TCE PLUME MANAGEMENT THROUGH EDIBLE OIL INJECTION AND NATURAL ATTENUATION

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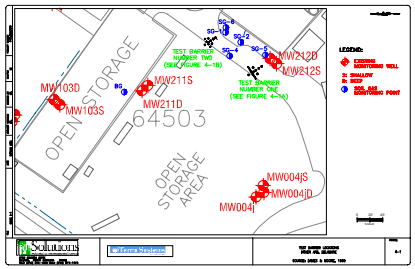
ABSTRACT: Two pilot-scale edible oil barriers were constructed in the upper portion of a 1,500 m long chlorinated solvent plume at Dover Air Force Base (AFB), DE. Edible soybean oil was injected into two 6.1 m-long barriers with monitoring wells spaced up to 4.6 m downgradient. Barrier 1 was treated by low pressure, direct injection of soybean oil into ten wells spaced 0.6 m apart. After eight months, a coarse emulsion was injected to increase the vertical and horizontal distribution of soybean oil. In Barrier 2, an emulsion of soybean oil and lecithin was injected under low pressure into four wells spaced 1.5 m apart. In both barriers, the injected edible oils have continued to release dissolved organic carbon (DOC) thirty-nine months after the initial injection with between 280 and 1,600 mg/L DOC found in injection wells of the two barriers. Before injection of the soybean oil, daughter products made up on average 34% of the total chlorinated ethenes and ethanes on a micromolar basis in Barrier 1. The daughter compounds increased to as much as 86.3% of total chlorinated ethenes and ethanes after 22 months. After 39 months, the daughter products represented an average of 78%. In Barrier 2, parent compounds initially represented an average of 55% of the chlorinated ethenes and ethanes. A maximum average of 77% percent daughter compounds was achieved after 9 months. Although little of the chlorinated ethenes and ethanes have been completely degraded, the edible oil in both barriers has been effective in supporting partial dechlorination of the parent compounds to daughter products which are then being degraded in the downgradient aerobic zone. Thus Dover AFB will be able to overall effectively remediate the site to target levels, without the need of reaching complete end products in the active treatment area. The emulsion barrier has recently been expanded.

Groundwater contaminants: Tetrachloroethene (PCE), Trichloroethend (TCE), cis-1,2-Dichloroethene (cDCE), 1,1,1-Trichloroethane (1TCA), 1,1-Dichloroethane (1DCA), 1,1-Dichloroethene (1DCE), and 1,2-Dichloroethane (2DCA). Little Vinyl Chloride (VC), Chloroethane (CA), ethene, or ethane.

Geological Setting

Site underlain by 12.2 m of fine to coarse sand with discontinuous layers of silt - Columbia Aquifer
clay aquitard beneath
~ 3.4 m to groundwater
groundwater flow velocities
- •shallow 11.9 to 40.5 m/yr (average 27.4)
- •deep 13.7 to 46.6 m/yr (average 29.9)



Pilot area

DAFB Barrier 1 Direct Oil Injection

Ten 2.5 cm PVC injection wells 0.61 m apart screened from 4.3 to 13.4 m below ground surface (bgs) installed February 2000
Injected 83 L soybean oil with fluorescein tracer not under pressure in April 2000
Chased with 871 L groundwater with 100 mg/L bromide

Direct Oil Injection Barrier

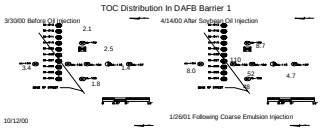
Direct Injection of Soybean Oil

Coarse Emulsion Injection

- •Initial poor distribution of TOC especially to deeper zones
- •Injected coarse emulsion (62 L soybean oil and 21 L of lecithin and 125 L groundwater) prepared with static in-line mixer in December 2000 to January 2001
- •Injected under pressure
- •Chased with 310 to 522 L groundwater

Barrier 1 NAPL Accumulation

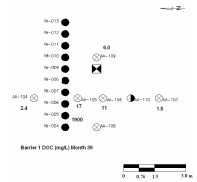
- •Oil accumulated in injection wells with 0.15 to 2.8 m in April 2000
- •Some oil in monitoring wells. After injection, 150 cm in AA-105 and 7.6 cm in AA-108. 0.61 cm or less by June 2000.
- •No NAPL observed in monitoring wells after coarse oil emulsion injection. Did see emulsion at ground surface.



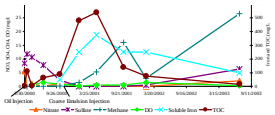
TOC 3.4 mg/L or less before direct oil injection.
Up to 110 mg/L in AA-105 after injection.

Six months after direct oil Injection, 88 mg/L in closest well AA-105, <10 mg/L elsewhere.
After coarse emulsion injection, up to 480 mg/L TOC.

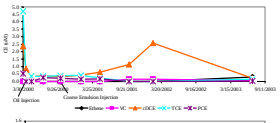
Nine months after coarse emulsion injection, up to 140 mg/L TOC
After 13 months following coarse emulsion injection, good TOC distribution



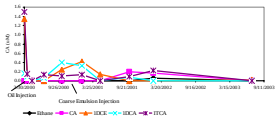
TOC Distribution June 2003
39 months after first injection
1,700 mg/L TOC in injection well, up to 17 mg/L in downgradient monitoring wells



AA-105 first downgradient well
TOC up to 550 mg/L
Dissolved iron and methane primary electron acceptors,
DO, nitrate, and sulfate down for most of pilot

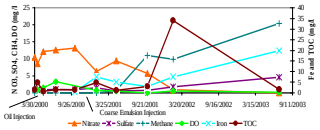


Initial adsorption into oil later PCE and TCE converted to cDCE and limited VC

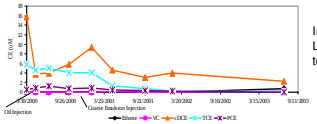


Initial adsorption into oil later 1TCA converted to 1DCE and 1DCA, some CA

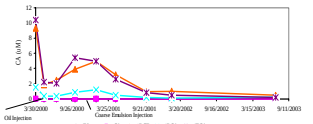
Electron Acceptors, Electron Donors, Chlorinated Ethenes, and Chlorinated Ethanes for Well AA-105 in DAFB Barrier 1



AA-107 4.6 m downgradient well
TOC up to 34 mg/L after coarse emulsion injection
Dissolved iron and methane primary electron acceptors, DO, nitrate, and sulfate down for most of pilot



Initial adsorption into oil.
Later PCE and TCE converted to cDCE and trace VC



Initial adsorption into oil and later 1TCA converted to 1DCE and 1DCA, but no CA

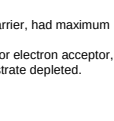
Electron Acceptors, Electron Donors, Chlorinated Ethenes, and Chlorinated Ethanes for Well AA-107 in DAFB Barrier 1

Barrier 1 Soil Gas

Soil gas monitoring point AA-110 installed in barrier at water table and shallow point (2.5 ft bgs) SG-5 across street.
Methane often above 100% LEL (5.5%) and >1000 ppm OVA with depressed oxygen in deep point AA-110 and injection wells throughout pilot.
No methane detected in shallow point SG-5.
Methane accumulated at water table, but was degraded in vadose zone.

Barrier 1 Conclusions

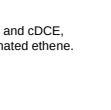
- •Better TOC distribution with coarse emulsion than direct oil injection
- •PCE and TCE converted to cDCE, little VC or ethene
- •1TCA to 1DCE, not much change in 1DCA, little CA or ethane produced
- •Methane produced at water table, consumed in vadose zone
- •Variable effects on hydraulic conductivity



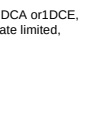
Well AA-114, 4.6 m from barrier, had maximum of 110 mg/L TOC.
Dissolved iron became major electron acceptor, sulfate increased after substrate depleted.

DAFB Emulsion Barrier

4 injection wells 1.5 m apart.
Injected 208 L soybean oil, 10 L lecithin, 7,570 L groundwater.
Used high shear mixer to prepare emulsion.
Added fluorescein and bromide tracers.



Little initial adsorption of TCE and cDCE, cDCE became primary chlorinated ethene.



Some 1TCA conversion to 1DCA or1DCE, and CA. Later, when substrate limited, 1TCA levels rebounded.

Electron Acceptors, Electron Donors, Chlorinated Ethenes, Chlorinated Ethanes for Well AA-114 in DAFB Barrier 2

Barrier 2 Soil Gas

Soil gas monitoring point AA-117 installed in Barrier at water table and shallow point (0.76 m bgs) SG-6 across street.
Methane often above 100% LELI (5.5% methane and >1000 ppm OVA with depressed oxygen in deep point AA-117 and injection wells headspace throughout pilot.
No methane detected in shallow point SG-6 and little methane in background point
Methane accumulated at water table, but was degraded in vadose zone

Barrier 2 NAPL Accumulation

Less than 61 cm found in injection wells immediately after injection
Less than 0.61 cm in monitoring wells through November 2000

Hydraulic Conductivity Barrier 2

Well No.	Screen Length (ft)	April 2000 - Preinjection Specific Capacity Test	May 2000 - Postinjection Specific Capacity Test	Jan. 2001 - 8 Months Later Specific Capacity Test
AA-111	15	14.7	26.1	26.6
AA-112	15	3.8	13.1	13.8
AA-113	15	4.6	19.2	13.9
AA-114	15	2.4	12	14.4
IW-014	30	6.3	0.4	0.07
IW-015	30			
IW-016	30	5.4	0.5	0.09
IW-017	30			

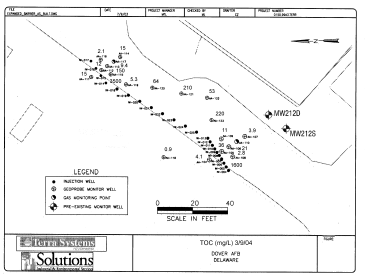
Notes:
April 2000 specific capacity tests used a gasoline powered centrifugal pump.
May 2000 and Jan. 2001 specific capacity tests used an electric peristaltic pump.

Monitoring wells showed little change in hydraulic conductivity as measured by specific capacity or slug tests.
Injection wells showed more than two-order-of-magnitude loss in hydraulic conductivity.

Barrier 2 Conclusions

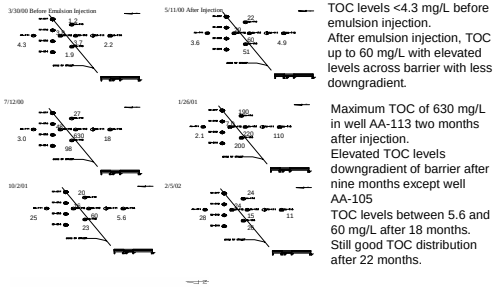
- •Better TOC distribution with depth than direct oil injection.
- •PCE and TCE converted to cDCE, little VC or ethene.
- •1TCA to 1DCE, 1DCA constant, some CA produced, little ethane
- •Methane produced at water table, consumed in vadose zone
- •Loss of two orders of magnitude in hydraulic conductivity in injection wells; no change in monitoring wells

Met DAFB goal of biodegrading most of PCE and TCE to cDCE which is degraded downgradient in aerobic zone
Expanded emulsion barrier between pilots
Installed 8 new injection wells at 2.3 m centers and six new monitoring wells
Injected emulsion and chased with water



TOC concentrations in March 2004 seven months after second emulsion injection. Highest TOC levels in injection wells and 6.1 to 7.6 m downgradient of Barrier.

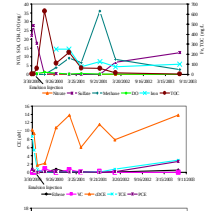
Barrier 2 NAPL Accumulation



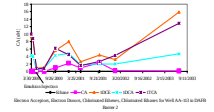
TOC levels <4.3 mg/L before emulsion injection.
After emulsion injection, TOC up to 60 mg/L with elevated levels across barrier with less downgradient.

Maximum TOC of 630 mg/L in well AA-113 two months after injection.
Elevated TOC levels downgradient of barrier after nine months except well AA-105
TOC levels between 5.6 and 60 mg/L after 18 months.
Still good TOC distribution after 22 months.

TOC levels after 39 months ranged from 3.8 to 280 mg/L in injection well.



Maximum TOC = 630 mg/L.
Methane and dissolved iron up, sulfate rebounded when TOC low.



Initial adsorption of TCE.
Conversion of most of PCE and TCE to cDCE.

Initial adsorption of TCE into oil followed by conversion of much of 1TCA to 1DCE and 1DCA with some CA

Electron Acceptors, Electron Donors, Chlorinated Ethenes, Chlorinated Ethanes for Well AA-103 in DAFB Barrier 2