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EFFECTIVE DISTRIBUTION OF EDIBLE OILS - RESULTS FROM FIVE FIELD APPLICATIONS

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ABSTRACT: Edible oil was injected at five sites to promote reductive dechlorination. The edible oil was injected as a non-aqueous phase liquid (NAPL) or as an emulsion of oil, an emulsifier, and water. At Dover Air Force Base, injection of the emulsion into a barrier resulted in greater distribution of the total organic carbon (TOC) and more rapid dechlorination than direct injection of the edible oil into another barrier. Direct addition of oil using a Geoprobe™ direct push rig promoted reductive dechlorination in two sites with shallow groundwater contamination. The emulsion moved at least 7.6 m at a site on Long Island, NY. An increase in the intermediate and final degradation products ethene and ethane was noted over the first four months after injection. The emulsion was distributed throughout a 7.6 m zone surrounding the four injection wells in a deep aquifer at Edwards Air Force Base. Little dechlorination has been observed at this site after two months. Direct oil injection is generally less expensive when the contamination is shallow and site conditions allow rapid installation of Geoprobe™ points. Injection of the oil-in-water emulsion is more cost effective when the contamination is deeper or where a larger area must be treated. However, injection of the emulsion requires an additional handling step and a suitable water supply, but results in a superior product that can be readily introduced into the subsurface.

INTRODUCTION

Numerous laboratory and field studies have shown that chlorinated solvents such as perchloroethene (PCE), trichloroethene (TCE), and 1,1,1-trichloroethane (1TCA) can be biodegraded by naturally occurring microorganisms when provided with an appropriate organic substrate (Ellis et al., 2000; Lee et al., 1997; Lee et al., 1998). The key to successful implementation of this technology is developing an effective low-cost method of distributing substrate throughout the treatment zone (Quinton et al., 1997). Previous studies using lactate, molasses, and other soluble substrates have successfully treated chlorinated solvent-contaminated aquifers by recirculating groundwater amended with the dissolved substrate. However capital costs are substantial because of the required tanks, pumps, mixers, injection and pumping wells, and related process controls. In addition, operation and maintenance (O&M) costs are high because of problems associated with clogging of injection wells and the labor for extensive monitoring and process control. High O&M costs are a particularly important issue in aquifers where cleanup rates are limited by slow dissolution of NAPLs or diffusion of contaminants from low permeability zones.

One potentially very cost-effective approach for enhancing anaerobic processes is using immobilized edible oils to promote anaerobic biodegradation in permeable reactive barriers (PRBs). Lee et al. (2000) demonstrated that a variety of edible oils can support reductive dechlorination in laboratory and column studies from five sites. The edible oils can be purchased for as little as $0.40 per pound. As solvents or other contaminants migrate through the barrier, the immobilized oils slowly dissolve, enhancing contaminant biodegradation, leaving uncontaminated water to emerge from the downstream side. When applied at full scale, O&M costs will be minimal since the oils are selected to last three to ten years between reinjections.

The key to successful implementation of this technology is developing an effective low-cost method of distributing and immobilizing the oils throughout the treatment zone. Two different injection and distribution approaches are being evaluated: (1) injection of the edible oil as a non-aqueous phase liquid (NAPL); and (2) injection as an oil-in-water emulsion. Performance results from five different sites are evaluated (Table 1). The cost and effectiveness of each approach is site specific and dependent on aquifer lithology, depth of contamination, drilling costs, and available water supply.

RESULTS

Dover Air Force Base. Two barriers were installed in a shallow aquifer contaminated with PCE, TCE, 1TCA, and daughter products (Zenker et al., 2000). A direct oil barrier was prepared by injecting soybean oil into ten injection wells 0.6 m apart. The oil was not injected under pressure. Seven hundred sixty liters of groundwater were used to chase the oil. Four injection wells in the second barrier received soybean oil that had been emulsified with groundwater and an emulsifying agent using a high-shear mixer. The emulsion was injected under pressure. About 7,600 L of bromide-amended groundwater were used to distribute the oil throughout the area. Six monitoring wells were installed around each barrier.

Nine months after the oil injection, the distribution of dissolved total organic carbon (TOC) was much better in the emulsion barrier than the direct oil barrier (Figure 1). The oil did not penetrate very deep in the direct oil barrier. More oil was injected at depth in the emulsion barrier. There has been limited production of *cis*-1,2-dichloroethene (cDCE), vinyl chloride (VC), and chloroethane (CA) in the emulsion barrier after nine months. Little dechlorination has been observed to date in the direct oil barrier, possibly as a result of poor distribution of the oil to depth or the need for bioaugmentation to complete the dechlorination reaction. Methane has accumulated at the groundwater table near both barriers, but has not reached the land surface.

Eastern VA. Soybean oil was injected into the area surrounding a dry cleaning machine at an industrial facility. The shallow unconsolidated aquifer was

TABLE 1. Site Descriptions.

Site	Geology	Contaminants	Depth to Water (m)	Treated Depth (m)	Project Size Length x Width m (# injection points)	Evidence for Dechlorination
Dover Air Force Base, DE	Fine to medium sand	PCE, TCE, cDCE, VC. 1TCA, 1DCA, 1DCE, CA	3.3	4.6-13.7	Direct oil 6.1 x 6.1 (10) Emulsion 6.9 x 6.1 (4)	Little dechlorination Limited production of cDCE, VC, and CA
Eastern VA	Unconsolidated clay, silt, sand, and limestone	PCE, TCE, cDCE, VC. 1TCA, 1DCA, 1DCE, CA	1.5	1.5-3.0	18 x 37 (35 direct oil)	Decreases in PCE, TCE, 1DCA, 1DCE, 2DCA, tDCE; increase in cDCE, VC, and ethene
Eastern NC	Silty-sand	TCE, 1TCA, 1DCA, 1DCE	3.0	3.0-7.3	8000 m^2 (185 direct oil)	Little change after 3 months
Long Island, NY	Fine to coarse sand, some silt and gravel	PCE, TCE, cDCE, VC. 1TCA, 1DCA, 1DCE, CA	3.0	6.7-14.6	15.2 x 6.1 (6 emulsion, 1 direct oil)	Decreases in cDCE, VC, 1TCA, 1DCA, and 1DCE; increase in CA and ethane
Edwards Air Force Base, CA	Clay, silty clay, sandy clay, silt, clayey sand, and fine to coarse sand	TCE	14.6	13.1-19.2	6.8 x 8.7 (4 emulsion)	No dechlorination after 3 months

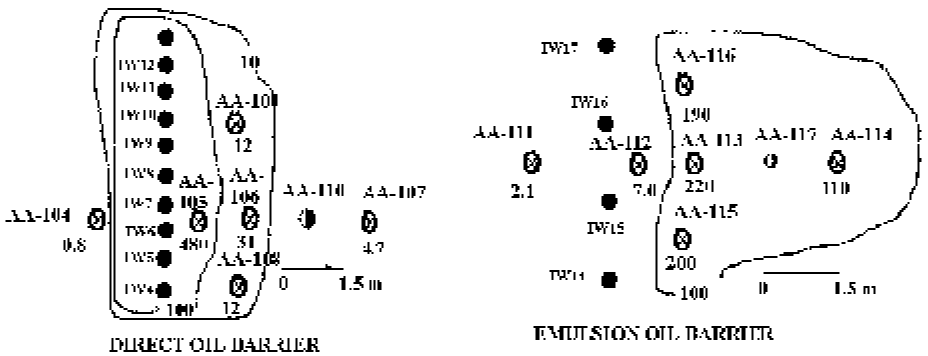

FIGURE 1. TOC Distribution DAFB Barriers after 9 Months.

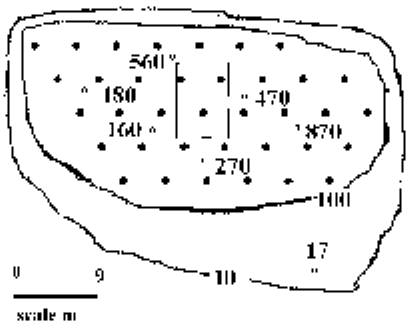

FIGURE 2. TOC Distribution Eastern VA Direct Oil Barrier after 7 Months.

contaminated with PCE, 1TCA, and daughter products. A total of 36 injections of soybean oil were made using a Geoprobe™. After seven months, TOC levels in the area ranged from 160 to 870 mg/L in piezometers within the treated area (Figure 2). The TOC in a piezometer outside of the treated area was 17 mg/L. Daughter products including cDCE, VC, and ethene increased in several wells with decreases in the PCE and TCE concentrations. Concentrations of 1TCA, 1,1-dichloroethane (1DCA), 1,1-dichloroethene (1DCE), 1,2-dichloroethane (2DCA), and *trans*-1,2-dichloroethene (tDCE) decreased in several piezometers, but without a concomitant increase in chloroethane and ethane increases. The soybean oil injection has improved groundwater quality at the site.

Eastern NC. TCE, 1TCA, and daughter products were found in the groundwater beneath a former manufacturing facility. Soybean oil was injected into 185 points at the facility including beneath the floor of the facility and as barriers to treat two separate areas of the plume. Decreases in the dissolved oxygen and redox potential have been noted over the seven months since oil injection. Ferrous iron and methane levels have increased as the groundwater becomes more reducing. However, little change in the dissolved contaminants was observed in the three months of data available after oil injection.

Long Island, NY. This industrial facility was contaminated with high concentrations of 1TCA, PCE, and their daughter products as well as a number of other organic constituents. A emulsion of soybean oil and water was injected into six points between 6.7 and 15.2 m bgs. Another point received direct injection of oil. The emulsion moved at least 7.6 m from an injection point to a shallow monitoring well. Three and a half months after the injection of the emulsion, the TOC ranged from <1 to 1,990 mg/L in shallow and deep monitoring points surrounding the barrier (Figure 3). Sulfate concentrations are declining and methane levels are increasing in a number of the nearby monitoring wells. There is evidence for complete dechlorination in many of the wells. For example, in shallow monitoring point S-2, cDCE has declined from 1.5 μM to <0.002 μM, VC from 2.8 to 0.6 μM, and ethene has been constant at 7.9 μM. Concentrations of 1TCA have declined from 24 to 7.5 μM, 1DCA from 41 to 12 μM, and 1,1-DCE from 1.1 to < 0.02 μM, but CA has increased from 19 to 47 μM and ethane from <0.2 to 1.3 μM.

Edwards Air Force Base, CA. TCE was the only chlorinated contaminant found in a relatively deep aquifer (water table at 15.2 m) at Edwards Air Force Base. A fine emulsion of soybean oil and groundwater was injected into four wells screened between 15.2 and 19.8 m bgs. Five monitoring wells were installed up to 4.6 m away. The emulsion reached all of the monitoring points except the well the furthest away. TOC distribution was greater than 1,000 mg/L in the injection wells and one downgradient well after two months (Figure 4). TOC levels in the remaining wells ranged between 29 and 320 mg/L versus the pre-treatment average of 9 mg/L. No evidence of dechlorination has been observed in the two months following substrate injection.

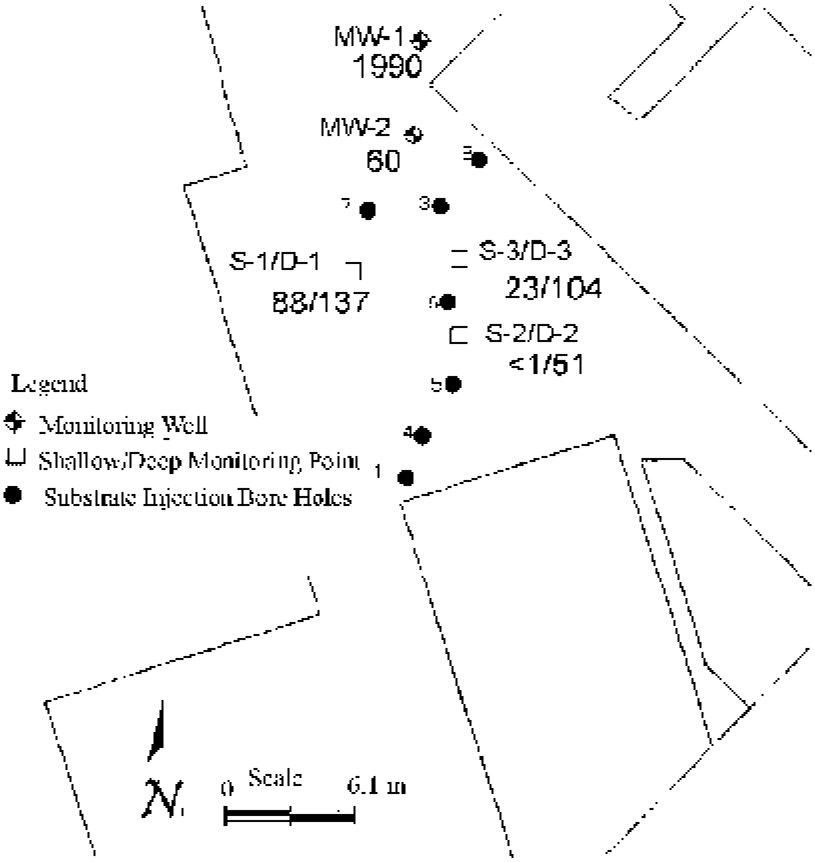

FIGURE 3. TOC Distribution Long Island Pilot after 3.5 Months.

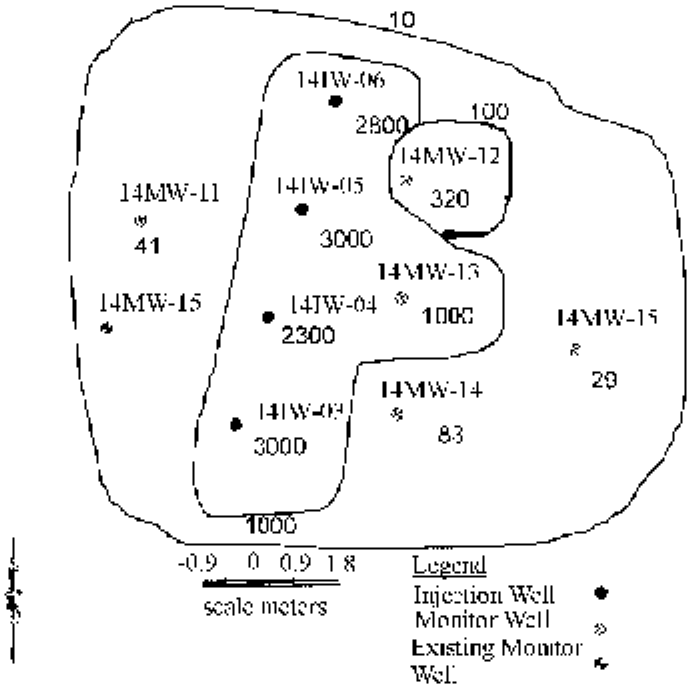

FIGURE 4. TOC Distribution at Edwards Air Force Base Emulsion Pilot after 2 Months.

DISCUSSION

Direct oil injection as a non-aqueous phase liquid (NAPL) is often less expensive when the depth of the contamination is low and site conditions allow rapid installation of Geoprobe™ points at relatively close spacing. However, it may be more difficult to effectively distribute NAPL oil over large vertical intervals because of density effects. NAPL oil in the pore spaces may also result in a greater loss of permeability and contaminant bypassing around the oil treated zones.

Injection of the oil as an oil-in-water emulsion is more cost effective when the depth of contamination is greater and drilling costs are higher. When properly prepared, oil-in-water emulsions may be distributed over substantial distances (at least 7.6 m) significantly reducing drilling costs and reducing the impact on aquifer permeability. The emulsion can provide over 1,000 mg/L TOC. However, injection as an emulsion requires additional handling and requires a suitable water supply.

Edible oils can be used to treat an entire plume, a source area, or could be applied as a barrier to intercept a plume. The oils should be useful for fractured bedrock sites where the oil can coat the surfaces of the fractures and support reductive dechlorination. Laboratory studies (Lee et al., 2000) have shown that the oils can be used in conjunction with bioaugmentation at sites where dechlorinating organisms are not present. Bioaugmentation may be necessary at the Dover AFB, Eastern NC, and Edwards AFB sites as limited dechlorination has been observed at these sites after two to nine months. Solutions Industrial & Environmental Services and Terra Systems, Inc. have a patent pending on the use of oil emulsions to support reductive dechlorination.

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