Bioclogging Effects Relevant to In-Situ Bioremediation of Organic Contaminants

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Motivation

- Types of contaminants found at Air Force Sites
  - Fuel spills (LNAPLs)
  - Aircraft De-Icing Fluids (ADF)
- Could bioclogging be significant under field conditions?
- Should bioclogging effects be incorporated into natural attenuation/remediation models?
  - Bioscreen, Bioplume, etc.

Comparison of Contaminants

- Fuel Spills
  - PAHs, alkanes, …
  - Readily biodegraded under range of redox
  - LNAPL
    - Continuous substrate source
  - Low/slow carbon availability
    - <100s mg/L
- Delcing Chemicals
  - ADF, PG, surfactants, AdPack
  - Readily biodegraded under range of redox
  - Intermittent input
  - High concentrations
    - <300,000 mg/L

Field Characteristics of Potential Importance

- Porous media type/size distribution
- Groundwater flowrates
- Groundwater chemistry
  - Electron acceptors [O_2, NO_3, Fe(III), SO_4]
  - Nutrient concentrations [N, P]
  - pH, temperature, etc.

These affect biokinetics, cell yield, EPS production…

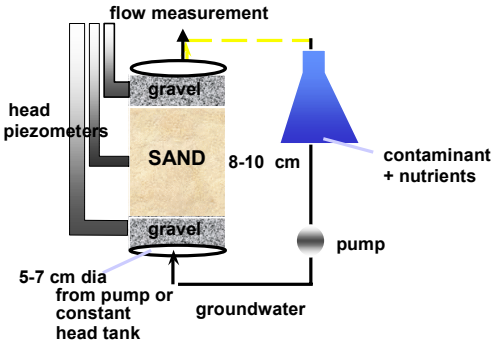
Overview of Results

- 1D fuel spill
- 1D de-icing fluid
- Mini 2-D diesel fuel spill
- 2D tanks with fuel or PG assoc. biogrowth

General Methods

- Well-characterized homogeneous sands
- Uncharacterized mixed bacterial cultures
- Hydraulic conductivity (K) by head loss and Q
- Dispersivity (α) by bromide tracer test, best-fit to breakthrough curve
- "Bulk" measurement of total biofilm (dry mass carbon) in effluent water & final sand
- Contaminant/substrate depletion
- Biokinetics [Y, b, deg. rate coefficients] in batch tests or calculated from column data

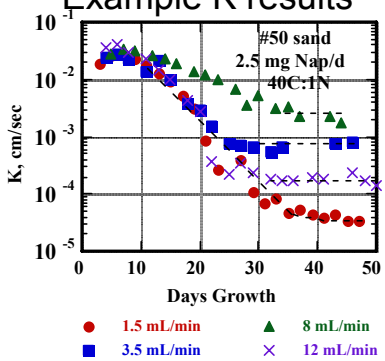
Methods: 1D columns



1D fuel tests

- Substrates: decane or naphthalene
  - Inlet oxygenated
- Grain size: d_{50} 0.49, 0.32, 0.19 mm
- Flowrate:
  - v = 0.03, 0.08, 0.21, 0.31 cm/min
- Nitrogen limitation: 7:1, 40:1, 100:1 C:N

Example K results



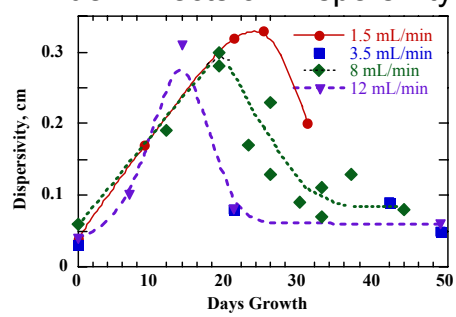
Effects on K

- Grain size:
  - larger grains had more biomass
  - 1.5, 1.2, 0.9 mg dry wt/g sand
- Kmin vs v
  - Decreasing Q from 0.21→0.03 cm/min decreased min. K by ~2 orders of magnitude
  - Logical with increased shear; 0.31 cm/min between 0.03&0.08 mL/min ?

Effects on K

- Nitrogen limitation
  - Similar minimum K for 5:1 and 40:1 C:N, significantly lower than 100:1
  - Fastest K decrease for 40:1, possibly due to affects on EPS production

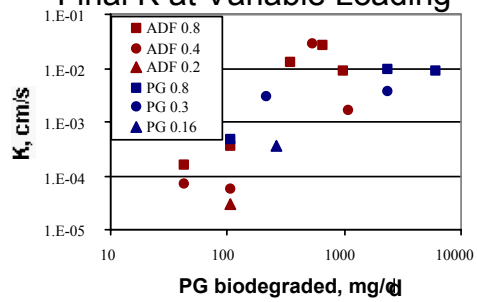
ID Fuel: Effects on Dispersivity



1D DeIcers: Effects on K

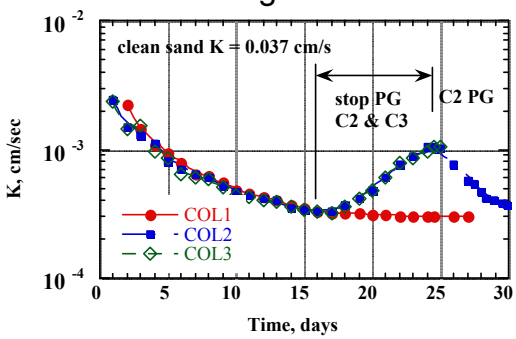
- Loading
  - Inlet 400-300,000 mg/L PG or ADF
  - Continuous vs intermittent (recirculated)
- Nutrient availability
  - N limited at high C loading since const. N
  - Vary with NO_3 and/or ammonia addition
- Flowrate: v 0.03-0.31 cm/min
- Endogenous decay: remove PG from feed

Final K at Variable Loading

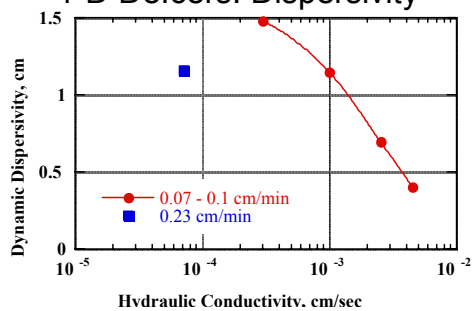


PG load 43 to 32,140 mg/d @ 99-3% biodegraded
C:N ratio 6:1 up to ~5000:1 at highest PG load

DeIcers: Endogenous Effects

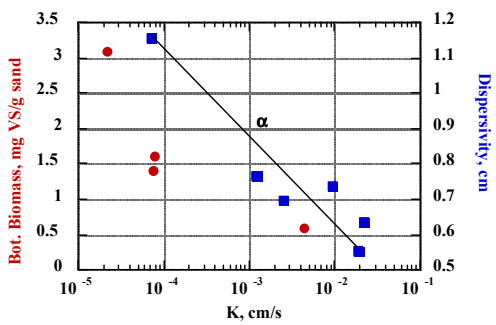


1-D DeIcers: Dispersivity



- α increased as biogrowth decreased K

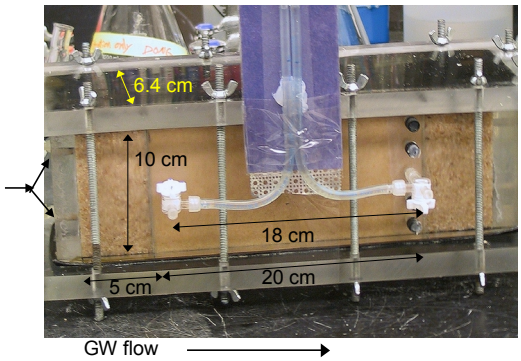
1-D ADF: K, α, X correlations



Mini 2D: Diesel fuel

- Goal: in field systems both vertical and transverse dispersion are important, so quantify in a lab system with biomass

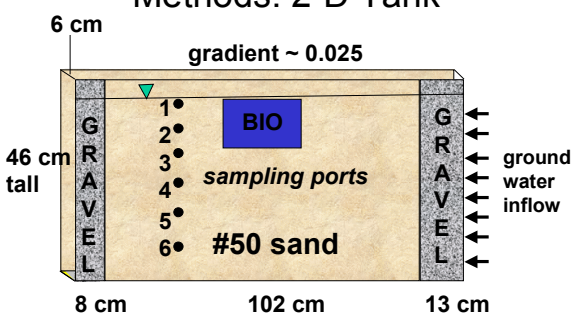
Methods: Biobox



Mini 2D: Diesel fuel

d_{50} cm	$\frac{K_{bio}}{K_{clean}}$	$\frac{\alpha_{x,bio}}{\alpha_{x,clean}}$	$\frac{\alpha_{z,bio}}{\alpha_{z,clean}}$	mg VS / g sand	ΔTOC mg/L
0.32	0.87	8.7	>1	0.35	0.59
0.19	0.90	2.6	>1	0.29	0.56

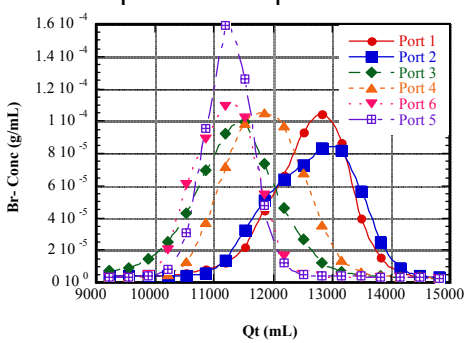
Methods: 2-D Tank



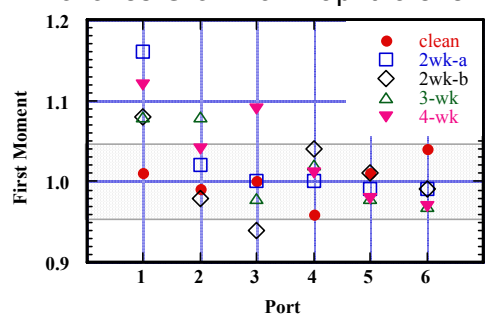
2D tank with Biozone

- Naphthalene or PG-grown biozones for different lengths of time [in theory pertaining to different X, bulk K and Disp]
- Bromide tracer tests conducted to determine breakthrough effects of clean and biomass-containing zones

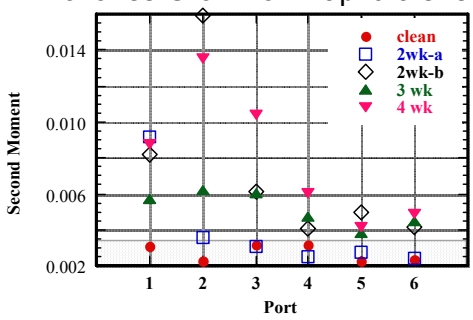
Example 3 wk Nap biozone data



Biozones Grown on Naphthalene



Biozones Grown on Naphthalene



2D tanks summary

- Minimal influence on K
  - $K_{biozone}/K_{clean}$ =0.08-0.8
  - $K_{tank+bio}/K_{clean}$ = 0.2-1.1
- Significant shear of biomass out of the biozone and measured downgradient
- Dye tracers contain C leading to biogrowth through tank over time

Implied effects on field scale

- Due to flow routing, overall effects on K may be minimal
  - Near well clogging may be significant
  - Biogrowth in well pack likely
- Due to microbial heterogeneity, may increase plume dispersion

Conclusions

- Biogrowth may have significant effects under many different conditions
  - Nutrient limitation minimizes bioclogging
- Further testing on 2D scale may be most helpful to predict field effects
- Vadose zone important for attenuation of ADF & LNAPLs, but bioclogging effects less clear