REMEDIATION ACTION PLAN FOR THE ANAEROBIC BIOREMEDIATION OF CHLORINATED ALIPHATIC HYDROCARBONS USING INVENTURES TECHNOLOGIES INC. gPRO LP TECHNOLOGY

Note:
The blue font in the document represents comments.
The black font in the document is text that can be inserted into the RAP.
The red font identifies information that the remediation designer should insert.

Purpose

The purpose of this document is to allow the remediation specialist to use parts of this document as a template for their specific remediation action plan (RAP) for the anaerobic bioremediation of chlorinated aliphatic hydrocarbons (CAH) using inVentures Technologies Inc. gPRO® LP Technology. Specific site information should be used in conjunction with the material provided herein as the specialist sees fit. This document summarizes aspects of the scope or insertions into the scope of work to be performed at a CAH site to remediate groundwater contaminated with various constituents of concern including but not limited to tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE) and vinyl chloride (VC). This methodology may be adapted to any compound that is subject to reductive dechlorination under anaerobic conditions.

Caution of Use

This document does not provide specific recommendations for the site. It is incumbent upon the plan designer to follow all regulatory requirements; federal, state, and local notifications; all jurisdictional permits and laws. The user assumes all responsibility for any consequences resulting from the use of this information or the use of any product described herein.

Proposed Remedial Action

Overview of Biological Reductive Dechlorination

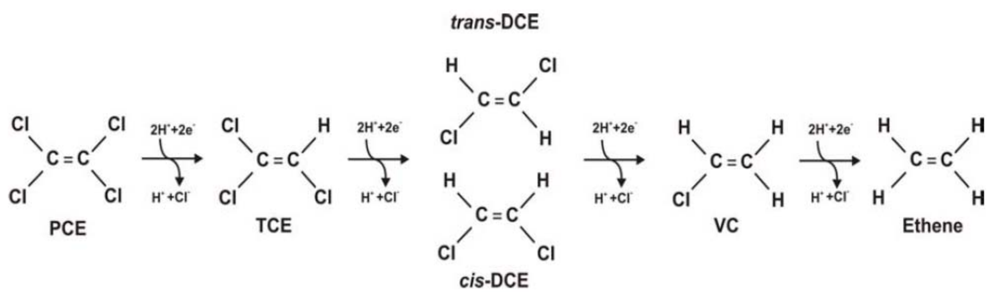
The in situ groundwater bioremediation process relies on microorganisms (soil bacteria) that are stimulated by adding electron donors, changing prevailing redox conditions where necessary, to biologically degrade contaminants in groundwater. Highly oxidized chlorinated aliphatic hydrocarbons such as tetrachloroethene (PCE) and lower CAHs are used as electron acceptors in the anaerobic process of biologically mediated reductive dechlorination. During the anaerobic biological process, hydrogen substitutes for a chlorine ion on the PCE molecule forming TCE, which can be further reduced to DCE, VC and ethene. The effect of electron donor addition depends on electron acceptors present. Competing electron acceptors include dissolved oxygen (DO), nitrate, ferric iron (Fe^{3+}), Manganese (IV) (Mn^{4+}) and sulfate.

The reductive dechlorination of CAHs in groundwater is implemented at a site by the infusion of hydrogen as an electron donor with the gPRO® LP Gas inFusion delivery system. If not already present, anaerobic conditions may be generated by the delivery of hydrogen. A sufficient mass of hydrogen must be delivered to satisfy hydrogen demand, calculated from estimates of competing electron acceptors and CAH mass present in the treatment zone.

Reductive Dechlorination Process

Anaerobic reductive dechlorination of CAHs using hydrogen as an electron donor proceeds by the following generalized reaction:

Where C-Cl represents a carbon-chloride bond in a chlorinated molecule, C-H represents a carbon-hydrogen bond, and C=C represents the carbon-carbon double bond. In these reactions, two electrons are transferred with molecular hydrogen (H_2) as the electron donor (which is oxidized) and the chlorinated molecule (R-C-Cl) as the electron acceptor (which is reduced).



(AFCEE 2004)

Where appropriate this calculation of hydrogen demand includes the mass of electron acceptors in the dissolved and solid phase within the treatment area and the mass flux of electron acceptors into the treatment area with groundwater flow. The required mass of hydrogen can then be compared to rates of hydrogen delivery by the gPRO® LP to determine the appropriate number of treatment units necessary for the projected treatment time frame. The design layout and number of delivery wells must also be developed in consideration of site specific hydrogeologic conditions. On a mass basis, 1.0 gram of molecular hydrogen is sufficient to dechlorinate the following mass of CAHs, assuming 100 percent utilization of molecular hydrogen by the dechlorinating microorganisms:

- 20.6 grams of PCE to ethene
- 21.7 grams of TCE to ethene
- 24.0 grams of DCE to ethene
- 31.0 grams of VC to ethene

One gram of molecular hydrogen is also required to reduce the following mass of competing electron acceptors:

- 7.9 grams of oxygen
- 10.2 grams of nitrate
- 55.9 grams of Iron III (reduced to Fe(II) - aquifer solid demand)
- 27.5 grams of Manganese IV (reduced to Mn(III) - aquifer solid demand)
- 10.6 grams of sulfate

- 5.5 grams of carbon dioxide

A detailed procedure for evaluation of hydrogen demand is included in *Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents*
Prepared by the Air Force Center for Environmental Excellence (AFCEE), 2004
http://www.afcee.brooks.af.mil/products/techtrans/Bioremediation/BIOREMresources.asp

Delivery of dissolved hydrogen with the gPRO® LP System is an effective technology to degrade CAHs in groundwater. Efficient delivery of dissolved hydrogen electron donor to ground water is essential to insure that an abundance of hydrogen is available for the bioremediation process safely and at a reasonable cost. The gPRO® LP System is based on inVentures' patented Gas inFusion technology - a unique method of infusing saturated and supersaturated levels of dissolved gas into liquids. At the heart of gPRO® systems is a proprietary structured polymer mass transfer device that is filled with micro-porous hollow fiber material that provides an enormous surface area for mass transfer. The system efficiently delivers gas to liquid by mass transfer without sparging. Hydrogen gas is supplied from a compressed gas tank or hydrogen generator though a pressure regulator and flow controller.

In an anaerobic bioremediation applications, the gPRO® LP saturates water in a tank with dissolved hydrogen, typically 1.6 to 4.0 PPM depending on the immersion depth of the gPRO® LP unit and water flow rate, and the water is delivered to injection wells. The gPRO® LP may also be installed in the delivery well to achieve higher head pressures and gas solubility. Each atmosphere of pressure allows for a maximum of approximately 1.6 ppm of dissolved hydrogen. The hydrogen rich water disperses around the delivery well into the adjacent groundwater forming a treatment zone and enhanced bioremediation removes target contaminants. Delivery well screens used for injection typically span the full thickness of the contaminated groundwater zone. Placement of delivery wells depends on site-specific conditions and treatment objectives as described further below.

Remedial Action Objectives

(Specify remedial objectives including contaminants of concern, target cleanup concentrations, treatment area(s) and time frame)

Treatment Strategy

(Specify treatment strategy)
The right strategy for a particular site will depend on objectives, site-specific conditions and site constraints. Strategies for applying the technology include:

- Directly recharging extracted groundwater following amendment with hydrogen
- Injecting an alternative water supply amended with hydrogen
- Developing recirculating groundwater treatment cells with a series of extraction and recharge wells
- Establishing in situ recirculation with dual screen wells

The treatment zone and delivery well locations may be targeted on specific areas of the site including:

- Source area treatment with delivery upgradient and within a source area
- Plume cut-off by establishing a dissolved hydrogen biobarrier with delivery wells located along a cross gradient line downgradient of the source of the plume and up gradient of the target point of compliance
- Hot spot treatment with targeted delivery wells
- A combination of all technology approaches

Treatment areas that exhibit higher hydrogen demand may require tighter spacing of injection or delivery wells. The treatment area developed around a gPRO® LP delivery well will depend on hydrogen demand, water recharge rate, and dissolved hydrogen concentration. In addition to hydrogen delivery, additional nutrients, pH control and bioaugmentation with dechlorinating strains of Dehalococcoides species may be required to optimize bioremediation.

Scope of Work for gPRO® LP System Design and Installation

The main components of gPRO® LP system are:

- Water system for hydrogen infusion including and infusion tank or in well system
- gPRO® LP units (number depending on system design, hydrogen demand and water flow)
- Two stage low-flow hydrogen regulator (gauge reading 0-100 PSI)
- Hydrogen flow controller
- Industrial grade hydrogen supply
- Stainless steel tubing and flexible Paflex hose for hydrogen gas
- Well head assemblies and related materials
- An above ground storage area (ventilated shed, trailer or security cage) for gas regulator, flow controller and cylinders
- Required OHSA signage

Items supplied by inVentures Technologies per gPRO® LP include:

gPRO® LP unit
gPRO LP Manual

Design Plans and Specifications

(Identify gPRO® LP design plans and drawings)

Necessary Figures for a gPRO® LP system RAP may include:

- Gas storage facility layout
- Site plan with extraction wells or water source and delivery well layout
- Process Flow Diagram
- Trenching and well head diagrams/details

gPRO® LP System Installation

Site installations will be installed according to specific plans prepared by a qualified professional engineer with diagrams and manufacturers specifications. All system components should be leak tested and monitored for hydrogen gas. gPRO® LP system installation requirements and guidance will be available on gproinfo.com. (Include an installation schedule)

gPRO® LP System Monitoring

Following startup of the hydrogen infusion system, cylinder gas pressure should be monitored to verify expected usage. Cylinders are not always 100% full, and flow may vary slightly. During each site visit the remaining cylinder pressure will be recorded along with gPRO® LP regulator pressure setting and flow controller flow rate. The estimated number of days to cylinder replacement will be calculated based on gas consumption since the last reading.

Remediation Waste Management

gPRO® LP system does not produce any wastes.

Performance Monitoring

Groundwater sampling events will be conducted on a quarterly basis. Each of the quarterly sampling events will consist of collecting groundwater samples from performance monitoring wells for analysis of the constituents of concern and indicator parameters. Sampling will be done in accordance with the approved methodology including (specify requirements). Prior to system implementation, a baseline sampling event will be conducted on a minimum of 2 wells within the plume. A summary of proposed analyses is shown below:

Indicator	**Analysis**
Contaminant	VOCs
Microbial Activity	Polymerase Chain Reaction (PCR) for detecting the presence of the bacterium Dehalococcoides ethenogenes
Field parameters	Dissolved Oxygen (DO) Oxidation-Reduction Potential (ORP) Temperature, pH, conductivity
Dissolved gases	Hydrogen, ethene, ethane, carbon dioxide and methane
Electron acceptors	Total and dissolved iron and manganese, nitrate, sulfate

This data will be used to assess remedial progress at the site for optimization as necessary.

gPRO® LP Bioremediation System Costs

(Insert site specific cost information where required)

The system capital costs include groundwater treatment system components and construction engineering. The suggested component headings for the system design include:

Groundwater Treatment System:

- Well installations
- Hydrogen infusion equipment
- Miscellaneous (baseline sampling event)

Construction Engineering

- Construction Labor & Equipment Rental
- Engineering Oversight
- Utility Clearance & Mobilization
- Construction Drawings & Specifications
- Bid Package Solicitation & Evaluation
- RA Startup Report (Includes As-Builts)
- Permitting & Mobilization
- Professional Surveying
- Oversight

The system O&M costs will consist of

- Analytical costs
- Quarterly Monitoring Reports
- System checks – minimum 2 times first month and then monthly
- Gas usage and tank rental
- Quarterly Sampling Visit

References and Suggested Reading

The following publications are suggested as references and informative reading for the remediation specialist.

Sutherson, Suthan S. Remediation Engineering; Design Concepts. New York: CRC Lewis Publishers, 1997.

Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents Prepared by the Air Force Center for Environmental Excellence (AFCEE), 2004
http://www.afcee.brooks.af.mil/products/techtrans/Bioremediation/BIOREMresources.asp