Large two-dimensional laboratory experiment with biodegradation of a PCE source zone

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Objectives

To investigate the effects of bioremediation on DNAPL source zones, we carried out an experiment in a two-dimensional tank filled with sand.

Material and methods

The tank, with inner dimensions of 2080 x 940 x 45 mm, contained 15 Time Domain Reflectometry probes and 85 sampling ports to monitor water saturation and chlorinated ethene concentrations, respectively (Figure 1).
The tank was filled with a homogeneous sand with a kaolinite clay lining at the bottom and a bentonite layer at the top.
A microbial assemblage originating from a contaminated field site was used for inoculation without prior enrichment.
Injection of 250 ml PCE into the tank yielded a residual zone of PCE with a pool at the bottom (Figure 2). After this injection, the tank was continuously flushed with anaerobic water containing sufficient electron donor and various nutrients.

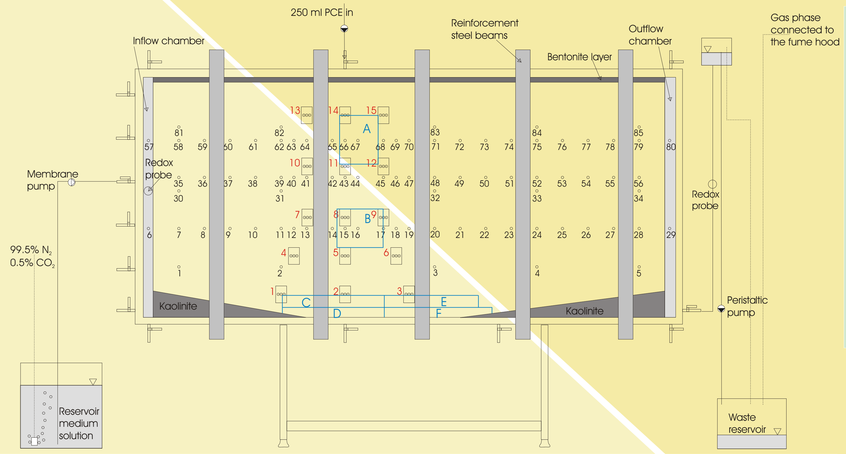

Figure 1: Schematic of tank setup; numbers 1 to 85 are sampling ports, red numbers 1 to 15 are TDR probes, and A to F are soil samples at the end of the experiment, dimension of the sand chamber is 21000 x 920 x 45 mm.

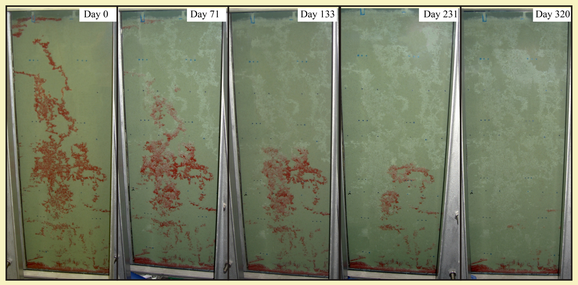

Figure 2: Pictures of the source zone at various times. Decrease in PCE residual zone and gas formation are visible.

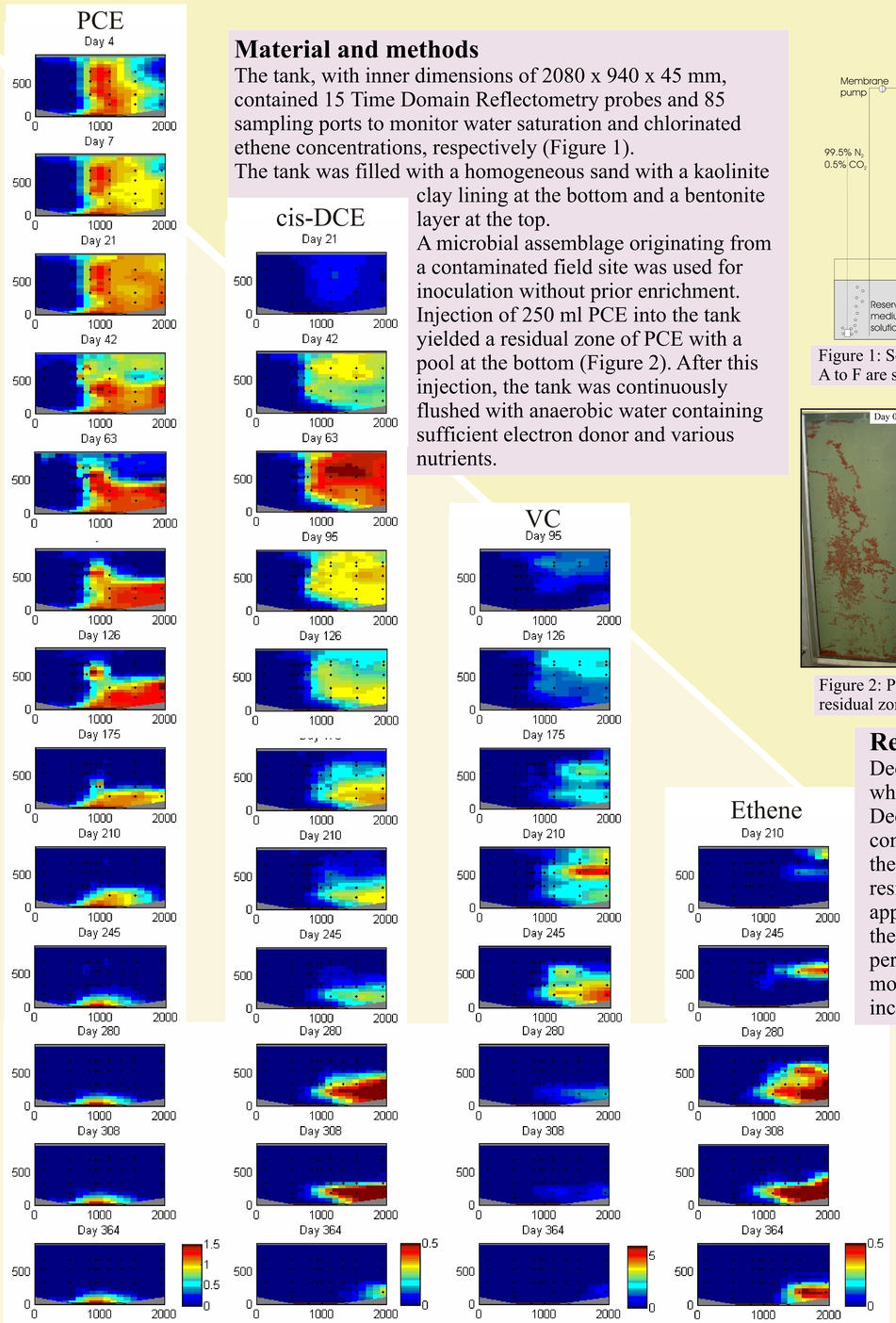

Figure 3: Evolution of PCE, cis-DCE, VC, and ethene based on kriging concentrations at various times. Black dots represent points used in the kriging process.

Results

Dechlorination of PCE occurred within the source zone (Figure 3) which resulted in a bio-enhanced dissolution factor of four. Dechlorination of cis-DCE to VC and ethene occurred when PCE concentrations were low (<0.1 mM). A decrease in residual PCE and the formation of gas were observed (Figure 2 and 4). Mobilization of residual PCE in the source zone occurred (Figure 5). After one year of experiment, approximately 135 ml of chlorinated ethenes were removed from the tank. PCE left in the tank was 90 ml and was only present in the pool. Spatial moment analysis were performed to investigate the general plume behavior (Figure 6) and were compared to model simulations (Figure 8). Microbial group counting showed that the number of cells increased for all bacterial groups. (Table 1).

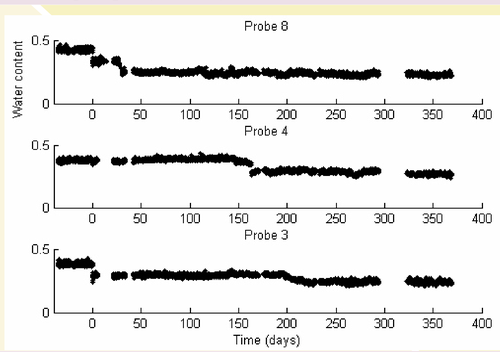

Figure 4: Water content measured with TDR probes; PCE injection at day 0.

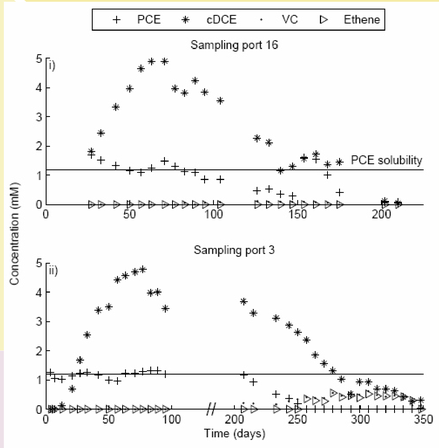

Figure 5: Chlorinated ethene concentrations in sampling port 16 (source zone) and 3 (plume).

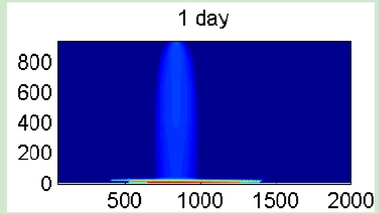

Figure 7: PCE saturation in the tank simulated with STOMP.

Model

Initialize PCE distribution with STOMP (Figure 7), followed by biodegradation with RT3D-OW(DNAPL). Model accounted for DNAPL dissolution from residual and pooled configurations and PCE dechlorination with Michaelis-Menten kinetics.

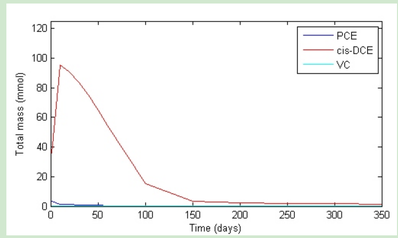

Figure 8: Total mass of chlorinated ethene in the aqueous phase from RT3D-OW(DNAPL).

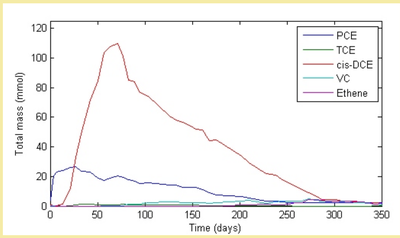

Figure 6: Total mass of chlorinated ethene in the aqueous phase from laboratory experiment.

Day	Sampling port	Bacteria	Archaea	*Dehalococcoides* spp.	Percentage *Dehalococcoides* from Bacteria
		cells ml^{-1}	*cells ml*$^{-1}$	*cells ml*$^{-1}$	%
-1	3	$1.2 \cdot 10^5$	$1.5 \cdot 10^5$	$< 6.3 \cdot 10^2$	< 1
	4	$1.9 \cdot 10^4$	$2.5 \cdot 10^4$	$< 6.3 \cdot 10^2$	< 3.5
	71	$2.8 \cdot 10^4$	$8.0 \cdot 10^4$	$< 1.0 \cdot 10^3$	< 3.5
	75	$5.4 \cdot 10^4$	$2.2 \cdot 10^4$	$1.3 \cdot 10^3$	2.5
180	3	$7.8 \cdot 10^8$	$1.3 \cdot 10^6$	$2.7 \cdot 10^7$	3.5
	4	$3.4 \cdot 10^7$	$1.4 \cdot 10^5$	$3.8 \cdot 10^6$	11
	71	$3.5 \cdot 10^6$	$4.6 \cdot 10^4$	$1.4 \cdot 10^7$	100
	75	$1.5 \cdot 10^9$	$2.2 \cdot 10^6$	$1.5 \cdot 10^8$	10

Table 1: Molecular analysis with q-PCR on water samples taken from the tank.

Conclusions

- Chlorinated ethenes analysis, microbial groups counting, and the visual observation of the colored PCE show that PCE was degraded in the source zone.
- Bio-enhanced dissolution occurred as cis-DCE concentrations were measured four times the solubility limit of PCE and because the PCE solubility limit in the source zone increased.
- Mobilization of residual PCE was observed.