Usage of Water-Filled Trench in Improving Groundwater Quality

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Shallow Vadose Zone BTEX, PCE, TCE and Iron Contamination

Groundwater in Florida
BTEX Contamination
Gasoline Composition

Percent BTEX In Gasoline (% weight)

- Other Hydrocarbons: 82%
- BTEX: 18%

BTEX Components of Gasoline (% weight)

- Toluene: 26%
- p-Xylene: 9%
- Ethylbenzene: 11%
- m-Xylene: 31%
- Benzene: 11%
- o-Xylene: 12%
Water-Filled Trench

- Organic compound degradation
- Volatile organic compound vaporization
- Metal oxidation and precipitation
Objectives

• Explore the possibility of the usage of water-filled trench in treating contaminated groundwater

• Identify dominating mechanisms
  – Organic decomposition
  – Volatile organic compound vaporization
  – Metal oxidation and precipitation

• Investigate the effect
  – Effect of dissolved oxygen
  – Effect of alkalinity

• Promote field applications
  – Quantify removal rate
Outline

• **Theoretical consideration**
  – Organic compound removal
  – Volatile organic compound removal
  – Metal removal
  – Effect of alkalinity

• **Simulated Groundwater**

• **Water-Filled Trench Experiments**

• **Water-Filled Trench with an Aerobic Filter**

• **Expected Results and Modeling**
Organic Decomposition

- BTEX, pesticides, and polycyclic aromatic hydrocarbons (PAHs)
- Aerobic process
- Nutrient requirement
- pH and temperature
Volatile organic compound vaporization

- Volatile organic contaminants
- High vapor pressure and low water solubility
- Temperature-dependent
- BTEX
- PCE and TCE
Metal Removal

- Heavy metals to be transformed and precipitate
- pH and redox conditions
- Alkalinity
Dissolved Oxygen

• Organic compound degradation

• Electron acceptor

• 1.0 mg/L DO required for 0.32 mg/L BTEX

• Mass transfer between air and groundwater

• Heavy metal oxidation and precipitation
Alkalinity

- $\text{HCO}_3^-$, $\text{CO}_3^{2-}$ and $\text{OH}^-$

- Alkalinity loss during organic degradation, $\text{CO}_2$ stripping and metal oxidation and precipitation

- Most important for heavy metal oxidation and precipitation

- Addition of external alkaline agents such as lime
Simulated Groundwater

- Benzene, 25 mg/L
- Toluene, 25 mg/L
- Ethylbenzene, 25 mg/L
- $p$-xylene, 25 mg/L
- PCE, 20 $\mu$g/L
- TCE, 200 $\mu$g/L
- Glucose, 50 mg/L
- Ferrous iron, 10 mg/L

Benzene, toluene, $p$-xylene, PCE, and TCE to be monitored by a GC with a flame ionization detector and helium as the carrier gas.

Glucose and iron to be quantified by HPLC and spectrophotometer.
Water-Filled Trench with a Filter
Other Parameters to Be Monitored

- Redox Potential
- pH
- Conductivity
- Temperature
Control Experiments

\[ C_p = C^* P \left[ \frac{(1 - P_w/p)(1 - \theta P)}{(1 - P_w)(1 - \theta)} \right] \]

- \( C_p \): oxygen concentration at nonstandard pressure
- \( C^* \): oxygen concentration at standard pressure
- \( P \): nonstandard pressure
- \( P_w \): partial pressure of water vapor
Expected Results — Water-Filled Trench

- Benzene, 25 mg/l
- Toluene, 25 mg/l
- Xylene, 25 mg/l
- PCE, 20 μg/l
- TCE, 200 μg/l
- Glucose, 50 mg/l
- Fe²⁺, 10 mg/l

DO Value (mg/l)

- Benzene=? Toluene=?
- Xylene=? Glucose=?
- PCE=? TCE=? Fe²⁺=?

pH=? Redox=? Microbial activity?
Expected Results — Water-Filled Trench

Organic Removal — Biological Process?

Effect of Alkalinity (mg/l)

- 0.25
- 0.5
- 1.0
- 1.5
- 2.0
- 3.0
- 4.0
- 5.0
- 6.0

DO Value (mg/l)

- 50
- 100
- 200
- 300
- 400
- 500

Removal Rate = ?
Expected Results — Water-Filled Trench

BTEX, PCE & TCE Removal — Evaporation?

Removal Rate = ?

DO Value (mg/l)

0.25
0.5
1.0
1.5
2.0
3.0
4.0
5.0
6.0

Flask
Autoclaved simulated groundwater
Air pump
Expected Results — Water-Filled Trench

Fe$^{2+}$ Removal — Biological or Chemical Oxidation and Precipitation?

Effect of Alkalinity (mg/l)

Removal Rate = ?

DO Value (mg/l)
Expected Results — Water-Filled Trench with Aerobic Filter

Benzene, 25 mg/l
Toluene, 25 mg/l
xylene, 25 mg/l
PCE, 20 μg/l
TCE, 200 μg/l
Glucose, 50 mg/l
Fe2+, 10 mg/l

Mulch Filter
Limestone Filter
Mulch & Limestone Combination Filter

Removal Rate = ?
Removal Rate = ?
Removal Rate = ?

DO Value (mg/l)
Biodegradation Simulation

Organic contaminant degradation:

\[
\frac{dS}{dt} = - \frac{\mu_{\text{max}} S}{K_m + S}
\]

\[
S = K_m W \left[ \frac{S_0}{K_m} \exp \left( \frac{S_0 - \mu_{\text{max}} t}{K_m} \right) \right]
\]

\[
W(x) + \ln[W(x)] = \ln(x)
\]

**S**: organic compound concentration

**\(\mu_{\text{max}}\)**: maximum bacterial growth rate

**\(K_m\)**: half saturation constant

**\(S_0\)**: initial organic compound concentration

**W**: Lambert function  
**x**: argument of W
Evaporation Simulation

Volatile organic contaminants mass transfer:

\[ M = K_L a \left( C_L^* - C_0 \right) \]

- \( M \): mass of volatile organic contaminants transferred per unit time and volume
- \( K_L \): mass transfer coefficient
- \( a \): effective mass transfer area
- \( C_L^* \): liquid phase concentration in equilibrium with gas phase concentration
- \( C_0 \): bulk phase liquid concentration
Oxidation/Precipitation Simulation

- For microbial mediated metal transformation, Monod function to be used

- For chemically mediated metal transformation, a stoichiometry relationship to be established and precipitation process to be simulated by Visual MINTEQ 2.51
Evaporation
Evaporation
Evaporation
Evaporation

- TCE
- Benzene
- Toluene
- Xylene

Percentage Removal (%) vs Time (min)
Ferrous Iron Sorption

ferrous iron concentrations investigated in this study: 0.25, 2.0, 3.5, 10.0, 15.0, and 30.0 mg/l
Ferrous Iron Sorption

\[ q = a(1 - b^C) \]

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<th>a</th>
<th>b</th>
<th>R²</th>
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<td>0.25</td>
<td>0.0085 ± 0.0002</td>
<td>0.9796 ± 0.0013</td>
<td>0.9970</td>
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<td>2.00</td>
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<td>0.9850 ± 0.0056</td>
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<td>3.50</td>
<td>0.1099 ± 0.0058</td>
<td>0.9818 ± 0.0025</td>
<td>0.9609</td>
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<td>10.0</td>
<td>0.5424 ± 0.0473</td>
<td>0.9931 ± 0.0010</td>
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<td>15.0</td>
<td>0.5779 ± 0.0317</td>
<td>0.9894 ± 0.0013</td>
<td>0.9788</td>
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<td>30.0</td>
<td>1.2890 ± 0.1837</td>
<td>0.9898 ± 0.0029</td>
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Ferrous Iron Sorption
Ferrous Iron Sorption
Questions?