Particle Transport through Porous Media

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Order of Events

• Introduction to topic
• Theory
• Application
• Remaining Uncertainties/Challenges
• Questions
Introduction to Topic

• Particulate
  – Size
• Porous Media
  – Collector
• Flow
  – Advection
  – Dispersion
  – Diffusion
Intro. Continued

• Adsorption
  – Sticking
• Desorption
  – Desticking
• Filter
• Strain

Picture from McGechan and Lewis (2002)
SEM of Bacteria in Soil

Why Study?

- Transport of pathogenic bacteria
- Spread of toxins
- Bioremediation
- Biomineralization
Theory

• What is transported?
  – What is the particle?

• What is it transported in?
  – What is the fluid?

• What is it transported through?
  – What is the porous media made of?

• Physical / Chemical / Biological

• CFT, DLVO, Collision Efficiency
Theory

• Physical
  – Porous media
    • Grain size
    • Shape
  – Particle concentration
  – Particle Size
  – Particle Shape
  – Fluid velocity
Theory Cont.

• Chemical
  – Porous medium surface coatings
  – Solution
    • Composition
      – What is in the fluid?
    • Ionic strength
      – How much is in the fluid?
Theory

• Biological
  – Surface macromolecule length and composition
  – Cell motility
  – Cell size
  – Cell shape
  – Organism type
  – Growth Phase
• Derjaguin, Landau, Verwy, Overbeek
• Describes the force between charged surfaces interacting through a liquid medium
  – van der Waals
    • Dipole-Dipole, Dipole-Induced Dipole, Dispersion
    • Totality of the intermolecular forces
    • Attraction and repulsion, not covalent or electrostatic ion
  – Double layer of counterions
DLVO Cont.

- Double layer of counterions
  - Surface of object in liquid
  - Inner Layer – Stern Layer
    - Surface layer
  - Outer layer - Diffuse layer
    - Outer part of
- Electrically neutral
- Zeta Potential
  - Estimating of DL
CFT

• Theory of deposition/filtration
  – Exponential decrease of attachment with distance
• Classical Clean Bed Filtration
  – Bacteria, Viruses, Protozoa
• Non-exponential Deviations
  – Heterogeneity
  – Blocking/Ripening
  – Microbial Release
CFT Model

• Collector Efficiency
  – Calculated from knowledge of system
• Collision Efficiency
  – Calculated after experiment
Collector Efficiency, $\eta$

• Function of
  – $A_s$ - Happel Correction Factor
    • collector radius, velocity
  – $N_{Pe}$ - Peclet Number
    • ratio of dispersive force to diffuse force
  – $N_{Lo}$ - London-van der Waals number
    • viscosity, particle radius,
  – $N_G$ - Gravitational Number
    • density of particle and fluid, viscosity, particle radius, velocity, gravity

$$\eta = 4A_s^{1/3}N_{Pe}^{-2/3} + A_sN_{Lo}^{1/8}N_R^{15/8} + 0.00338A_sN_G^{1.2}N_R^{-0.4}$$
Collision Efficiency, $\alpha$

- Ratio of the rate of particles sticking to collector to the rate they strike the collector
- To Determine $\alpha$
  - Measuring the retained fraction of bacteria in a column
  - Measure the steady-state breakthrough concentration of column effluent
Collision Efficiency Cont.

• The fraction of cells retained, $F_R$, is a function of porosity, characteristic size, length of travel, and moisture content.

• Determination of $F_R$ can be used to find the collision efficiency, $\alpha$

$$F_R = \left(1 - \frac{C}{C_0}\right) = 1 - \left\{\exp\left[-\frac{3}{2} \frac{(1 - \theta)}{d_c} \alpha \eta L\right]\right\}$$
Retained Fraction

- X axis – Mass Fraction
- Y axis – Dimensionless Depth

![Graph showing retained fraction with X axis as Mass Fraction, Y axis as Dimensionless Depth, and a graph with data points indicating mass fraction particles vs. dimensionless depth.]
Breakthrough Curve

- X axis – Pore Volume
- Y axis – Relative Concentration
Application

• Bioremediation
  – Transport of bacteria to metabolize constituent

• Biomineralization
  – Transport of bacteria to create biominerals

• Pollution Transport
Remaining Uncertainties/Challenges

• Kinetics of Microorganisms alter transport
  – Life cycle
• Heterogeneity of porous medium
• Lots of them


Tufenkji Dissertation “Spatial distributions of retained colloidal and microbial particles in porous media”


