Project # 1: Interaction of Nanoparticles with Microbial Biofilm in Water Treatment Facility Processes

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Project Summary

Bacterial growth is associated with the formation of a protective layer that is composed of extracellular polymeric substance (EPS) and water channels that serve as a permeable barrier. Biofilms are hence surface-associated and highly-stratified microbial communities consisting of dense, highly hydrated clusters of bacterial cells embedded in a hydrogel matrix of the EPS. Over 99% of microorganisms on earth live in these biopolymers, colonizing and covering large areas of wetted surface. Biofilm usually grow at solid-liquid interfaces. A familiar case in our daily life is the biofilm that grows on our teeth and causes plaque if we do not brush our teeth constantly. Cyanobacterial mats commonly found in natural lake are very visible biofilm.

Biofilms are the oldest and most successful form of life on earth and act as carriers of the environmental "self-purification" process. In environmental engineering, biofilms may be found in sand filtration, membrane separation processes, and activated carbon columns, where they degrade the organic compounds and play an important role in the water treatment plant. Biofiltration, biomembranes, or bioreactors are processes designed to work with the biofilm community, utilizing them as main carriers to treat the water. However, biofilms are not always welcome in our lives. Biofilms that grow on surgical sites may cause clinical infection. Biofilms could also easily cover the filter in our air conditioner, which will decrease the efficiency of heat exchange. As for environmental engineering, we are concerned about the biofilm growing in the drinking water distribution system, which may retain accidentally (or intentionally) released pathogens and cause potential health risk to humans. On the other hand, biofilms in the
The environment can influence the mobility of colloids and colloid-bound contaminants such as nanoparticles (NPs) either by sorption of NPs within biofilm matrix, or by remobilization of NPs due to the decomposition of biofilm and detaching biofilm compartments. This potential bioaccumulation of colloid contaminants, heavy metals or NPs is also a huge risk to human health safety.

Nowadays, the number of products on the market containing nanoparticles (NPs) has been increasing. However, fully understanding the human health and the environment risks of NPs is lagging. Recent studies suggested that exposure to NPs could lead to oxidative stress, DNA damage and cell membrane damage. This brings out several questions to environmental engineers: 1. Are NPs able to be treated through biofilm reactors within treatment plants? 2. Will the anti-microbial effect of NPs cause failure in the biofilm reactors and influence removal of organic and inorganic compounds? 3. If the NPs are released to the environment, how will the biofilms in nature impact its transportation and fate? 4. Is there any potential application of NPs on biofilms prevention considering its anti-microbial effect? All these questions can be summarized as interaction of nanoparticles with biofilms, which is the main topic of this project. Research Experience for Undergraduate (REU) students will participate with the teachers in the Research Experiences for Teachers (RET) program to find some of the answers to these questions.

Drinking water biofilms in Cincinnati drinking water distribution system will be transplanted to a series of biofilm reactors (Fig.1). Each biofilm reactor has a volume of 1 L with an effluent spout placed above the 400 mL level. Each reactor consists of eight (8) polypropylene coupon holders suspended from a polyethylene lid. Each coupon holder can accommodate three 12.7 mm diameter polycarbonate coupons allowing a total of 24 samples per batch study. The lids for the glass vessel biofilm reactors have side-arm discharge port. Nutrient solution with suspended bacterial strains will be mixed in the vessel by using a magnetically driven baffle stir bar. Nutrient solution including nitrate and glucose supply will be fed to the reactor continuously to maintain the biofilm growth. The biofilms will be characterized via PCR-test followed by Microarray analysis. Citrate reduced silver nanoparticles (Ag-NPs) will be synthesized and further purified by tangential flow filtration system (Fig.2) for study purpose. Ag-NPs will be characterized by Dynamic light scattering system (DLS) for size distribution. The experimental approach for the sorption kinetics study will be mainly designed in two ways: 1) time course quantifying the loss of NPs in the bulk phase and the adsorbed NPs in biofilms by using UV-Vis spectrometer; 2) Laser Scanning Microscopy (LSM, Fig.3) will be used to determine the shrinkage of biofilms during the interaction with NPs. Scanning Electron Microscope (SEM, Fig.4) and Transmission Electron Microscope (TEM, Fig.5) will help to gain an insight on distribution of NPs penetration through the biofilm and the adsorption sites within the biofilm. In the end, both numerical and geometrical data gained from experiments will be tested against a model in commercial software called COMSOL Multiphysics® (Fig.6).

Research Experiences for Undergraduate (REU) students will benefit from working closely with the research team to gain hands-on laboratory research experience and communication skills, and they will also provide important student perspective to the junior high and high school teachers participating on the team as part of the Research Experiences for Teachers (RET). Teachers will also gain research and communication skills. In addition, they are expected to gain ideas from the project for implementation in their classrooms. For example, in a science class, students can try to use different materials as substratum for developing biofilms to see which one is the best material for a drinking water pipe system in terms of biofilms prevention. In a math class, students could construct a calibration curve and/or plot a sorption curve to discuss how linear or nonlinear regression are used in engineering. To build relationships, the AC/SAC and/or GRA will visit the teachers’ class to serve as source of information and/or to provide feedback on students design. If the participating REU students are available locally during the school year, they may also visit the teachers’ classrooms. Teachers and their students may be invited to tour the AC/SAC labs at UC.
Fig. 1. Biofilm reactors setup

Fig. 2. Tangential Flow Filtration System

Fig. 3. Laser Scanning Microscopy

Fig. 4. Typical SEM graph of biofilm

Fig. 5. Typical TEM graph of cells cross-section

Fig. 6. Interface of COMSOL Multiphysics®