MATHEMATICAL MODELING OF MULTISPECIES BIOFILM FOR WASTEWATER TREATMENT

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A biofilm is a layer of prokaryotic and eukaryotic cells anchored to a substratum surface and embedded in an organic matrix of biological origin [1]. Biofilms are important components of food chains, and are involved in self-purification processes in soil, water and sediments and the biodegradation of organic compounds including environmental pollutants. They have been used to treat wastewater since the end of the 19th century. Comparing with suspended cells, bacteria growing in biofilms show some advantages: i) they cannot be washed away with the water flow but they grow in locations where their food supply remains abundant; ii) they show an increased resistance to antimicrobial agents and allow to achieve a higher biomass concentration value in bioreactors; iii) their physical structure allows the formation of several bacterial species contributing to the treatment of different organic and inorganic substrates.

The growth of biofilm is a complex and dynamic process characterized by several steps and governed by complex systems of nonlinear partial differential equations. Mathematical modeling of biofilms growth was extensively performed during the last decades [2-3]. Essentially, two different classes of models have been developed: continuum models and differential-discrete models. Continuum models do not take directly into account small-scale details of an individual microorganism but they generate deterministic solutions [4-6]. Differential-discrete models are able to represent the typical structural heterogeneity of biofilm, that has been recently elucidated through experimental observations, but they generate computational results that include elements of randomness [7-10]. All models are mostly centered on the biofilm growth dynamics including the evolution of biofilm's thickness and spatial distribution of microbial species and substrate concentration.

This research project is aimed at developing a mathematical model and numerical simulations to predict the growth of multi-species and multi-substrate biofilms. The model will deal with different microbial kinetics and biomass detachment mechanisms; it will predict the short-term responses of biofilm performance to substrate variations in the bulk liquid as well as the long-term development of film thickness and microbial species. The mathematical model will be a powerful tool to understand the basic principles determining biofilm formation, composition, structure and function. It will be able to integrate different mechanisms occurring at different spatial and temporal scale and will be a simulation tool to analyze the performance of biofilm processes. The model will link microscale phenomena occurring within the biofilm with macroscale indicators of full-scale process performance.

The mathematical modeling will be combined with experimental research in order to acquire the knowledge and ability to "engineer" the biofilm structure and its function. A lab-scale biofilm reactor is planned to be set-up and run. Techniques for measuring biofilm will be based on two types of analyses: chemical analysis of bulk water and local chemical and physical measurements inside the biofilm. Chemical analysis of bulk water will deliver information about average biofilm activity. In particular a mass balance based on chemical analysis of the influent and effluent of a biofilm reactor

will be performed. Such results would reflect average properties of the system. Bacterial species and their distributions inside biofilms will be determined using molecular biology techniques. To investigate the influence of hydrodynamics and kinetics on biofilm systems microelectrode concentration measurements of chemical constituents across biofilm systems and nuclear magnetic resonance imaging measurements of the flow velocity profiles near biofilms will be used. The data collected through experimental observations will be used to calibrate the mathematical model. In particular a sensitivity analysis will be performed to define the model parameters which are candidates for model calibration and a calibration mathematical approach will be defined. Moreover, the mathematical model will be validated on data collected from the operation of a full-scale plant. The validated model could be used to evaluate novel process designs without the cost, time, and risk of building a physical prototype of the process and to test a wide range of operating strategies. It could be used to individuate the best operational conditions to optimize the management of biofilm based wastewater treatment plants.

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