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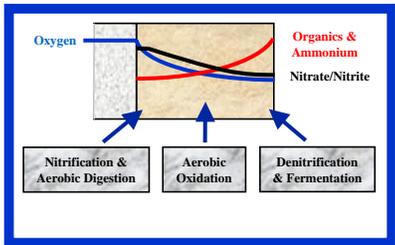


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Numerical and Experimental Studies of a Membrane-Aerated Biofilm Reactor

Background Information

Membrane-aerated biofilm reactors (MABRs) offer an innovative new technology for the treatment of municipal wastewaters. Within the MABR, a biofilm grows on gas permeable membranes submerged in wastewater. Oxygen is supplied to the membrane interior and diffuses through pores in the membrane fabric to the base of the biofilm, while ammonium and organics diffuse from the wastewater into the biofilm at the liquid-biofilm interface. This counter-diffusion of substrates leads to micro-niches across the biofilm depth, which in turn allow for the simultaneous removal of carbon and nitrogenous compounds in a single biofilm. In this system, the membrane separates the supply from the bulk wastewater, so, low pressures are necessary to provide high gas flows through the membrane interior. As a result, the MABR may provide a significant energy savings over conventional activated sludge systems that rely upon bubble aeration of wastewater.



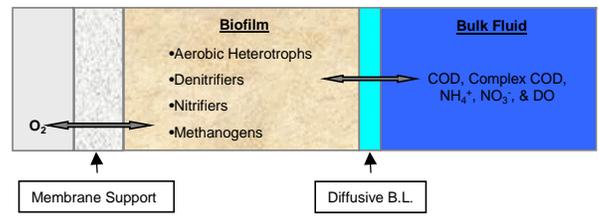
Counter-diffusion of bacterial populations in a membrane-aerated biofilm resulting from the counter-diffusion of substrates and oxygen in the biofilm.

Research Approach

- Hypothesis: An optimally designed membrane-aerated biofilm reactor can provide for the treatment of chemical oxygen demand (COD) and nitrogenous compounds in a more economical than wastewater treatment technologies that rely on bubble aeration.
- To identify optimally designed MABRs, information regarding the performance of membrane-aerated biofilms grown under well-defined conditions is needed. This information will be generated and used via the following tasks:
- Develop a mathematical model to describe the performance of and ecological interactions within a membrane-aerated biofilm over a range of operating conditions.
- Cultivate membrane aerated biofilms in a laboratory scale reactor to quantify biofilm performance under well-defined conditions. Results from this task will be used to verify/calibrate the model.
- Simulate MABR removal performance over a range of operating conditions with the verified model for identification of optimal reactor design. Model results will be used in preparation of an economic analysis between optimized MABR systems and conventional systems for the treatment of municipal wastewater.

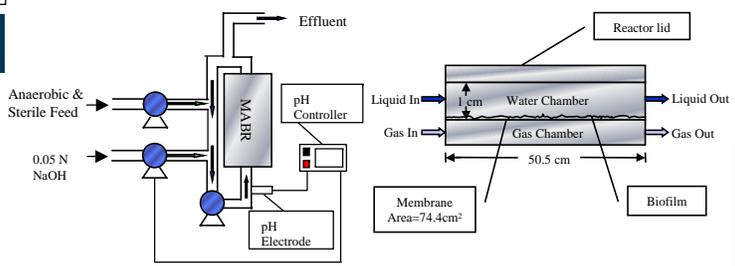
Model Development

- Model Details:
- One-dimensional dynamic model of membrane-aerated biofilms constructed with Aquasim 2.0 software
 - Monod kinetics are used to describe the growth/decay of bacterial populations within the biofilm
 - Processes considered include substrate diffusion, nitrification, denitrification, aerobic respiration, fermentation, bacterial decay, hydrolysis of decay products, and facultative switching between aerobic heterotrophs and denitrifying bacterial populations



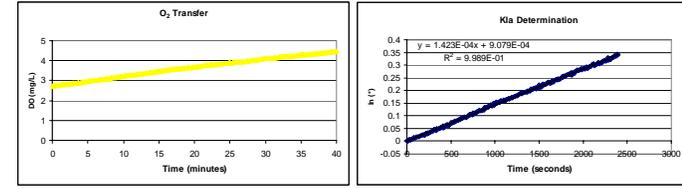
Schematic of the biofilm model illustrating the bacterial populations and chemical species considered.

Experimental Setup



- Left: An illustration of the experimental apparatus used in this study. The reactor is located in a recirculation loop to allow independent control of hydraulic residence time and Reynolds number in the water chamber. A pH probe and controller are linked to a sodium hydroxide pump for pH control.
- Right: Detail of the membrane-aerated biofilm reactor. The reactor consists of a gas chamber, liquid chamber, and a reactor lid that are bolted together. A micro-porous, polypropylene membrane separates the liquid and gas compartments and serves as a substratum for biofilm growth.

Reactor Characterization

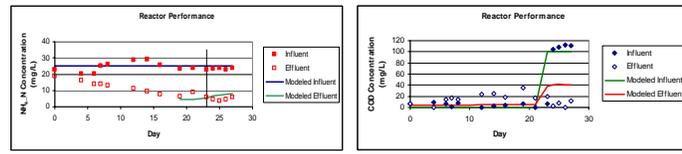


The clean membrane behavior was characterized via standard oxygen transfer tests prior to inoculation of the system with bacterial cells. The average cross-flow velocity was set to 1.6 cm/s. Oxygen transfer was described via a mass transfer coefficient ($K_{La} = 0.52 \text{ min}^{-1}$). Results from this and other studies demonstrated that oxygen transfer could be increased by increasing flow velocity, membrane area, and/or oxygen partial pressure in the membrane.

Preliminary Results

Table of operating conditions: On day 0, the reactor was inoculated with a nitrifier enrichment culture and the reactor was supplied with an ammonium based synthetic wastewater. On day 23, organics were added to the feed, and the reactor was re-inoculated with activated sludge.

Day	0-23	23-27
Influent COD (mg/L)	0	100
Influent NH ₄ -N (mg/L)	25	25
HRT (hours)	~6	~6
DO @ Membrane (mg/L)	~8	~8
Average Cross-Flow Velocity (cm/s)	1.6	1.6



Preliminary comparisons between experimental results and model simulations of the membrane-aerated biofilm reactor. Model results are in close agreement with experimental measurements of ammonium removal. The model under-predicted COD removal in the system. This disparity may have resulted from heterogeneities in the biofilm surface → increased available surface area.