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FULL-SCALE *IN SITU* BIOREMEDIATION OF TRICHLOROETHYLENE IN GROUNDWATER: PRELIMINARY MODELING STUDIES

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INTRODUCTION

A full-scale study of in-situ bioremediation is being planned for implementation at Edwards Air Force Base. The bioremediation system that is being proposed has been developed over 8 years of research and testing in the laboratory and at a pilot field site located at Moffett Naval Air Station in Mountain View, California. Studies conducted at the Moffett field site have demonstrated that trichloroethylene (TCE), the contaminant found at Edwards, can be effectively biodegraded cometabolically through the introduction into the subsurface of a primary substrate (such as phenol or toluene) and an oxygen source (such as hydrogen peroxide) to support the growth and energy requirements of a native population of microorganisms (1,2,3).

One of the main questions that needs to be answered, prior to full-scale demonstration of this technology on the Edwards TCE plume, is how best to mix a primary substrate, an oxygen source, and TCE, and subsequently get the mixture to the microorganisms. At Moffett Field, mixing of these three components was accomplished above ground, with the mixture then introduced into the subsurface through an injection well. In the full-scale demonstration, the TCE will, of course, already be in the groundwater. A major objective of the demonstration will be to investigate how a primary substrate and an oxygen source can be efficiently mixed and transported to indigenous microorganisms, in order to promote cometabolic degradation of TCE. For the demonstration, it is anticipated that a subsurface recirculation system, similar to that described by Herrling (4) and McCarty and Semprini (5) will be used. The proposed remediation system is shown in Figure 1. The system consists of a pair of recirculation wells, each screened at two depths. In operation, a submersible pump installed between the two screens of each well would draw TCE contaminated water into the well at one of the screened intervals. The primary substrate (toluene) and oxygen source (hydrogen peroxide) will then be introduced into the well through feed lines, and the water, which contains TCE, toluene, and oxygen, will be discharged into the aquifer from the second screened interval. An in-situ treatment zone will be created in the aquifer, around the discharge screen. The second treatment well will extract water from the injection zone of the first well, and inject water at the level where the first well is extracting water. Thus. water will circulate through the aquifer, from one treatment well to the other. The injection/extraction levels of each well can be periodically reversed.

METHODOLOGY

To help plan and design the demonstration, a computer model which incorporates all the significant flow and transport processes was used. A two-dimensional flow code was used, to simulate pumping through the two treatment wells. The streamtubes which were output by the flow code were used as input for the transport code. The one-dimensional transport code (6,7) was applied along each streamtube. The transport code includes the microbial processes of bacterial growth, toluene and oxygen utilization, and the cometabolic transformation of TCE coupled with the transport processes of advection, dispersion, and rate-limited sorption onto aquifer solids. Model simulations could be run for different parameter values, with TCE concentrations output as a function of space and time. In addition, TCE concentrations may be numerically integrated over space, to obtain plots of TCE mass versus time.

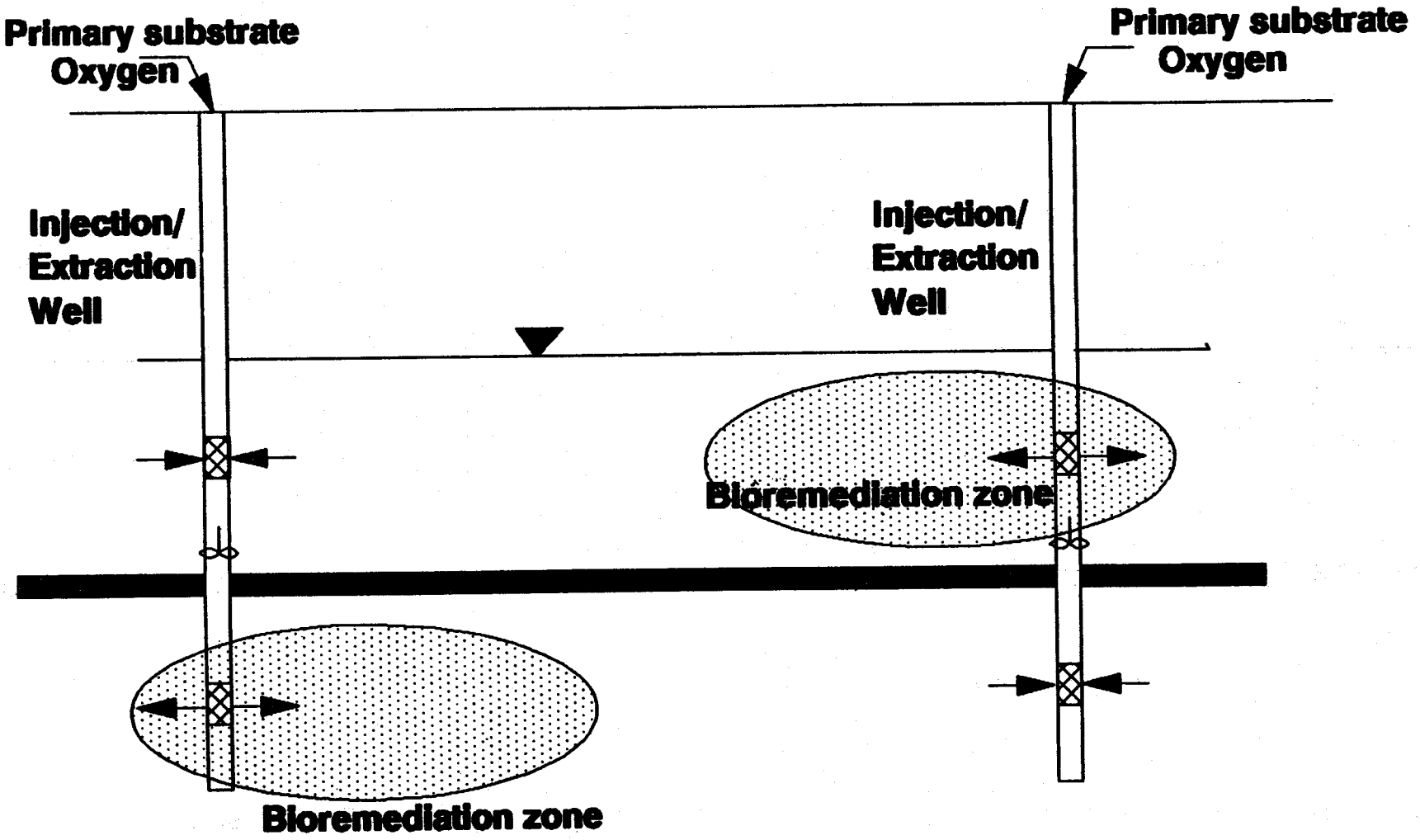

Figure 1. Bioremediation concept.

RESULTS

Based on preliminary data obtained from the Edwards demonstration site and the Moffett Field experimental site, and using "best-guess" design values for the treatment system, a base line simulation was run. Base line parameter values are listed in Table 1.

TABLE 1. PARAMETER VALUES USED FOR BASELINE SIMULATION OF BIOREMEDIATION MODEL

Parameter	Value
Distance between treatment wells	10.0 meters
Flow rate through each treatment well	15.0 gallons per minute
Treatment well screen length	4.0 meters
Concentration of oxygen source (hydrogen peroxide) added	100 milligrams per liter (mg/L)
Time-averaged concentration of primary substrate (toluene) added	9 mg/L
Toluene pulse length	20 minutes every 8 hours
Initial TCE concentration in aquifer	0.2 mg/L
Sorption distribution coefficient	0.2 milliliter per gram
Sorption/desorption rate coefficient	0.010 per day
TCE retardation factor	2.0
Cometabolism rate constant	0.015 per day
TCE half-saturation coefficient	0.5 mg/L

The simulation shows how TCE mass declines in both the dissolved and sorbed phases over the four months planned for the demonstration (figure 2). Notice that initially, the mass of TCE in the dissolved and sorbed phases is equal. This is due to the fact that the retardation factor used for the simulation is 2.0, and TCE concentrations in the dissolved and aqueous phases are initially assumed to be at equilibrium. Over approximately the first 50 days of the simulation, dissolved mass drops relatively rapidly, due to biodegradation of TCE in the aqueous phase. After about 70 days, the mass of TCE in the aqueous phase becomes relatively constant, while the mass in the sorbed phase shows a slow but steady decline. What has happened is that after about 70 days, slow desorption has begun to control the rate of mass removal. A pseudo-steady state has been attained where the rate of biodegradation of dissolved TCE equals the rate at which TCE desorbs from the aquifer solids into the aqueous phase. Thus, based on the assumed parameter values, we see that the decline in total mass after the initial 70 days of bioremediation is controlled by the rate of TCE desorption from aquifer solids. A critical value in the simulations is thus the sorption/desorption rate coefficient, a value which was estimated. Because of its importance, this value needs to be determined experimentally in the laboratory for the Edwards site. The simulation also demonstrates that using preliminary design values, a significant drop in TCE mass may be expected to be seen in the demonstration area over the course of the four month demonstration. Figure 3 shows aqueous and sorbed TCE concentrations between the two treatment wells along one of the streamtubes after 120 days of bioremediation. Note how the aqueous concentration drops rapidly near the injection well, and then slowly rises. The rapid drop results since most of the microbial mass is predicted by the model to reside close to the injection well. This prediction is consistent with the results from the Moffett Field studies. The slow rise in TCE concentrations is due to the relatively clean water moving through the aquifer towards the extraction well. The clean water causes sorbed TCE to desorb, thus leading to the concentration rise in the aqueous phase. Also note that the TCE concentrations after 120 days are well below the initial values of 0.2 mg/L in the dissolved phase and 0.04 mg/kg in the sorbed phase.

CONCLUSIONS

Based on reasonable parameter values and results of prior work at an experimental field site, preliminary modeling studies have been used to show that the planned operation of an in-situ aerobic cometabolic bioremediation system can be expected to result in observable decreases in TCE mass and concentration at the proposed technology demonstration site.

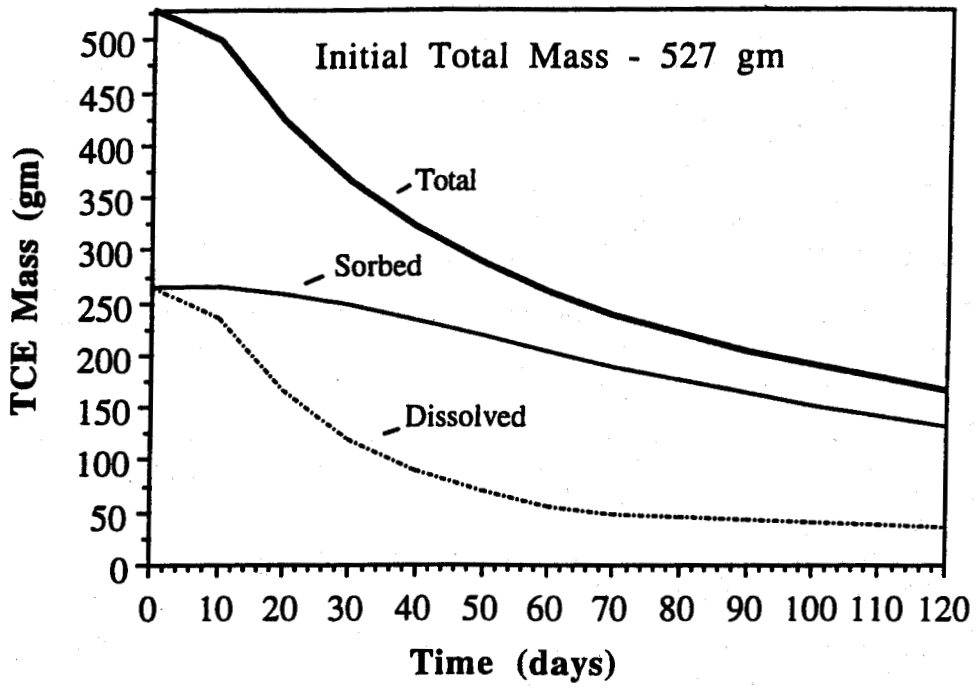

Figure 2. TCE mass vs. time

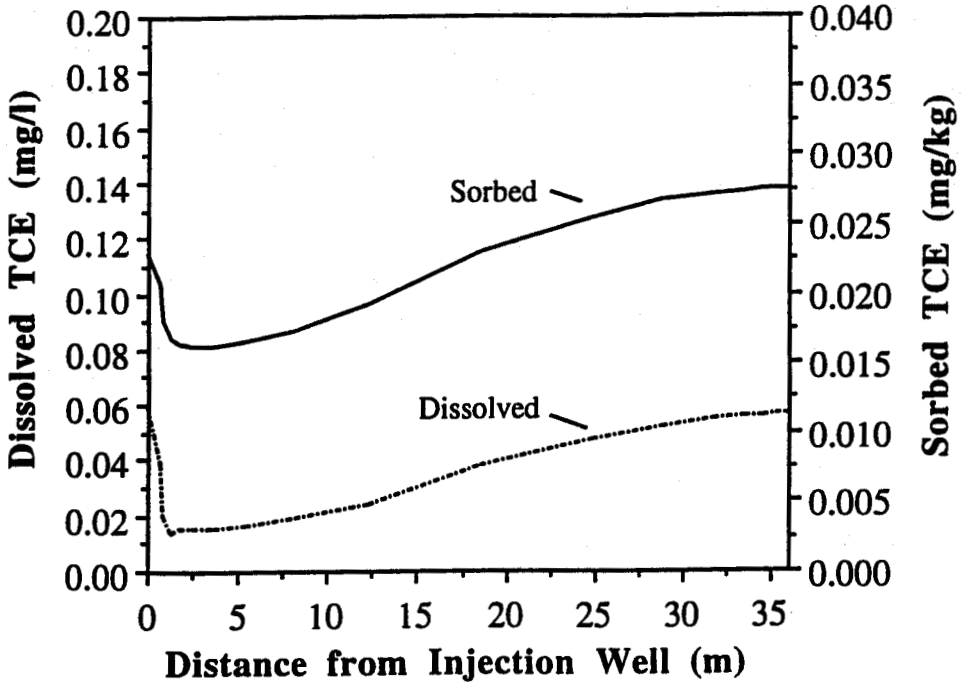

Figure 3. Dissolved and sorbed TCE concentration vs. distance between wells

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A MICROBIOLOGAL SURROGATE FOR EVALUATING TREATMENT EFFICIENCY

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INTRODUCTION

In this study we report on the use of a microbial surrogate system which can be used to evaluate the efficiency of various unit processes used in drinking water treatment for the removal of microbial contaminants. The proposed procedure uses Gram-positive, mesophilic, aerobic spore-forming bacteria as the surrogate organisms. These bacteria do not pose a public health threat and are naturally occurring in most surface water supplies. The aerobic spore-formers are easy to culture and are present throughout the treatment train. This group of organisms consists primarily of species of the genus *Bacillus*. These organisms form endospores which are ellipsoidal to spherical in shape and measure on average approximately 0.5 X 1.0 X 1.5 micrometers, and are environmentally resistant. Like pathogenic *Giardia* cysts and *Cryptosporidium* oocysts endospores of aerobic bacilli may be found far into the treatment train.

MATERIALS & METHODS

Both naturally occurring aerobic spore-forming bacteria and pure cultures of *Bacillus subtilis* spores were used in this study. *B. subtilis* spores were purchased from a commercial laboratory (Raven Biological Laboratories, Omaha, Nebraska 68106). The protocol for the enumeration of the aerobic spores was a modification of a procedure used for the detection of *Bacillus* spores in raw milk (1). The following equipment is used in the protocol:

- Sterile Erlenmeyer flasks with screw-caps or sterile bottles with closures.
- Thermostatically controlled water bath with shaker for constant agitation
- Thermometer
- Sterile pipettes
- 60 x 15 mm Petri dishes with loose lids
- 47 mm, 0.45 μm porosity membranes
- Membrane filtration apparatus
- Incubator, 35°C

The medium used for growing the bacteria consisted of nutrient agar plus the dye trypan blue. The dye was added to aid in the visualization of the colonies.