^-/DO) within the biofilm in the 6-hour aeration at day 250 (♦- NH_4^+, ●- NO_2^-, ▲- NO_3^-, ■- O_2).

NOB suppression is the result of competition between AOB and NOB: the one with a higher net growth rate will win, while the other one is outcompeted. To explain how different influencing factors affected the suppression process, the effects of DO and pH on maximum growth rates were checked individually at different aeration times along the first 100 µm (the measured O_2 penetration depth) of the biofilm (Figure 2). pH substrate-speciation effect, leading to transient and dynamic FA inhibition of NOB growth, was the governing factor in suppressing NOB in the biofilm. It was re-confirmed in a suite of simulations that considered transitions from continuous aeration to various aeration strategies with different degrees of intermittency.

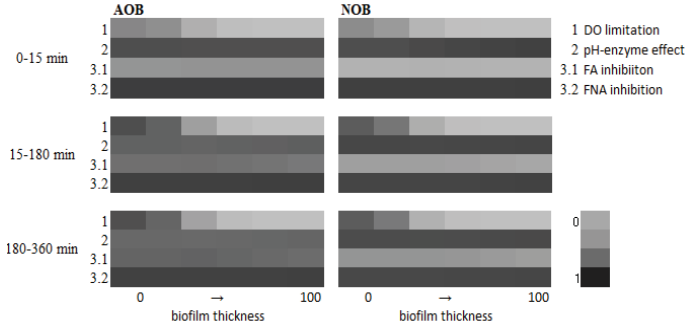

Figure 2 Individual inhibition and limitation effects on AOB and NOB growth within the 100µm-aerated biofilm during the aerated period. A value of 0 or 1 means severe or no limitation/inhibition.

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