COST AND PERFORMANCE REPORT

Aerobic Degradation Field Demonstration
at Moffett Naval Air Station,
Mountain View, California

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EPA
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

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Summary Information [1,4,12]

Site Name, Location	Moffett Naval Air Station, Mountain View, CA
EPA ID Number	CA2170090078
Mechanism(s)	Aerobic Oxidation (Cometabolic and Direct)
Technology	Electron Acceptor Addition (Oxygen and Hydrogen Peroxide) Electron Donor Addition (Methane, Toluene, and Phenol)
Configuration	Groundwater Recirculation
Technology Scale	Field demonstration
Media/Matrix Treated	Groundwater
Contaminants Targeted	TCE, cis-DCE, trans-DCE, VC
Period of Operation	September 1986 to November 1988 (methane addition studies)

Site History/Source of Contamination [1,4,6,7]

Moffett Naval Air Station (Moffett), used for aircraft operations and maintenance, operated from 1933 to 1994. In 1994, the Navy ceased operations and the airfield was transferred to the National Aeronautics and Space Administration (NASA). Moffett is located 35 miles south of San Francisco in Santa Clara County. Soil and groundwater at the site are contaminated with petroleum products and chlorinated aromatic hydrocarbons (CAHs) such as tetrachloroethene (PCE) and trichloroethene (TCE). Moffett is adjacent to other Superfund sites in the Middlefield-Ellis-Whisman (MEW) study area, and a large groundwater plume crosses Moffett from off-site sources. This site was added to the National Priorities List (NPL) on July 22, 1987 and is being addressed through Federal actions. Several Records of Decision (RODs) have been signed for this facility, including RODs for OU 1 (Sites 1 and 2 Landfills), dated August 1997; OU 2 (East Side Soils), dated December 1994; and OU 5 (East Side Aquifers), dated June 1996. In addition, for the West Side Aquifers, the Navy adopted an adjacent site's ROD, dated 1989.

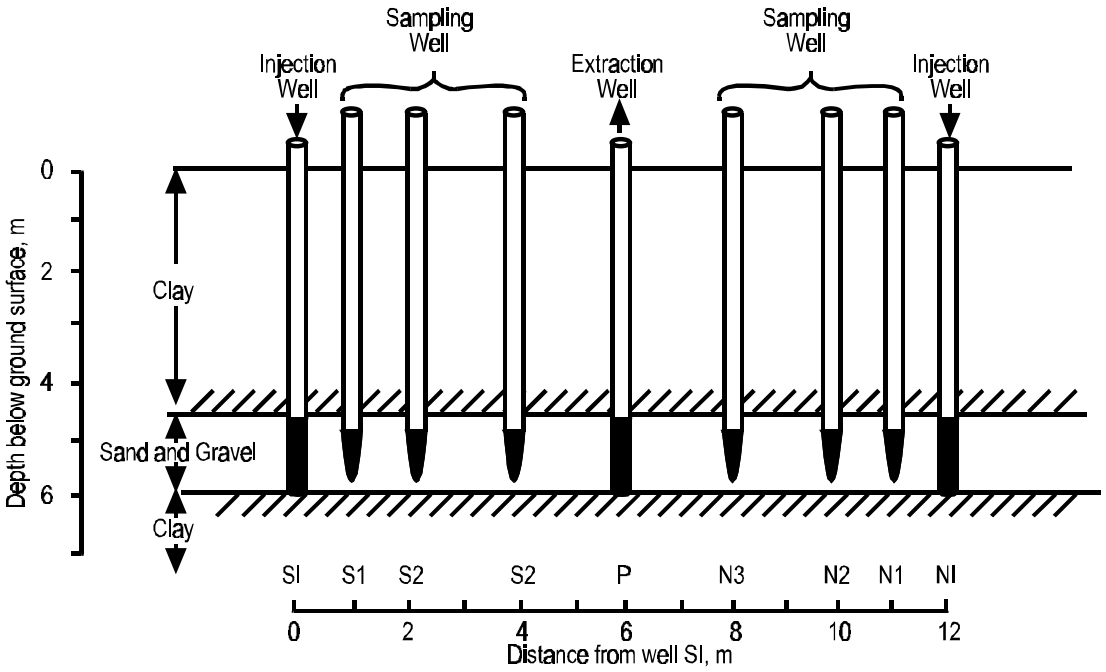
Moffett was selected by researchers from Stanford University for a field demonstration of in situ aerobic degradation to treat groundwater contaminated with CAHs. A series of experiments was conducted between September 1986 and November 1998 to evaluate native bacteria enhanced through addition of methane, toluene, and phenol in degrading CAHs, including PCE and TCE.

Geology/Hydrogeology/Contaminant Characterization [3,5,11,12]

As shown in Figure 1, the demonstration site (test zone) was approximately 4 to 6 meters (m) below ground surface (bgs), located in a shallow, confined aquifer (1.5 m thick)consisting of sands and gravels. The groundwater velocity ranged from 1.5 to 3 m/day and the hydraulic conductivity of the aquifer was 0.11 cm/sec. In addition, indigenous methanotrophic bacteria were reported to be present in the aquifer.

The CAHs present in the test zone prior to the demonstration included 1,1,1-trichloroethane (TCA) and 1,1-dichloroethane (DCA). However, TCE, cis-dichloroethene (cis-DCE), trans-dichloroethene (trans-DCE), and vinyl chloride (VC)were not detected in the groundwater in the test zone. As described below, regulatory approval was obtained to inject TCE, cis- and trans-DCE, and VC into the groundwater for the demonstration.

Figure 1. Cross-section of Well Field Used at Moffett [4,5,12]



Matrix Characteristic	Value [11,12]
Soil Type	sand and gravel
Depth to Groundwater	4 to 6 m bgs
Thickness of Aquifer(s)	1.5 m
Fraction of Organic Carbon	0.00112 ± 0.00020
Hydraulic Conductivity	0.11 cm/sec
pH	6.5
Nitrogen	30 to 60 milligrams per liter (mg/L) (as nitrate)
Phosphorus	<0.1 mg/L (as phosphate)
Groundwater Velocity	1.5 to 3 m/day

Technology Description [4,5,7,12]

The demonstration of aerobic degradation was performed under induced-gradient conditions created by the extraction and injection of groundwater. As shown in Figure 1, groundwater was extracted at well P, amended chemically, and injected at wells SI and NI, located 6 m from extraction well P (information about the construction and operation of the wells was not provided). Regulatory approval was obtained for injecting TCE, cis- and trans-DCE, and VC into the groundwater.

Table 1 presents a summary of the nine experiments that were conducted over three seasons of the demonstration, including the period of operation, groundwater extraction and injection rates, chemical amendments, and processes studied. The experiments included biostimulation (Biostim) to stimulate the activity of native methane-using bacteria, and biotransformation (Biotran) to transform TCE into lower chlorinated compounds. Tracer experiments, using bromide, were performed to evaluate organic transport and "Decmeth" experiments were performed to evaluate methane addition.

Concentrations of CAHs, methane, DO, and bromide were monitored using the wells shown in Figure 1. An automated data acquisition and control system was used to provide as many as six sets of analyses per day at each of the sampling locations.

Additional experiments performed at the site included using phenol and toluene (alternative electron donors) as substrates in place of methane, and using hydrogen peroxide as an alternative to oxygen.

Table 1. Summary of Experimental Conditions Used at Moffett [4]

Experiment	Extraction (E) and Injection (I) Rates	Duration	Chemical Amendments (average mg/L)	Processes Studied
First Season				
Biostim 1	E: 8 L/min I: 1 L/min	9/5/86 - 9/30/86	Methane: 5.9 DO: 20.8 Bromide: 166	Biostimulation of native methane-using bacteria. Alternating pulse injection of methane and DO.
Biotran 1	E: 8 L/min I: 1 L/min	9/30/86 - 10/21/86	Methane: 5.7 DO: 22.2 TCE: 0.097	Biotransformation of TCE with active biostimulation. Nonsteady-state conditions.
Biotran 4	E: 8 L/min I: 1 L/min	12/10/86 - 12/31/86	Methane: 5.2 DO: 23 Bromide: 159 TCE: 0.051	Biotransformation of TCE with active biostimulation. Steady-state conditions.
Second Season				
Tracer 8	E: 10 L/min I: 1.5 L/min	7/6/87 - 8/15/87	DO: 14.3 Bromide: 78 TCE: 0.048 cis-DCE: 0.110 trans-DCE: 0.112	Transport and breakthrough of bromide, TCE, cis- and trans-DCE without biostimulation.

Table 1. Summary of Experimental Conditions Used at Moffett [4] (continued)

Experiment	Extraction (E) and Injection (I) Rates	Duration	Chemical Amendments (average mg/L)	Processes Studied
Biostim 2	E: 10 L/min I: 1.5 L/min	8/17/87 - 10/26/87	Methane: 5.3 DO: 23.4 Bromide: 44 TCE: 0.036 cis-DCE: 0.091 trans-DCE: 0.092	Simultaneous biostimulation and biotransformation of TCE, cis- and trans-DCE.
Decmeth 1	E: 10 L/min I: 1.5 L/min	10/27/87 - 11/8/87	DO: 24.5 TCE: 0.045 cis-DCE: 0.136 trans-DCE: 0.095	Test if active biotransformation occurs without addition of methane.
Third Season				
Tracer 11	E: 10 L/min I: 1.5 L/min	8/10/88 - 10/10/88	Bromide: 72 TCE: 0.047 cis-DCE: 0.085 trans-DCE: 0.050	Transport and breakthrough of bromide, TCE, cis- and trans-DCE without biostimulation.
Tracer 12	E: 10 L/min I: 1.5 L/min	10/10/88 - 10/20/88	Bromide: 44 TCE: 0.042 cis-DCE: 0.100 trans-DCE: 0.054 VC: 0.044	Transport and breakthrough of bromide and VC while continuing injection of TCE, cis- and trans-DCE.
Biostim 3	E: 10 L/min I: 1.5 L/min	10/20/88 - 11/23/88	Methane: 6.6 DO: 21.3 Bromide: 45 TCE: 0.046 cis-DCE: 0.100 trans-DCE: 0.052	Simultaneous biostimulation and biotransformation of TCE, cis- and trans-DCE, and VC.

Technology Performance [2,3,4,7,12]

The objective of the field demonstration was to collect data to be used in evaluating aerobic degradation of CAHs under several different experimental scenarios. Specific remedial goals were not established for this demonstration.

Several methods were used to evaluate the amount of CAHs that were biodegraded in these experiments, including mass balances on the amounts of CAH injected and extracted, and comparison of breakthrough concentrations using controlled experiments and bromide tracers. Results showed that active use of methane in the treatment zone was required for biodegradation of CAHs, and that groundwater residence times in the treatment zone of 1-2 days resulted in biodegradation of TCE at 20 - 30%, cis-DCE at 45 - 55%, trans-DCE at 80 - 90%, and VC at 90- 95%. The results indicated a similar degree of

biodegradation of TCE over the three seasons of field testing, suggesting that there was no apparent increase in the ability of the bacteria to degrade TCE. In addition, results showed that an intermediate biotransformation product, trans-DCE oxide, was produced in a manner consistent with the expected transformation pathway for trans-DCE. Detailed analytical results for each of the nine experiments are provided in reference 4.

Table 2 summarizes the results from the third season of the methane addition experiments, and the experiments with phenol and toluene as primary substrates. As shown in the table, the use of phenol and toluene achieved higher percent removals of TCE (93 - 94%) compared with use of methane (19%). Additional detail about the experiments conducted using phenol and toluene are provided in references 8 - 10, cited at the end of this case study.

Hydrogen peroxide was found to achieve TCE removals similar to those achieved using oxygen. While 1,1-DCE was partially transformed in the study with phenol, the transformation products were found to be toxic to the transforming bacteria.

Table 2. Summary of Results (% Removal) Using Different Substrates at Moffett [3]

Primary Substrate	Substrate Concentration (mg/L)	% Removal by Constituent				
		TCE	1,1-DCE	cis-DCE	trans-DCE	Vinyl Chloride
Methane (third season)	6.6	19	NE	43	90	95
Phenol	12.5	94	54	92	73	>98
Toluene	9	93	NE	>98	75	NE

Note:
NE - not evaluated

No exceptions to established quality assurance/quality control (QA/QC) protocols were noted in the available information.

Technology Cost

No information was provided about the cost for the in situ bioremediation treatment system used at Moffett.

Summary Observations and Lessons Learned [3,4,7-12]

The results of the field demonstration at Moffett showed that native bacteria enhanced with methane, phenol, or toluene, plus oxygen or hydrogen peroxide was effective in degrading CAHs in groundwater. Concentrations of CAHs were reduced by as much as 94% for TCE, 92 % for cis-DCE, and 98% for VC. Native bacteria enhanced with phenol and toluene achieved higher removal rates for TCE than bacteria

enhanced with methane. The results from the field experiments were consistent with the results from batch soil column laboratory testing using aquifer solids from the test zones.

The presence of 1,1-DCE in the groundwater was found to be toxic to the bacteria, and should be considered when evaluating this technology for use in other applications. However, the relatively low concentration of phosphate in the groundwater did not limit the biodegradation of CAHs at this site. According to the researchers, other phosphate minerals may have dissolved in the groundwater to replenish this mineral as it was being removed by the bacteria.

During the field demonstration, the use of alternating pulsed addition of methane and oxygen minimized biofouling in the area near the injection well.

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