Design and assessment of electrochemical zones for remediation of chlorinated solvents in natural groundwater aquifer settings

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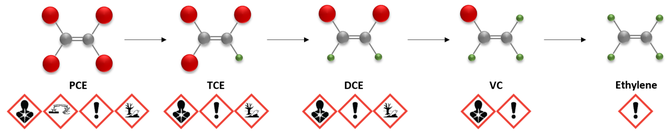
I Project objectives

- Optimization of electrochemical zone(s) for complete degradation of the harmful chlorinated solvents and their chlorinated degradation products in natural hydrogeological settings as a precautionary measure

II Motivation

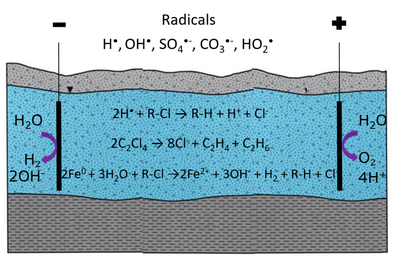
- Chlorinated solvents threatens the quality of groundwater and cause health risks [1]. Consequently, extraction wells for drinking water are closed
- The compounds' properties challenge the current treatment systems

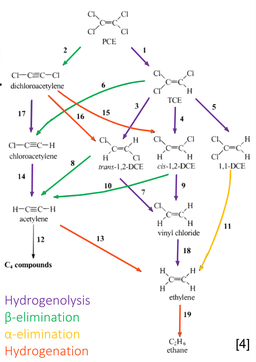


- Commonly used pump-and-treat systems for hydraulic containment are long-term solutions with substantial operation and maintenance costs
- Optimized means of protecting the groundwater from these contaminants are requested. We propose, establishment of electrochemical zones for *in situ* degradation of chlorinated solvents and degradation products.

III Relevant chemical processes

- Reactants can be generated and subsequently reduce or oxidize the chlorinated solvents [3] and fast electrochemical reduction of chlorinated solvents near the electrodes can be obtained [2].





[4]

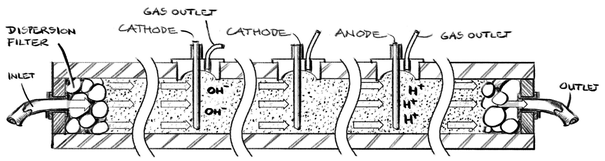
IV State of the art

Reduction	Half-cell reaction [5]	E° [V]
PCE	$C_2Cl_4 + H^+ + 2e^- \rightarrow C_2HCl_3 + Cl^-$	0.43
TCE	$C_2HCl_3 + H^+ + 2e^- \rightarrow C_2H_2Cl_2 + Cl^-$	0.42
Cis-DCE	$C_2H_2Cl_2 + H^+ + 2e^- \rightarrow C_2H_3Cl + Cl^-$	0.31
VC	$C_2H_3Cl + H^+ + 2e^- \rightarrow C_2H_4 + Cl^-$	0.38
Oxidation	**Half-cell reaction** [5]	**E° [V]**
DCE	$C_2H_2Cl_2 + 4H_2O \rightarrow 2CO_2 + 10H^+ + 8e^- + 2Cl^-$	0.70
VC	$C_2H_3Cl + 4H_2O \rightarrow 2CO_2 + 11H^+ + 10e^- + Cl^-$	0.50

- Focus has been on the influence from electrode materials [6,7,9] and configurations [7,8], and of system parameters such as current density [6,7,8,9,10], flow rate [6,7] etc. in spiked, synthetic liquid phases
- Knowledge gaps between state of the art and field implementation:
  - influence of naturally occurring geochemistry and aged contamination at natural groundwater temperatures

V Method

- We have designed 1D and 2D experimental set-ups targeting electrochemical plume control in field realistic designs
  - allows for assessment of single parameters; current density, flow and electrode material, and power consumption, lateral dispersion of reactants, electrode configuration and spacing
  - replicates site conditions: Flow-through of natural groundwater with an aged contamination of PCE in a sandy aquifer material at common groundwater flow rates and temperatures



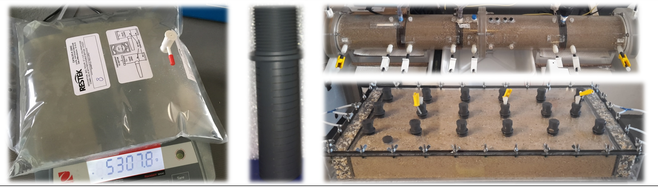
VI The field realistic design

- The field realistic parameters

Sampled groundwater	Conc.
PCE [µg/l]	40
TCE [µg/l]	30
Cis-1,2-DCE [µg/l]	70
Trans-1,2-DCE [µg/l]	1
VC [µg/l]	0.1
pH [-]	6.9
Conductivity [mS/cm]	1.7

Sampled groundwater	Conc.
Ca^{2+} [mg/l]	370
K^+ [mg/l]	4
Mg^{2+} [mg/l]	30
Na^+ [mg/l]	25
Cl^- [mg/l]	45
NO_3^- [mg/l]	4
SO_4^{2-} [mg/l]	400

Sampled sand	
Porosity [%]	31
Grain density [g/cm^3]	2.57
Carbon content [%]	0.95
Chalk content [%]	15
d(0.1) [mm]	0.2
d(0.5) [mm]	0.4
d(0.9) [mm]	0.9



VII Challenges and opportunities

- Contaminant fate when no current is applied is unexpected; upon test completion, dissolved and gaseous fractions are low. When current is applied, these fractions are high in proportion.
- Alterations in redox conditions induce e.g. deposition and eventually clogging of the pore spaces in the geological matrix. One design solution may be short-term polarity reversal.
- Present geochemistry competes with dechlorination for electrons, e.g. reduction of carbon dioxide to methane followed by polymerization to ethane and oxidative dehydrogenation to ethylene [11]. These hydro-carbons may interfere with the resulting mass balances of dechlorination.
- Some precipitates formed may improve the abiotic dechlorination of chlorinated ethylenes, e.g. magnetite and green rust [12].
- The reduced conditions in the proximity of cathodes visually appear to enhance microbial growth. Dependent on the microbial culture, biodegradation of the chlorinated ethylenes may establish [13].

IIX Acknowledgement

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