Pilot Testing of an Electrokinetic Barrier–Dissolved Chloride at the Former CN Irma Landfill

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Presentation Outline

- Background and Site Conceptual Model
- Remedial Objective
- Description of Electrokinetics (EK)
- EK Pilot Setup
- Pilot Results
- Next Steps
Site Location and Setting
Monitoring Well Network and Geology
Contaminant of Concern in Groundwater

- Chloride (From Landfilled Potash - KCl)
  - 2 Components: Localized Brine Pool, Dilute Plume

2014 Concentrations in mg/L
2013 Groundwater Modelling Results

- FEFLOW 6.2 used to predict impacts on Gratton Creek
- Chloride concentrations above guideline expected to reach Gratton Creek in about 50 years
- Suggested mitigation is required to control chloride plume
- Remedial Options Analysis using GoldSET CN SR® carried out in 2013
- Recommended a combination of Electrokinetics and Phytohydraulics
Pilot Test Location

Electrokinetic Pilot Zone
Contaminant plume
Direction of groundwater flow
Source of Contamination
Electrokinetic fence
Electric power supply and electrode management
Anodes & cathodes

Electrokinetic Fundamentals
Electrokinetic Fundamentals

Two Main Processes Involved:

**Electromigration**: Migration of ions toward the oppositely charged electrode

**Electro-Osmosis**: Migration of water from the anode to the cathode
Geochemical Reactions:

- At the Anodes:
  \[2H_2O - 4e^- \rightarrow O_2(g) + 4 H^+(aq)\]  
  (acidity production)

- At the Cathodes:
  \[2H_2O + 2e^- \rightarrow H_2(g) + 2 OH^-(aq)\]  
  (alkalinity production)
Electrokinetics In The Field

**CELL 23**: Chloride Source

**89-6-5**: Up-Gradient Reference Monitoring Well

*Electrokinetic Pilot Test Area (Located 5 m Downgradient from Monitoring Well 89-6-5)*

**Shed** (Power Supply & Voltage Readings)

**Exclusion Zone**

- Anodes
- Cathodes

**Generator**

[Images and diagrams related to the setup and location of the electrokinetics test area]
Electrokinetics In The Field - Layout

5 m Upgradient:
- Cell 23 (Cl⁻ source)
- Monitoring well 89-6-5

3 Anode Wells:
- Groundwater monitoring and sampling
- Gas monitoring
- Voltage measurements

2 Cathode Wells:
- Groundwater monitoring and sampling
- Gas monitoring
- Voltage measurements

4 Monitoring Wells:
- Groundwater monitoring and sampling
- Voltage measurements
- Gas measurements

8 Monitoring Points:
- Voltage measurements
- Soil moisture
- Soil conductivity
- Soil temperature
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Baseline Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater level</td>
<td>1.654 to 1.985 mbgs</td>
</tr>
<tr>
<td>Groundwater temperature</td>
<td>10.3 to 11.2 °C</td>
</tr>
<tr>
<td>pH</td>
<td>5.8 to 6.11</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>1.0 to 5.9 mg/L</td>
</tr>
<tr>
<td>Redox potential</td>
<td>258 to 276.6 mV</td>
</tr>
<tr>
<td>Conductivity</td>
<td>38 000 to 50 000 µS/cm</td>
</tr>
<tr>
<td>Cl- concentration</td>
<td>24 000 to 25 000 mg/L</td>
</tr>
<tr>
<td>Trace metals (Al, Co, Cr, Cu, Fe, Ni, Pb, Se, Zn)</td>
<td>Below detection limits</td>
</tr>
</tbody>
</table>
Voltage Measurements In The EK Test Cell During 6 Week Pilot Test

October 21, 2014
Voltage Evolution Through Time

Power supply output voltage and voltage sum at the electrodes

- Power supply output voltage
- Electrodes voltage sum

Voltage (V) vs. Time (h)
Field Parameters:
Depth To Groundwater

Anodes

Cathodes
Field Parameters: Groundwater Temperature

Anodes

Cathodes
pH at monitoring wells between anodes and cathodes remained close to background
Field Parameters:
Groundwater Conductivity

- **Anodes**
  - Device precision range limit

- **Cathodes**
  - Device precision range limit
Evolution Of Chloride Concentration During The Pilot Test

Baseline

Cl- concentration (mg/L)

Distance to closest anode (m)

Anodes

Cathodes

Baseline (Aug 27)
Evolution Of Chloride Concentration During The Pilot Test
Evolution Of Chloride Concentration During The Pilot Test

**Baseline**

- **Day 15**
- **Day 29**
- **Baseline (Aug 27)**

**Week 2**

**Week 4**

- **EK-AN-1**
- **EK-AN-2**
- **EK-AN-3**
- **EK-MW-1**
- **EK-MW-2**
- **EK-CA-1**
- **EK-CA-2**
Evolution Of Chloride Concentration During The Pilot Test

- **Baseline (Aug 27)**
- **Week 2**
- **Week 4**

**No noticeable accumulation of chloride at the anodes...**

**Clear “repelling” effect on chloride at the cathodes**

**Decreasing Cl- concentration through the test**

- EK-AN-1
- EK-AN-2
- EK-AN-3
- EK-MW-1
- EK-MW-2
- EK-MW-3
- EK-CA-1
- EK-CA-2

- Day 15
- Day 29
- Day 43
- Baseline (Aug 27)
Potential-pH Equilibrium Diagram For Chlorine-Water At 25°C

Field Evidence:

- **Greenish/yellowish water and a strong Cl odour** were noted during anode monitoring very early into the pilot test.
  
- **Cl₂** was detected at the anodes well headspaces in the field.

- Two samples of air released at the anodes were taken and analysed to quantify **Cl₂** emission (~ 7 ppm).
Nitrate and sodium are not affected by changes in geochemical conditions.

**Typical Anion (NO₃⁻) & Cation (Na⁺) Response To Electrokinetics**

**Nitrate (NO₃⁻)**
- NO₃⁻ is attracted by the anodes and accumulate at the anode site.

**Sodium (Na⁺)**
- Na⁺ is attracted by the cathodes and accumulate at the cathode site. There is also a clear repelling effect at the anode.
Health and Safety Concerns

Acidification/Alkalinisation of Groundwater:
- Low pH at anodes
- High pH at cathodes.
⇒ These concerns were managed using a specific H&S procedure

Chlorine Gas Emissions:
- Chlorine gas detected in anode wells
⇒ These concerns were managed using a specific H&S procedure
Main Conclusions

- Migration of Cl\textsuperscript{-} towards the anode was observed during the pilot test.

- As expected, positively charged ions migrated toward the cathodes and negatively charged ions migrated toward the anodes.

- No accumulation of Cl\textsuperscript{-} near the anodes was identified due to transformation of Cl\textsuperscript{-} to other forms such as Cl\textsubscript{2} and HCl.

- No need for water treatment?

- pH conditions remained close to background levels between the cathodes and the anodes.
Data Gaps:
- Determine vertical profile of chloride concentrations in full scale EK barrier area - needed to finalize electrode design (length);
- Evaluate optimal voltage (energy savings);
- Assess effect of longer term pilot on chloride concentrations;
- Determine Cl₂ mass flux (vapor phase treatment);
- Assess alternative sources of energy (solar panels) for full-scale implementation

Next Steps:
- Extended pilot test (August to October 2014)
- Full scale detailed design and GoldSET update
- Full scale implementation in 2015 (depending on 2014 results);
Thank You!