Redox Stratified Controlled Biofilm Reactor for Completely Autotrophic Nitrogen Removal

Pellicer i Nàcher, Carles; Lackner, Susanne; Terada, Akihiko; Lardon, Laurent; Smets, Barth F.

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1. Towards a novel reactor technology

Growing biofilms on oxygen permeable membranes, whereby oxygen supply to the bottom part of the biofilm can be easily controlled, can create redox stratification in the biofilm and, subsequently, micro niches for different bacterial communities which can perform simultaneous oxidation and reduction of pollutants from wastewater. These Redox-Stratified Controlled Biofilm Reactors (ReScoBiR) are a promising technology for stabilizing completely autotrophic nitrogen removal.

Anaerobic Ammonium Oxidizing Bacteria (AOB) [2]

\[ \text{NH}_4^+ + 1.38 \text{O}_2 + 1.98 \text{HCO}_3^- \rightarrow 0.018 \text{BC} + \text{NO}_2^- + 0.98 \text{NO}_3^- + 0.98 \text{NO}_2^- + 1.89 \text{CO}_2 + 2.93 \text{H}_2 \text{O} \]

Anaerobic Ammonium Oxidizing Bacteria (AnAOB) [2]

\[ \text{NH}_4^+ + 1.12 \text{O}_2 + 0.13 \text{H}^+ + 0.066 \text{HCO}_3^- + 1.02 \text{N}_2 + 0.26 \text{NO}_2^- + 2.03 \text{H}_2 \text{O} \]

Modeling studies have confirmed that counter-diffusion biofilm (in which substrates are supplied from both sides of the biofilm) are more advantageous for completely autotrophic nitrogen removal than a conventional co-diffusion biofilm [8]. Thus, this configuration will be the object of the present study.

2. Challenges in ReScoBiR

**Advantages**

- High removal efficiencies are expected: ACOAs have reported biological removal rates up to 26 kg N/m^2.d [4].
- Oxygen demand is 63% lower than in the conventional denitrusation process [3].
- Oxygen transfer is very efficient in these systems, leading to lower power requirements [6, 17] [4].
- Compact reactor configuration with high biomass retention where control systems are easier accessible.
- No organic carbon is required: The optimum for bacteria growth is provided by \( \text{HCO}_3^- \) [2].
- Low CO\(_2\) and NO\(_2\) emissions, causing a minor climate change impact [9].

**Disadvantages**

- Out component of nitrite oxidizers is not as easy as in modeling treatment review.
- Long start-up times until AnAOB show activity in the system [19].

**Nitrification stability and hydrodynamic behaviour of the counter-diffusing modules [4]**

In this study:
- Construction of the reactor system.
- Study of the nitrification in order to achieve AnAOB stoichiometry.
- Modeling of the constructed reactor.

3. Materials and methods

**Reactor monitoring**

Most of the process variables are tracked on-line:
- pH
- Dissolved Oxygen.
- Dissolved Redox Potential. \( \text{NH}_4^+, \text{NH}_3 \), and \( \text{NO}_2^- \) concentrations.
- Air Flow.
- Reactor Temperature.

Other variables tracked offline:
- Influent flow
- Gas line pressure
- Total Organic Carbon.
- \( \text{NO}_3^- \) Concentration.
- Total Suspended Solids

These readings are accessible from any computer with internet.

**Substrate Composition**

The substrate is synthetic wastewater adapted from [28], consisting of:
- \( \text{NH}_4\text{NO}_2 \) (300-600 mg N/l)
- \( \text{KH}_2\text{PO}_4 \)
- \( \text{NaCl} \)
- \( \text{MgCl}_2\cdot6\text{H}_2\text{O} \)
- \( \text{CaCl}_2\cdot2\text{H}_2\text{O} \)
- Trace elements

- Difficulties to reach the proper \( \text{NH}_4^+:\text{NO}_3^- \) ratio, but fast response of the bacteria to disturbances. Calculations based on stoichiometric relations with \( \text{NH}_4^+, \text{NO}_2^- \) and \( \text{NO}_3^- \) steady state concentrations show an oxygen transfer rate about 10 times higher than the one predicted in the clean water tests.

**4. Experimental results**

Operation started in February, with nitrifying biomass from the Lundtofte wastewater treatment plant (Lundtofte, Denmark). The objective was to keep the \( E_{\text{Nar/NO}} \) ratio at the optimal level [3] for attainment of the Anamox stoichiometry.

Batch tests were carried to estimate bio-kINETIC parameters and the current global mass transfer coefficient via parameter estimation with the implemented model. Another objective was to test the potential to reach the Anamox stoichiometry.

Current status and future work:
- Reactors inoculated with Anamox biomass cultivated in a plug flow reactor at 37°C in laboratory conditions.
- Continued operation to achieve complete nitrogen removal at room temperature.

**5. Modeling**

A mathematical model for the presented Counter-diffusion ReScoBiR was built using AQUASIM [16], taking the model in [27] as guidance. A parameter estimation fits the data presented in FIGURE 11 was performed. Bio-kinetic parameters and global mass transfer coefficient obtained were used to build a simplified MATLAB model, which accounted for the following processes in the biofilm as they are presented in [28] and [29].

- Growth, decay and hydrolysis processes.
- Advection due to biofilm growth.
- Diffusion (implementation improved the convergence of the model).

The model represents quite accurately the batch and the dynamics of the posterior continuous operation without aeration.

- Empirical and modeling results confirmed that the mass transfer is 10 times higher than expected.
- ACOB growth rate is 10% lower than the expected.
- NOB growth rate is 60% lower than the one in the literature.

- The MATLAB model will extend and Anamox bacteria activity were also incorporated.
- The model shows similar behaviour when compared to respective AQUASIM simulations. The model should be refined to represent better the biofilm growth and the stratification.
- A control strategy to shorten Anamox start-up time is being designed.
- MATLAB model will give the possibility to implement real-time control in the system.

References: