

Multidimensional Modeling of the Hydrogen-Based, Membrane Biofilm Reactor for Denitrification of Potable and Wastewater

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Water shortages, rising energy costs, and tightening regulations have increased demands for technologies that sustainably treat nitrate and other oxidized contaminants from drinking water and wastewater. A promising option, the membrane biofilm reactor (MBfR), treats oxidized contaminants biologically by way of membranes that deliver hydrogen gas to a biofilm growing on the membrane exterior. Hydrogen, a non-toxic donor that leaves no residual, supports autotrophic processes that produce less biosolids than those based on organic donors.

A new hydrogen-based MBfR, based on a spiral-wound configuration, was recently released commercially. In this configuration, alternating layers of membrane fabric and inert spacer material form flow channels between them. The flow channel, partially obstructed by spacer material, experiences complex fluid dynamics and mass transport schemes, which result in uneven biofilm distribution. Multidimensional modeling was used to provide a more fundamental understanding of how spacer design and operational conditions affect MBfR performance. A particle-based biofilm model, where individual biomass entities are subject to processes of attachment, growth, division, spreading, and detachment, was coupled to solution of fluid dynamics and substrate mass transfer. The results demonstrated how channel spacer design influences the distribution of low and high shear within the channel, and therefore can be used to manage biofilm distribution and thickness, factors strongly affecting MBfR performance.

Modeling was also used to explore competition among denitrifying, sulfate-reducing and methanogenic bacteria in a hydrogen-based MBfR. Sulfate-reduction and methanogenesis must be minimized to avoid formation of toxic sulfide, changes in pH, and emission of methane. A one-dimensional model was used to evaluate competition as a function of buffer strength, bulk liquid pH, and substrate ratios. A separate, multidimensional, particle-based model was used to investigate the effect of biofilm detachment on competition. Overall, denitrifying bacteria dominated the outer portions of the biofilm, while sulfate-reducing bacteria and methanogens mostly resided in the deeper regions. Frequent sloughing favored faster-growing, denitrifying bacteria and helped to decrease the sulfate-reducing and methanogenic populations. This work demonstrated the importance of multidimensional modeling for complex flow schemes, where uneven mass transport, protected niches, and sloughing events can significantly impact biofilm performance and ecology.