Preventing the Initiation of Biofouling of Membrane Bioreactors in Wastewater Treatment t

Basic Information

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Principal Investigators:	Daniel Barton Oerther, Dionysios Dionysiou, George A Sorial

Publication

Project Title. Preventing the Initiation of Biofouling of Membrane Bioreactors in Wastewater Treatment

Project Team.
Daniel B. Oerther, Ph.D., Tenure-track Assistant Professor
Dionysios Dionysiou, Ph.D., Tenure-track Assistant Professor
George A. Sorial, Ph.D., Tenure-track Associate Professor

Department of Civil and Environmental Engineering, University of Cincinnati

Summary of Annual Progress. Membrane bioreactors (MBR) can be expensive to operate because of fouling of the membrane that results in high operating pressures, excessive membrane cleaning, and decreased membrane life. We hypothesize that preventing the initiation of biofilm formation on membrane surfaces is the best approach for eliminating fouling of the membranes in MBR systems. To test this hypothesis, we are investigating the connection between the physiochemical properties of membranes and the ecology of microbial communities inhabiting MBR systems. The specific interdisciplinary aims that are being undertaken in this study include:

a) determining the physicochemical properties of membranes;
b) examining the impact of synthetic pulp and paper wastewater on the physiochemical properties of membranes;
c) determining the biochemical interactions between microorganisms and membranes;
d) examining the impact of synthetic pulp and paper mill wastewater on the microbial community colonizing membranes; and
e) determining the role of microbial ecology in the initiation of biofilm formation on membrane surfaces.

The research team working on this project includes: a tenure-track faculty member with experience in physiochemical properties of membranes (Dionysiou); a tenure-track faculty member with experience in biological treatment of industrial wastewaters (Sorial); a tenure-track faculty member with experience in molecular biology and conventional microbiological analysis of environmental samples (Oerther); and two doctoral students. Milestones for the first year of the project include:

1. Designing, fabricating, and pilot-testing a laboratory-scale membrane reactor system to quantify transmembrane flux (to date, the system has been used to test membranes for a total running time of approximately 80 hours).
2. Designing, fabricating, and operating four laboratory-scale membrane bioreactor systems using activated sludge to treat a synthetic pulp and paper mill wastewater (to date, the reactors have been operated continuously for a period of 120 days).
3. Developing appropriate analytical procedures to characterize the physiochemical properties of membranes including brighfield, phase contrast, and epifluorescence microscopy; transmission electron microscopy; scanning electron microscopy; and FTIR analysis.
4. Developing appropriate analytical procedures to characterize the microbiological community in the various experimental systems including the Full Cycle 16S rRNA Approach and Fluorescence In Situ Hybridization targeting 16S rRNA.
5. Developing and evaluating a mechanistic model that accurately predicts the relationship between loss of transmembrane flux and various aspects of fouling on the surface of a membrane.

In the upcoming year, we plan to complete this project by integrating the separate membrane and bioreactor systems described above. We expect that the results of this project will provide fundamental knowledge that can be used to understand and ultimately to eliminate fouling of the membranes in MBR systems.

Background. The application of membranes to separate particulate and suspended materials from waste streams is an evolving technology. Membrane bioreactors (MBRs) have many advantages as compared to suspended growth wastewater treatment systems that rely upon clarifiers and quiescent settling to remove suspended materials. MBRs:

a) eliminate the problems associated with bulking sludge in conventional activated sludge systems,

b) allow increased biomass concentrations in reactors permitting increased loading rates and promoting higher reaction rates,
c) increase the concentration of extracellular enzymes which improves the kinetics and extent of biodegradation reactions, and
d) permit excessively long sludge ages which promote higher endogenous decay rates, lower excess sludge production, and maintains sludge age sensitive populations including grazing protozoa and higher life forms as well as nitrifiers.

The primary disadvantages of MBRs include capital costs for the membranes and operating costs associated with routine membrane cleaning. Biofouling is a serious problem for the operation of membrane bioreactor systems because it results in decreased transmembrane fluxes. Biofouling involves the synergistic effects of physical, chemical, and biological clogging of membrane pores. Clogged pores result in: (a) reduced transmembrane fluxes, (b) a need for higher operating pressures, and (c) irreversible destruction of the membrane. We hypothesize that preventing the initiation of biofilm formation on membrane surfaces is the best approach for eliminating biofouling of MBRs. To test this hypothesis, we are investigating the fundamental mechanisms of biofilm initiation on membrane surfaces. By understanding the mechanisms of biofilm formation, we expect to provide improvements in MBR technology to eliminate biofouling. If biofouling of MBRs is eliminated, the associated costs should be dramatically reduced. Lower costs for MBR technology should help in the widespread application of this technology for protecting the quality of the water environment in the state of Ohio and the protection of human health.

Nature, Scope, and Objective.

The overall objective of this project is to identify approaches to eliminate fouling of membrane surfaces due to the action of biological components.

To accomplish this objective, our research team is examining the initiation of biofilm formation on membrane surfaces through a synergistic study of the physicochemical properties of select membranes; the impact of synthetic pulp and paper wastewater on the physiochemical properties of select membranes; the impact of synthetic pulp and paper mill wastewater on the microbial community colonizing select membranes; the biochemical interactions between microorganisms and select membranes; and the role of microbial ecology in the initiation of biofilm formation on membrane surfaces.

Figure 1 shows a schematic of a membrane bioreactor system. Wastewater is treated in the reactor system (on the left of the figure). Purified water passes through the membrane (shown in green), and membrane permeate is the effluent from the system. The chemical composition of the wastewater is indicated in red. Microorganisms are shown in black, and extracellular polysaccharides (EPS) are shown in blue. The flux of purified water through the membrane is controlled by the available pore space and the operating pressures across the membrane. Chemical precipitates, EPS material, and microorganisms block available pore space resulting in reduced

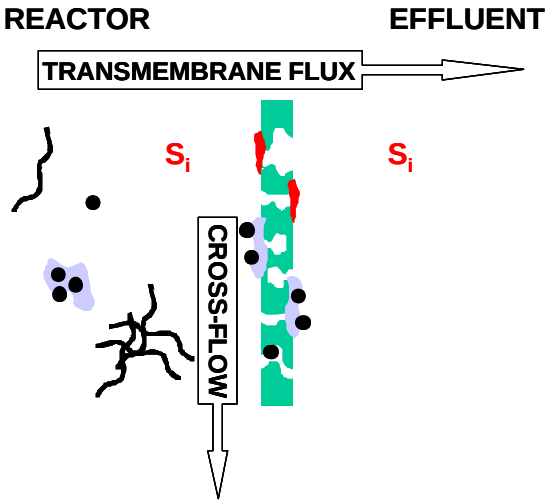

Fig. 1 Schematic of a membrane bioreactor system. Purified water moves from left to right from the reactor to the effluent. The water passes through the membrane (green). Soluble chemical components are indicated in red. Microorganisms are shown in black, and extracellular polysaccharide material is shown in blue.

transmembrane flux at constant operating pressures. In a complex manner, physical, chemical, and biological properties act together to reduce available pore space resulting in reduced transmembrane fluxes.

To study the complex process of biofouling, we are addressing three central questions. Figure 2 shows the three central questions and their relationship to the physical, chemical, and biological principles involved in biofouling. The primary physical question that is being examined in this study is, "Which membrane properties and operating conditions prevent biofouling?" The chemical and biological questions that are being answered are, "Which wastewaters can be treated with membrane bioreactors without biofouling?", and "Which microorganisms are responsible for initiating biofilm formation?", respectively.

For the purposes of our project, <u>we have defined biofouling as the reduction of transmembrane flux through the complex interaction of microorganisms and suspended materials with the surfaces of membranes</u>. Thus, the extent of biofouling is quantified by measuring the loss of transmembrane flux. By relating the definition of biofouling to transmembrane flux, we are reducing the level of complexity of physical principles. For this study, laboratory-scale MBRs are being operated using membranes under a vacuum of less than 5 psi. To reduce the level of complexity of chemical principles, we are using the bioreactors to treat a well-defined synthetic wastewater developed to mimic the waste streams of typical pulp and paper industries. By using a synthetic wastewater, we are able to control the type and levels of suspended materials. In addition, we are able to control the balance of nutrients within the waste stream (i.e., the carbon to nitrogen to phosphorus ratios). By providing experimental control for the levels of suspended materials and nutrients, we expect that we are reducing the levels of physical and biological complexity. To reduce the level of complexity of the biological components, we have initially tested biofilm formation with membrane samples using pure cultures of individual microorganisms and mixtures of pure cultures of individual microorganisms including *Pseudomonas*, *Escherichia*, *Acinetobacter*, *Corneybacterium*, and *Aeromonas*. Recently, we have also begun to use samples of membranes to develop microbial biofilms in the absence of transmembrane flux. Thus, we expect that the simplest example of biofouling – the growth of a biofilm on a membrane surface without transmembrane flux – will provide an appropriate experimental base line for our work.

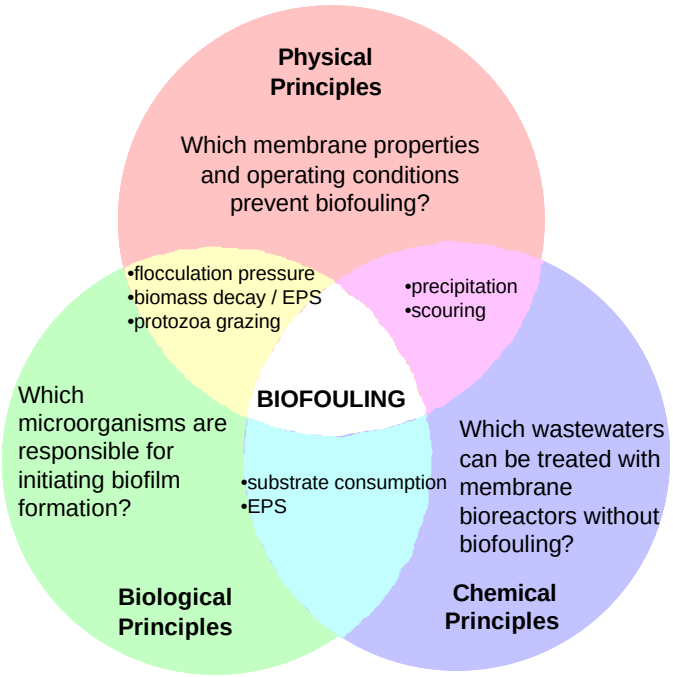

Fig. 2 Relationship among critical research questions and physical, chemical, and biological principles of membrane biofouling.