Ten years of experience with the new TCE-concept for bioaugmentation in full-scale applications

Maurice Henssen, Bioclear (the Netherlands)
Spring meeting 13-14 April 2011, Sundsvall, Sweden
Presentation

- Introduction: What is bioremediation and why need for bioaugmentation?
- History of the TCE-concept and the first application...
- Experiences in various cases
- Conclusions
What is bioremediation and why bioaugmentation?

• sufficient electron donor (feed to bacteria for VOC degradation)
• suitable redox conditions (reduced environment) and pH
• presence of suitable microorganisms (Dehalococcoides)

Chemical structures:
- PCE
- TCE
- trans-DCE
- cis-DCE
- VC
- ethylene
“the introduction of microorganisms into contaminated media to promote degradation”

“Emerging technology” for treatment of groundwater plumes and possibly DNAPLs with chlorinated solvents”

ESTCP, October 2005
History of TCE-concept

Column experiments 1996-1998

Natural attenuation in the Netherlands

Often ethylene (reduced) $\rightarrow$ DHC

Often c-DCE (moderate reduced, anoxic) $\rightarrow$ no DHC

PCE $\rightarrow$ ethylene (99%)
TCE-concept
History of TCE-concept

Column experiments, 1996-1998

- PCE -> ethylene (99%)

Full scale 100 m$^3$ bioreactor, 2000

- PCE to ethylene in 28 days
- Effluent: $\approx 10^5$ cells/ml
• plume remediation (400,000 m$^3$, up to 50,000 µg/l PCE)
• successfully remediated, total VOC < 10 µg/l
• more than 98% degradation within 9 months
• core zone stimulation by injection of suitable electron donor (2011)
• augmented organisms still active (4 years after end of active remediation)
• Monitoring tools developed at own laboratory (2001)

• Using modern DNA-based / PCR analyses, quantitative (q-PCR)

• Follow augmented organisms in treated zone, spreading of organisms after injection and growth
Fixed system,
100 m³ reactor

• mobile anaerobic bioreactor
• automated dosing unit C, N & P
• treatment of effluent bioreactor before infiltration
• ‘plug and play’
Experiences in various cases (2003-2010)

→ Almelo site

- former chemical laundry
- ‘residual’ PCE contamination after air sparging
- plume of approx. 12,000 m³
- PCE up to 15,000 µg/l
- no *Dehalococcoides* present,
  no Natural Attenuation (only PCE)
Almelo site

Dechlorination

Start: 6-okt-03
Stop: 14-dec-05

Concentration (µg/l)

- PER+TRI+CIS+VC
- Ethene+ethane

Active phase: 23-apr-04 to 1-aug-04
Monitoring phase: 1-aug-04 to 14-dec-05
## Concentrations contamination and degradation products

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PCE</td>
<td>15,000</td>
<td>7,000</td>
<td>&lt; 0.1</td>
<td>0.2</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>TCE</td>
<td>&lt; 40</td>
<td>1,300</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>cis-DCE</td>
<td>&lt; 40</td>
<td>1,300</td>
<td>10,000</td>
<td>45</td>
<td>33</td>
<td>0.76</td>
<td>0.30</td>
</tr>
<tr>
<td>VC</td>
<td>&lt; 40</td>
<td>n.a.</td>
<td>n.a.</td>
<td>23</td>
<td>27</td>
<td>0.80</td>
<td>0.13</td>
</tr>
<tr>
<td>Ethylene</td>
<td>0.2</td>
<td>4</td>
<td>58</td>
<td>2,100</td>
<td>680</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Ethane</td>
<td>1.3</td>
<td>2</td>
<td>13</td>
<td>6</td>
<td>470</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

- 4 months active treatment, 13 months monitoring
- Remediation to levels below 1 µg/l
- € 13 per m³ soil volume
Gl. Kongevej, Copenhagen

- Former chemical laundry
- Source in clayey till, no reasonable remediation possibilities
- Groundwater contamination in limestone aquifer (tenths µg/l)
- Plume approx. 2,350 m³
- TCE as long-term containment method
Results *Dehalococcoides*

![Graph showing the growth of Dehalococcoides over time (days) for different samples KB2, KB3, KB4, KB5, and infiltration.](image-url)
Gl. Kongevej, Copenhagen

![Graph showing the degree of dechlorination and total VOCl (uM) over time for different samples KB2, KB3, KB4, and KB5.]

- **Degree of Dechlorination**
  - 0,00 (60%)
  - 0,10 (70%)
  - 0,20 (80%)
  - 0,30 (90%)
  - 0,40 (100%)

- **Total VOCl (uM)**
  - KB2 (%)
  - KB3 (%)
  - KB4 (%)
  - KB5 (%)
  - KB2 (uM)
  - KB3 (uM)
  - KB4 (uM)
  - KB5 (uM)

The graph plots the percentage of dechlorination and total VOCl levels against time from 21-Aug-06 to 9-Mar-07.
• active period from 1st September to 27th November 2006 (as planned)
• sulphate completely reduced
• even distribution of TOC and *Dehalococcoides ethenogenes*
• complete degradation in limestone aquifer (< 0.5 µg/l)

active barrier created:
addition of substrate every 1 to 1.5 years
Boreelstraat The Hague

- VOC contamination due to 2 dry cleaners
- Contamination down to 15 m-gl, sandy soil
- Inner city, builded area The Hague
- Contractor NTP
- Remediation 2009-2010
- Volume approx. 400,000 m³
Boreelstraat The Hague

Design
Boreelstraat The Hague

Phase 1 (t=90 d)
Boreelstraat The Hague

Phase 2 (t=180 d)
Phase 3
(t=270 d)
Boreelstraat The Hague

Phase 4
(t=360 d)
Boreelstraat The Hague

Phase 5
t=420 d
Boreelstraat The Hague

Phase 6
(t=480 d)
- Decreasing chloroethene concentrations
- Improved soil conditions for biological remediation
### Summary TCE Remediations

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil</th>
<th>$K$ (m/d)</th>
<th>Volume (m$^3$)</th>
<th>Start [VOC] (ug/l)</th>
<th>End [VOC] (ug/l)</th>
<th>Active Phase (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoogeveen</td>
<td>sand</td>
<td>15</td>
<td>400,000</td>
<td>50,000</td>
<td>&lt; 10</td>
<td>9</td>
</tr>
<tr>
<td>Almelo</td>
<td>fine sand</td>
<td>10</td>
<td>12,000</td>
<td>15,000</td>
<td>&lt; 1</td>
<td>4</td>
</tr>
<tr>
<td>Twello</td>
<td>sand</td>
<td>10-20</td>
<td>50,000</td>
<td>7,500</td>
<td>&lt; 10</td>
<td>10</td>
</tr>
<tr>
<td>The Hague</td>
<td>sand</td>
<td>10</td>
<td>3,000</td>
<td>3,000</td>
<td>in progress</td>
<td>5 (est.)</td>
</tr>
<tr>
<td>The Hague</td>
<td>sand</td>
<td>15</td>
<td>400,000</td>
<td>1,000</td>
<td>&lt; 1</td>
<td>3 months per Phase</td>
</tr>
<tr>
<td>Driebergen</td>
<td>sand</td>
<td>8</td>
<td>2,500</td>
<td>2,500</td>
<td>in progress</td>
<td>4-6 (est.)</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>Sandstone</td>
<td>20-30</td>
<td>2,350</td>
<td>20</td>
<td>&lt; 0.5</td>
<td>3</td>
</tr>
</tbody>
</table>

Cost indication for plumes of $> 10,000$ m$^3$: 3-8 €/m$^3$ soil volume
### Energy, including production of Carbon source

<table>
<thead>
<tr>
<th>Parameter</th>
<th>P&amp;T</th>
<th>TCE-concept</th>
<th>Ozone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>700.000 KWH</td>
<td>63.000 KWH</td>
<td>600.000 KWH</td>
</tr>
<tr>
<td>C-source production</td>
<td></td>
<td>304.000 KWH</td>
<td></td>
</tr>
<tr>
<td>Per m3</td>
<td>8,8 KWH/M3</td>
<td>3,8 KWH/M3</td>
<td>7,9 KWH/M3</td>
</tr>
<tr>
<td>CO2-total</td>
<td>397.000 KG</td>
<td>244.000 KG</td>
<td>361.000 KG</td>
</tr>
<tr>
<td>Per m3</td>
<td>5,0 KG/M3</td>
<td>3,1 KG/M3</td>
<td>4,5 KG/M3</td>
</tr>
</tbody>
</table>

*Note: KWH stands for Kilowatt Hours, KG stands for Kilograms.*
Conclusions

Using bioaugmentation, very low concentrations (< 1 µg/l) can be reached within 1 to 2 years

Not only useful when *Dehalococcoides ethenogenes* is absent, but also when redox conditions are moderately reduced and numbers of *Dehalococcoides ethenogenes* are low

The TCE concept is especially interesting for large plume remediations

Savings compared to conventional pump&treat in the order of 30-50%, short active phase, then monitoring phase

TCE is also a sustainable solution in comparison with conventional techniques

**Bio-augmentation = a powerful proven technology**
Thanks for your attention!

Maurice Henssen, Bioclear, The Netherlands

henssen@bioclear.nl