Diffusive Transport and Biodegradation of Volatile Organic Contaminants in Unsaturated Porous Media

Ali Möngol Khan, Martin Thullner, Lukas Y. Wick
Motivation

Observation

Gas phase chemicals (VOCs) can undergo significant reduction in the vadose zone.

Hypothesis

Biodegradation in the vadose zone effectively reduces the emissions of GW-VOCs to the atmosphere.

DeBiase et al., 2012

CoTra II – Leuna Pilot Plant
Approach
Experimental Investigations

The fate of VOCs in the porous media
Experimental Approach

- Glass beads
- *Pseudomonas putida* KT2442 dsRed pWW0
- Toluene (H8:D8)
- MTBE (tracer)
Pore Scale Processes

- Volatilization
- Biodegradation
- Diffusion
Methodology

Cell Density
$3.30 \times 10^7 \text{ cm}^{-3}$
Results: “Non-Reactive” Transport

Non-biodegradable Tracer

Toluene

\[ y = -0.0232x + 0.7214 \]

\[ y = -0.2344x + 7.179 \]
Results: Reactive Transport

Non-biodegradable Tracer

Toluene

\[ y = -0.0232x + 0.7214 \]

\[ y = -0.0227x + 0.6972 \]

\[ y = -0.2344x + 7.179 \]

MTBE

Column Length (cm)

Column Length (cm)
Results: Reactive Transport

Non-biodegradable Tracer

Toluene

\[ y = -0.0232x + 0.7214 \]
\[ y = -0.0227x + 0.6972 \]
\[ y = -0.022x + 0.6879 \]

MTBE

Abiotic

Bio_1

Bio_2

Column Length (cm)

Column Length (cm)
Results: Reactive Transport

Oxygen

Toluene

\[ y = -0.2344x + 7.179 \]
Isotope Fractionation

Isotope Ratio (R) = $^{2\text{H}}/^{1\text{H}}$

Toluene (H8:D8)
Assessment of Biodegradation

Rayleigh plot

Enrichment factor (ε)
-900 %

Decrease in Concentration

Change in Isotope Ratio

Hoefs et al., 1997
Results: Assessment of Biodegradation

Abiotic

Isotope Ratio $\ln \left( \frac{R}{R_0} \right)$

$y = -0.0042x + 0.0005$

Change in Isotope Ratio $\ln \left( \frac{R}{R_0} \right)$

Decrease in Concentration $\ln \left( \frac{C}{C_0} \right)$

$y = -0.0042x + 0.0005$
Results: Assessment of Biodegradation

Abiotic

Bio_1

Change in Isotope Ratio [ln (R/R0)]

Decrease in Concentration [ln (C/C0)]
Results: Assessment of Biodegradation

<table>
<thead>
<tr>
<th>Abiotic</th>
<th>Bio_1</th>
<th>Bio_2</th>
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<td>1,5</td>
<td>2,0</td>
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Change in Isotope Ratio [ln (R/R0)]

Decrease in Concentration [ln (C/C0)]

- $y = -0.0042x + 0.0005$
- $y = -0.4837x - 0.0456$
- $y = -0.4664x - 0.0312$
Outlook

✓ **Biodegradation** is the main removal process of gas phase GW-VOC

✓ **High potential for bioremediation** of gas phase VOC

✓ Coupled with **numerical modeling**; Up-scaling to the field scale
Thank you for your attention!

ali.mongol@ufz.de