Oil droplet behavior at the membrane surface during filtration of oil-water emulsions

by

Emily Tummons

Advisor: Volodymyr Tarabara

Friday, May 27 @ 9:00 a.m.

3540 Engineering Building

Abstract:

Oily wastewaters are produced in large volumes by petrochemical, automotive, and several other major industries. Difficult to treat, these waste streams pose significant environmental risks. Treatment required for environmental compliance may be expensive and constitutes a financial burden for companies in both public and private sectors. Membrane-based separations are often the best treatment technology capable of removing micron-sized oil droplets. Membrane fouling, however, remains a major deterrent for broader acceptance and adoption of membranes in large scale wastewater treatment. The importance of elucidating the fundamental mechanisms of membrane fouling by emulsified oil is in the value of that knowledge for decreasing the operational costs that managing membrane fouling entails. Two strategies are to modify either the membranes or the emulsions so as to limit the egregious forms of fouling that decrease water throughput. This study combined real-time direct visualization tests with microfiltration (MF), ultrafiltration (UF) and nanofiltration (NF) membranes in the presence of crossflow to observe the different patterns of membrane fouling by oil. Experimental variables included membrane pore size, surfactant concentration, concentration of divalent ions, as well as membrane charge and hydrophilicity. All experiments employed hexadecane-in-water emulsions stabilized with sodium dodecyl sulfate (SDS). Visualization tests using the Direct Observation Through the Membrane (DOTM) system with MF membranes revealed three characteristic stages of membrane fouling: 1) droplet attachment and clustering, 2) droplet deformation, and 3) droplet coalescence. The qualitative visualization work was supplemented with quantitative modeling that described the forces acting on an oil droplet pinned at an entry to a pore on the membrane surface as a way to predict the eventual fate of that droplet. Force models predicted a critical droplet size corresponding to the droplet removable by the crossflow shear, which was validated by direct visualization observations. Permeate flux analysis indicates that membrane fouling by emulsified oil is controlled by droplet coalescence and crossflow shear: the transport of oil to the membrane surface by the permeate flow is balanced by the shear-induced removal of the droplets that coalesce to exceed a critical size. In contrast, DOTM tests with NF membranes and SDS-stabilized oil-water emulsions in the presence of divalent cations revealed the formation of oil films due to favorable droplet-droplet and droplet-membrane interactions needed for coalescence. A range of membrane and emulsion characteristics were screened, and the results indicate that droplet stability, electrical charge and a membrane’s affinity for oil govern oil fouling behavior. The study also points to the possibility of managing membrane fouling by oil via the manipulation of the ionic composition of the dispersed phase. By promoting coalescence with conditions of a moderate affinity between droplets and membranes; oil droplets could reach a critical size and be removed by the crossflow shear prior to forming a contiguous film on the membrane surface.