Effect of evolving biofilm structures on modeling the flow in bio-clogged porous media

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Motivation

Stormwater accumulates on the impervious surfaces as stormwater runoff, which can result in streambed erosion and flooding events. The runoff can pick up contaminants and pathogens from the surfaces and eventually enter natural aquatic systems

Elevated concentrations of bacterial pathogens, such as E. coli and fecal coliform, have been detected in urban stormwaters, and bacterial pathogens have been reported to be the most common contaminant that impairs stormwater for its non-potable reuse

Engineered infiltration systems (EIS) are structures in urban areas that contain porous filtration media for the infiltration of stormwater to reduce the volume of surface runoff and they recently gained popularity in sustainable stormwater management

EIS are designed to have high hydraulic conductance. Since bacteria are ubiquitous in stormwater, biofilms will undoubtedly grow on the filtration media of EIS that may lead to reduction of conductivity or sectional clogging

Objectives

The visionary goal of this research is to understand how biofilms in EIS influence the flow and contaminant removal in porous media

A microfluidic channel is used to evaluate the effect of biofilms at micro scale

Simplification methods are studied to abridge the arduous modeling procedure of the real biofilm geometry

Methods and Experimental Setup

COMSOL Multiphysics

- *Modeling interface*: free and porous media flow (fp)
- *The fluid domain*: Navier-Stokes equations
- *The biofilm domain*: Forchheimer-corrected version of the Brinkman equation
- *Varied biofilm properties*: Biofilm permeability (k_b) and biofilm porosity (ε_b)
- *Main value of interest*: Bulk permeability (k)

ibidi Pump System

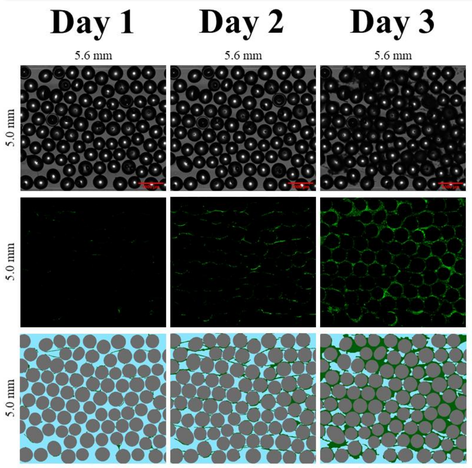
Microfluidic channel (50 × 5 × 0.6 mm)
Packed with 0.5 mm glass beads
E. Coli K-12 MG1655 used to form biofilm
LB broth used as the feed

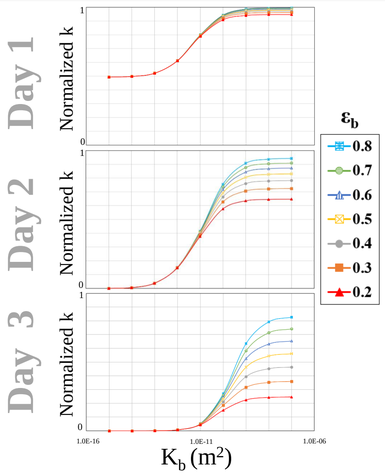
Confocal Imaging and Analysis

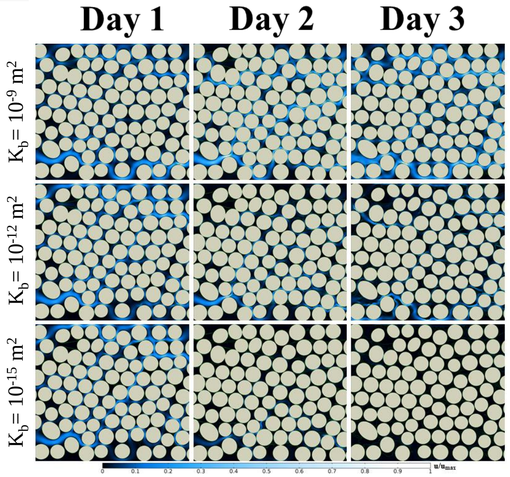
Time	Porosity (%)	Biofilm Ratio* (%)
Day 1	30.8	2.7
Day 2	26.6	17.6
Day 3	32.1	55.2

$$^{*}Biofilm\ Ratio = \frac{Area\ covered\ by\ biofilm}{Pore\ area} \times 100$$

Modeling the Experimental Data Using COMSOL Multiphysics

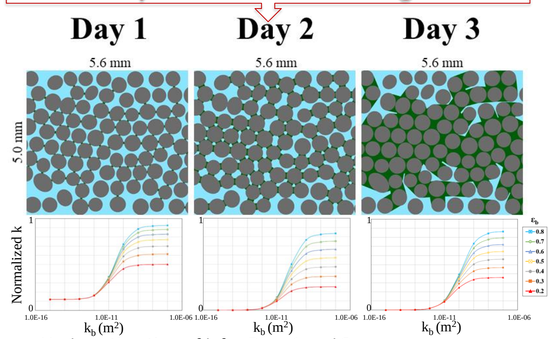






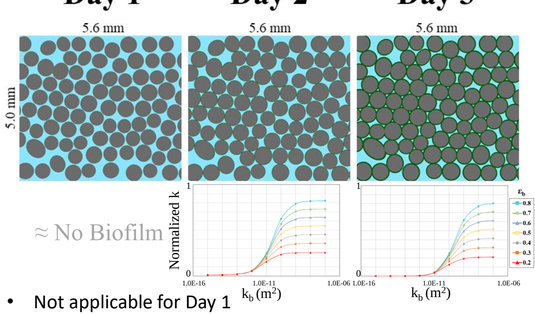
Simplified Modeling Approaches

Symmetric Contact Filling



- Underestimation of k for Days 1 and 2
- Very accurate k values for Day 3

Uniform Coating



- Not applicable for Day 1
- Underestimation of k for Day 2
- Very accurate k values for Day 3

Major Findings

- Considering biofilms as impermeable leads to significant inaccuracies
- Biofilm permeability and biofilm porosity directly affect the flow and bulk permeability
- Both simplification scenarios can be used only at the biofilm ratios above 50%
- For initial stages of biofilm formation, the experimental data should be used for modeling

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