Technical University of Denmark

# In-situ microbial activity in membrane-aerated biofilms for autotrophic nitrogen conversion

**Pellicer i Nàcher, Carles; Domingo-Felez, Carlos; Smets, Barth F.**

*Publication date:*
2012

*Document Version*
Publisher's PDF, also known as Version of record

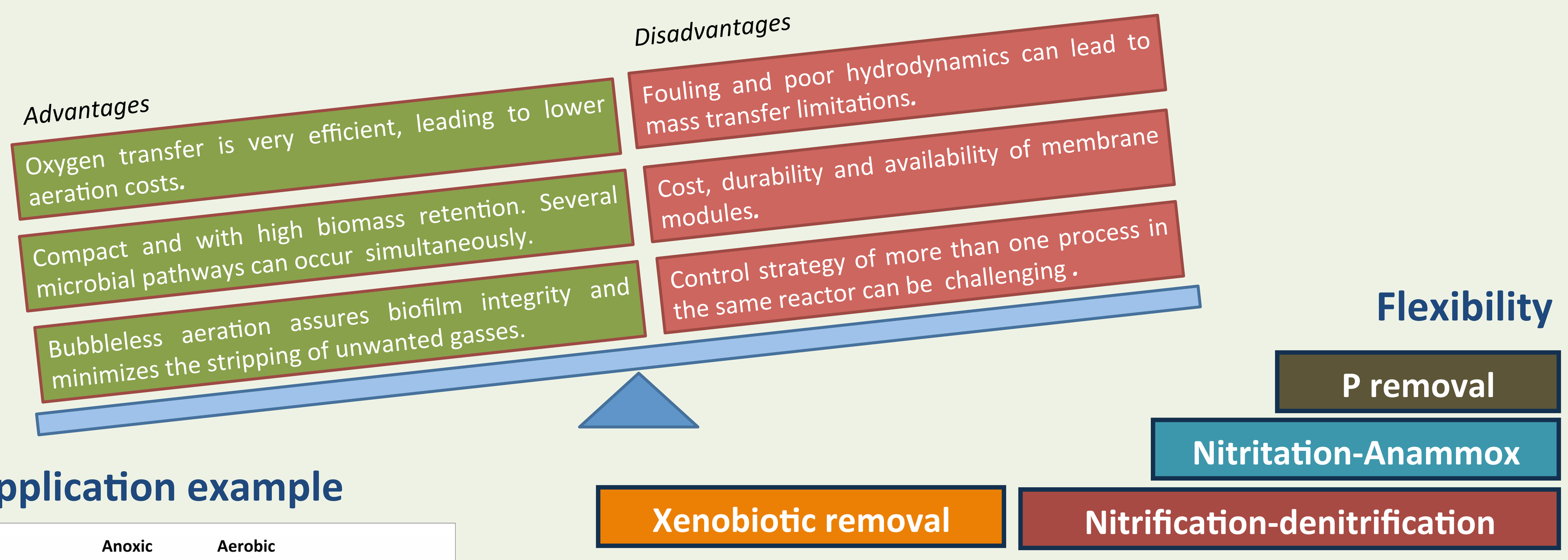
# In-situ microbial activity in membrane-aerated biofilms for autotrophic nitrogen conversion

DTU Environment
Department of Environmental Engineering

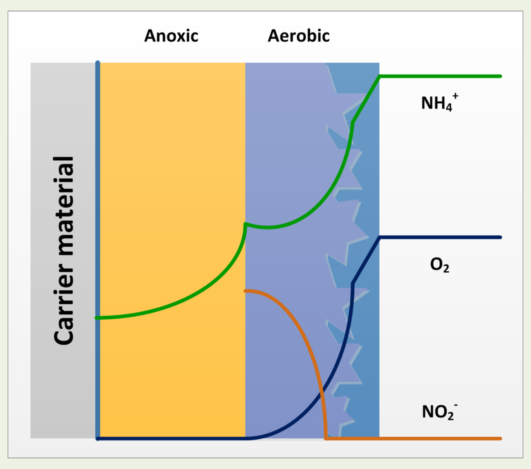
Carles Pellicer-Nàcher, Carlos Félez-Domingo, Barth F. Smets
Department of Environmental Engineering, Technical University of Denmark
E-mail: capn@env.dtu.dk

## 1. Introduction

**Membrane-aerated biofilm reactors (MABRs) are systems where oxygen diffuses through a membrane (submerged in wastewater) that serves as the substratum for biofilm growth. The counter-diffusion of nutrients within the biofilm matrix creates unique niches for the co-existence of distinct microbes.**




**Application example**

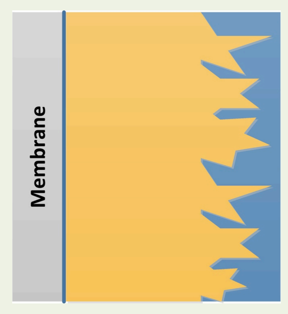



*MABRs can be used for simultaneous Nitritation-Anammox treatment in wastewaters (aka completely autotrophic nitrogen removal: CANR). After reactor inoculation a layered biofilm develops: Ammonia Oxidizing Bacteria (AOB) convert part of the incoming ammonium to nitrite in the first 100-200 mm by using the oxygen diffusing from the membrane surface. The produced nitrogen can be denitrified by Anaerobic Ammonium Oxidizing Bacteria (Anammox) in the upper anoxic biofilm region in completely autotrophic fashion:*

$$NH_4^+ + 1.26\ NO_2^- \rightarrow N_2 + 0.26\ NO_3^-$$

## 2. Research questions

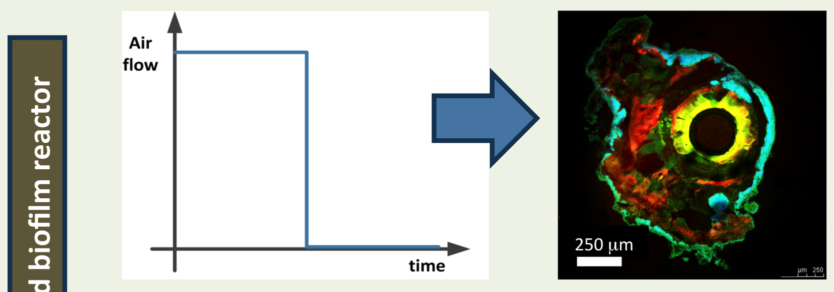
**Q1. Biofilms developed in MABRs affect significantly the Oxygen Transfer Rate (OTR) in these reactors, but how?**




**A1. Microbial activity in deep biofilm layers enhances OTRs (Pellicer-Nàcher et al. 2009, Lackner et al. 2010).**

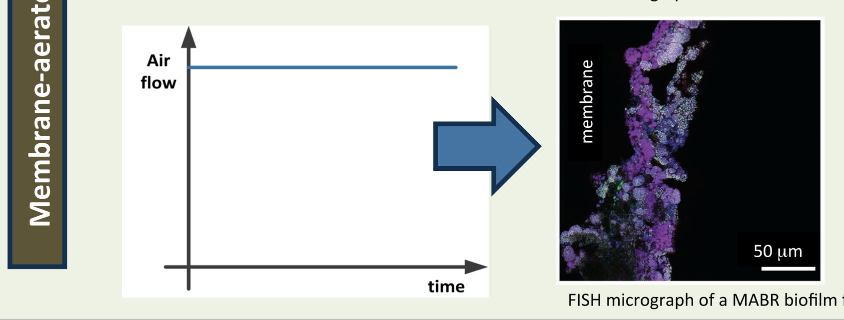
**A2. Biofilm eventually increases the resistance to the oxygen mass transfer (Shanahan et al. 2006), reducing OTRs.**

**Q2. When MABRs for completely autotrophic N removal (CANR) are aerated in cycles of aeration / no-aeration, they show enhanced performance… why?**




FISH micrograph of a MABR biofilm for CANR (yellow: AOB, cyan: Anammox, green: Other bacteria)

**Good $NO_2^-$ accumulation and eventual Anammox activity (Pellicer-Nàcher et al. 2009)**




FISH micrograph of a MABR biofilm for CANR (white: *N. Oligotropha*, magenta: other AOB, blue: other bacteria)

**$NO_2^-$ accumulation occurs at lower efficiencies. Microbial community composition in inoculum plays an important role (Terada et al. 2009).**

## 3. Experimental setup

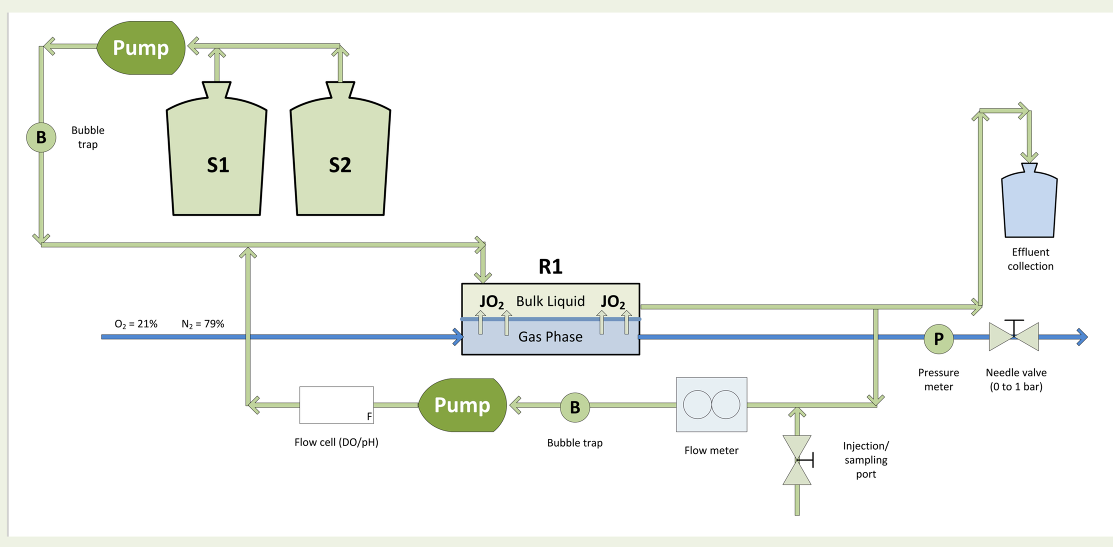



Diagram of the experimental setup used

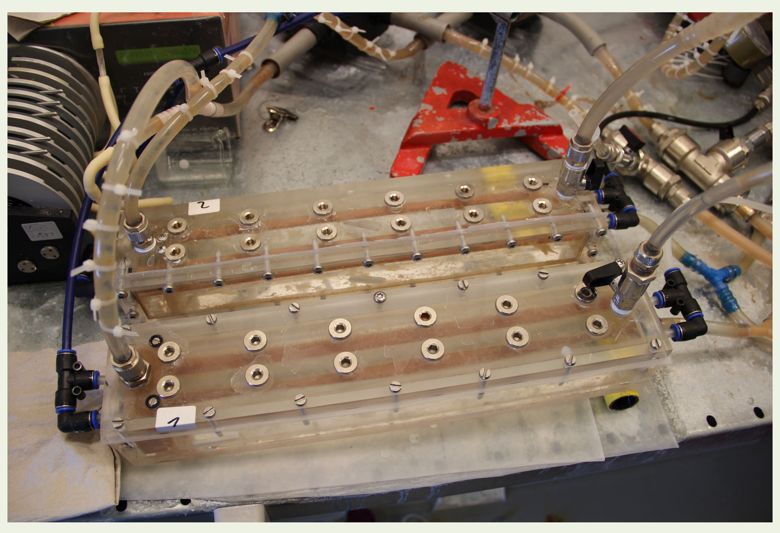
**Setup characteristics:**

- **Silicone hollow fiber membranes (14 $m^2/m^3$).**
- **Lab air used as $O_2$ source.**
- **Innoculum from previous lab reactor performing nitritation – anammox.**
- **Loaded with synthetic wastewater.**

**The experiments:**

**3 Ammonium surface loads were tested (5, 11 and 29 g-N/$m^2$/day) under the same oxygen load (100 mL/min air at 0.35 bar: 21 g-$O_2$/$m^2$/day in clean water)**

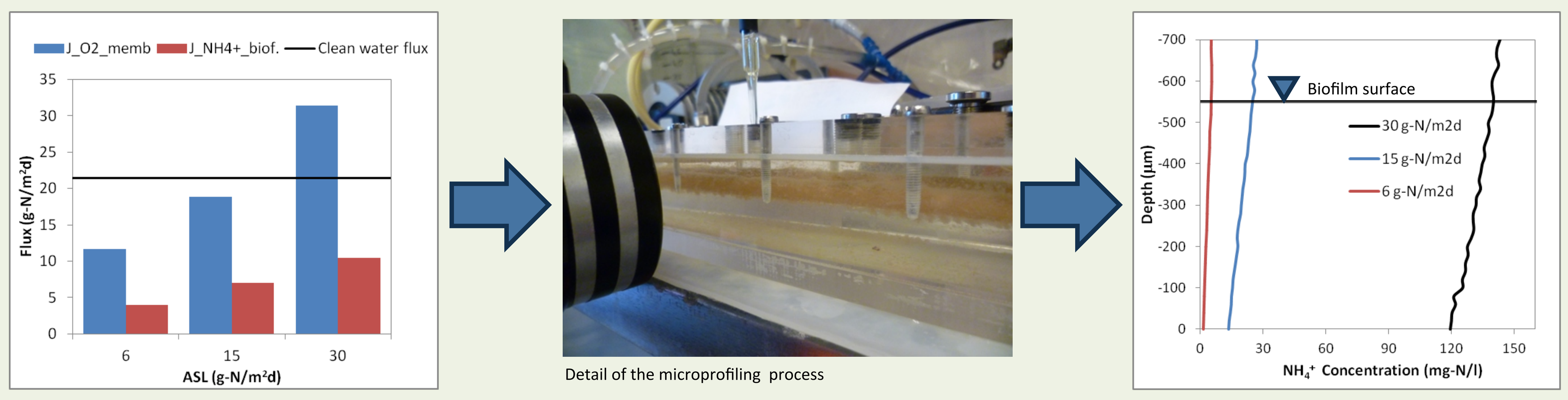
- **Bulk concentrations of N-species analyzed daily to assess reactor performance.**
- **Microsensor profiles at different times within an aeration cycle to detect changes in activities of the different microbial communities involved.**



Top-view of the flow cells used

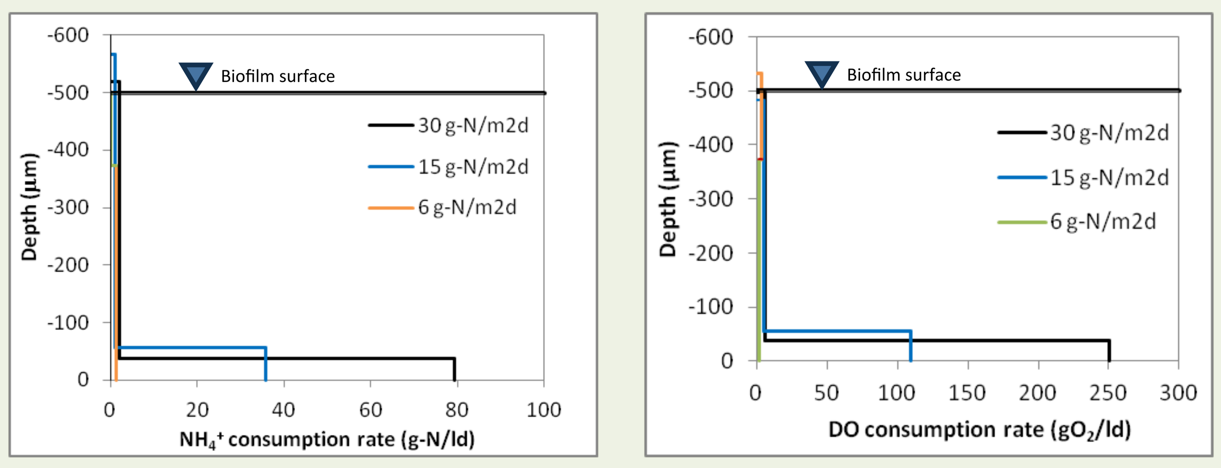
## 4. $NH_4^+$ surface loads enhance oxygen transfer rates

**Increases in the $NH_4^+$ surface load produce increases in the $NH_4^+$ flux converted by the biofilm. Such an enhancement rises the oxygen flux diffusing from the membrane (50% higher than in clean water)**

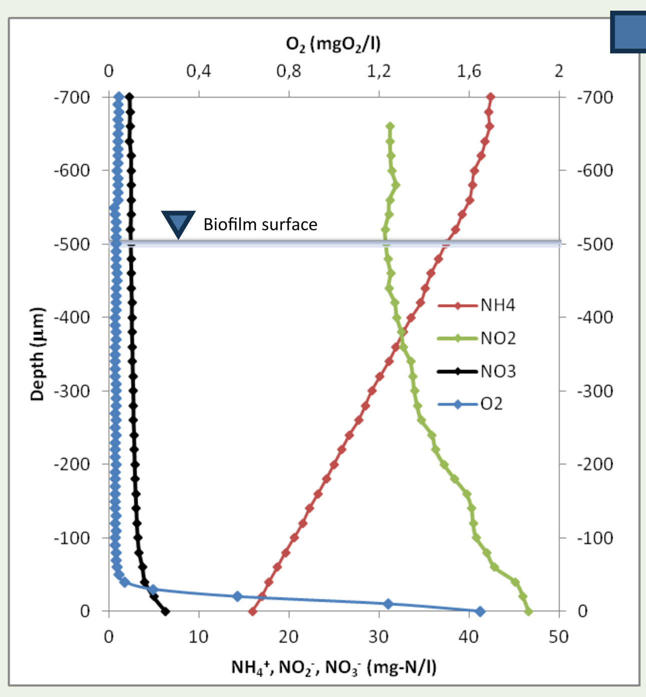



Detail of the microprofiling process

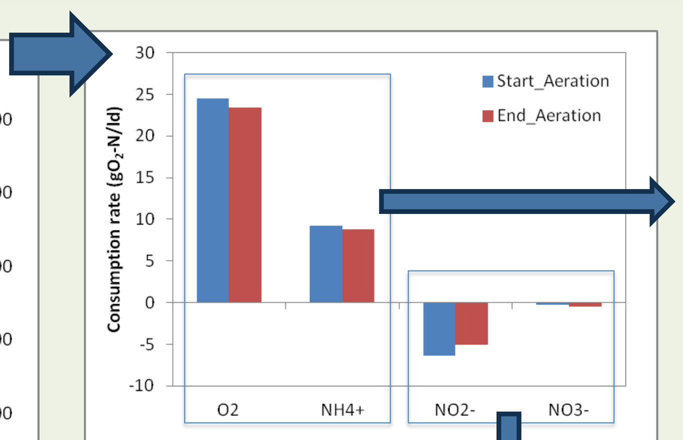
**Microprofile analyses show enhanced in-situ microbial activities within the aerobic biofilm region when they have higher $NH_4^+$ availability**




## 5. Periodic aeration impacts microbial activity

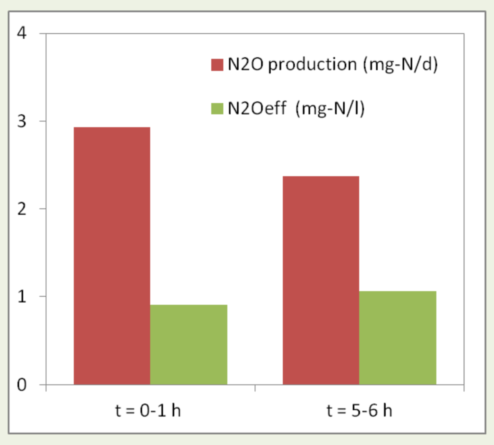



Typical microprofiles for relevant N species and DO during aeration phases



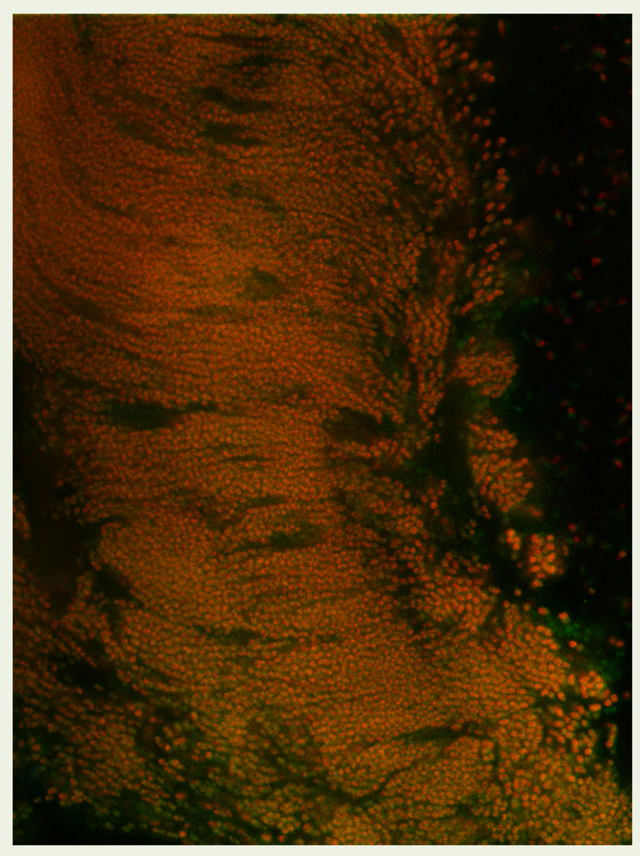

**Famine conditions during non-aerated periods stimulate in-situ DO and $NH_4^+$ consumption rates once $O_2$ becomes available.**

**The net $NO_2^-$ production rates decrease after the oxygen onset due to the lower DO flux, but also to the increase of the-situ activity of Nitrite Oxidizing Bacteria (NOB) in the deep biofilm region.**




**The $N_2O$ production within the biofilm declines with time after the start of the aeration phase. 40% of the $N_2O$ produced permeates through the aeration membrane**

## 5. Conclusions - Outlook



Detail of AOB in MABR for CANR

- **High $NH_4^+$ loads increase substrate availability in the biofilm base and stimulate deep in-situ microbial activities in MABRs. This enhancement results in OTRs 50% higher than the ones predicted from experiments without biofilm and explains divergences among literature results.**
- **The success of periodic aeration in accumulating $NO_2^-$ for successful CANR resides on its potential to inhibit NOB activity. The mechanism of inhibition remains unknown, but seems to decline with time. The reactor has higher $N_2O$ emissions by being operated this way, but up to 40% can be recovered.**

**Biofilms grown on aeration membranes enhance the mass transfer capabilities of these systems and allow microbial community management for a cleaner and more cost-effective wastewater treatment**

**References:**

Terada, A., S. Lackner, et al. (2010). "Inoculum effects on community composition and nitritation performance of autotrophic nitrifying biofilm reactors with counter-diffusion geometry." *Environmental Microbiology* 12(10): 2858-2872.
Pellicer-Nàcher, C., S. P. Sun, et al. (2010). "Sequential Aeration of Membrane-Aerated Biofilm Reactors for High-Rate Autotrophic Nitrogen Removal: Experimental Demonstration." *Environmental Science & Technology* 44(19): 7628-7634.
Lackner, S., A. Terada, et al. (2010). "Nitritation performance in membrane-aerated biofilm reactors differs from conventional biofilm systems." *Water Research* 44(20): 6073-6084.
Shanahan, J. W. and M. J. Semmens (2006). "Influence of a nitrifying biofilm on local oxygen fluxes across a micro-porous flat sheet membrane." *Journal of Membrane Science* 277(1-2): 65-74.

Research was supported by VEOLIA ENVIRONNEMENT Recherche & Développement