iSOC® Technology

Remedial Action Plan for Aerobic Cometabolic treatment of Chlorinated Aliphatic Hydrocarbons using iSOC® Technology

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 aerobic cometabolic bioremediation of chlorinated aliphatic hydrocarbons (CAH) using inVentures Technologies Inc. iSOC® 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 impacted site to remediate groundwater contaminated with various constituents of concern including but not limited to trichloroethene (TCE), dichloroethene (DCE) and vinyl chloride (VC). This methodology may be applicable to any compound that is subject to aerobic cometabolic treatment.

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.

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.

Proposed Remedial Action

Overview of Aerobic Cometabolic Treatment

In the aerobic cometabolic bioremediation processes indigenous bacteria or bioaugmented strains are stimulated by adding oxygen and a cometabolic growth substrate to trigger the production of enzymes that can oxidize or degrade the target pollutant via cometabolism. The iSOC® system is used to deliver oxygen as a terminal electron acceptor along with a gaseous growth substrate, typically an alkane gas, in a process known as Co-infusion to stimulate complete in-situ contaminant destruction. The method is most useful for bioremediation of pollutants that are not themselves good aerobic growth substrates for bacteria.

Cometabolic treatment has been found to be particularly effective for the chlorinated solvent trichloroethylene (TCE) and other lower or less oxidized chlorinated aliphatic hydrocarbons (DCE, VC, TCA, DCA, CF, and MC). The process has also been found to be effective for treatment of groundwater contaminated with the gasoline additive MTBE and other persistent organic compounds such as pesticides. At some sites with mixed groundwater contaminants (i.e. petroleum hydrocarbons with chlorinated solvents or MTBE), the necessary substrate for inducing aerobic cometabolism of the target pollutant may already be present and all that is needed is the infusion of oxygen. Various aliphatic and aromatic hydrocarbon compounds have been found to function as cometabolic treatment substrates and significant research and development has focused on the use of alkane gases (i.e. methane and propane) for the purpose.

Delivery of Oxygen and Gaseous Cometabolic Substrates with the iSOC® System for Bioremediation

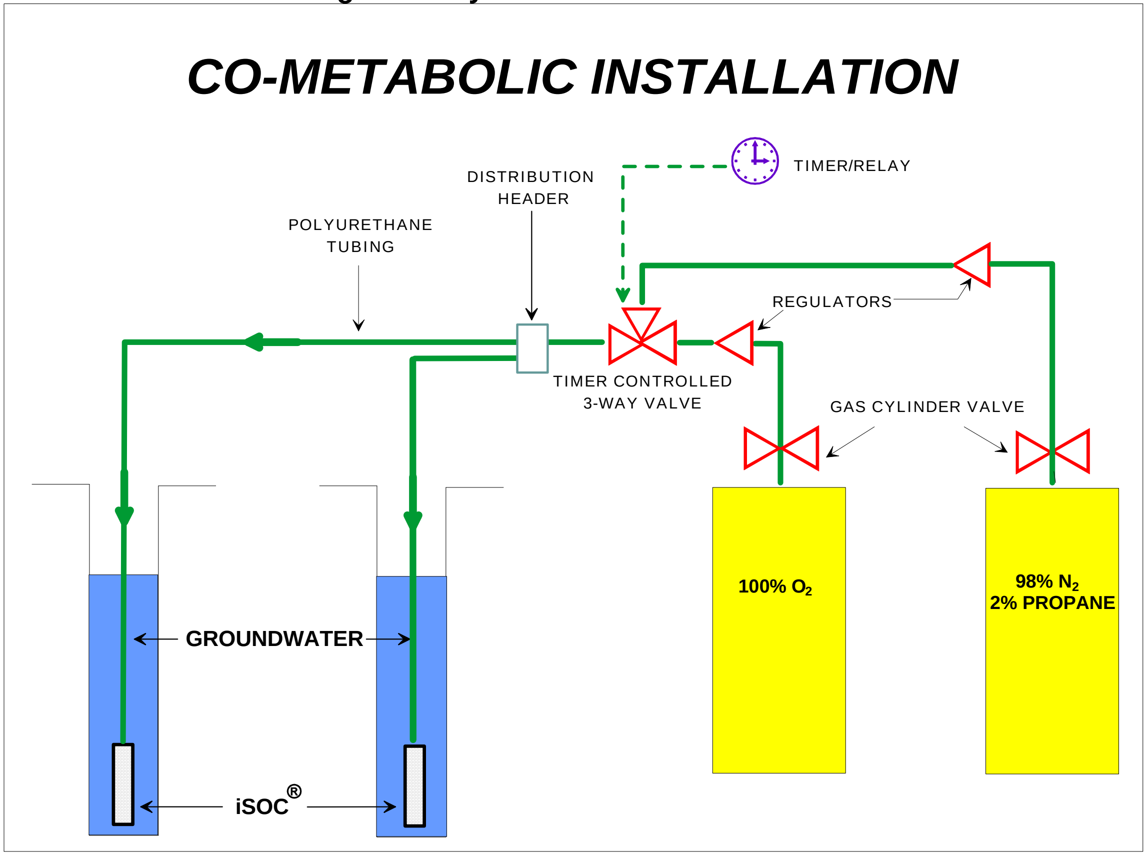
Implementation of the aerobic cometabolic bioremediation processes utilizes the iSOC® gas delivery system based on inVenture's patented Gas inFusion technology - a unique method of infusing supersaturated levels of dissolved gas into liquids. At the heart of iSOC® is a proprietary structured polymer mass transfer device that is filled with micro-porous hollow fiber material and provides a large surface area for mass transfer - in excess of 7000 m2/m3. The fiber is hydrophobic and therefore excludes water. The system efficiently delivers gas to liquid by mass transfer without sparging.

The Co-infusion process involves the configuration of iSOC treatment wells to deliver oxygen and a dilute (2 to 4.5%) non-flammable mixture of alkane gas (i.e. propane) or alkene gas (i.e. ethene) in inert nitrogen gas to the groundwater treatment area. The iSOC units are placed in treatment wells and provide an inherently large surface area that allows for oxygen and alkane gas mass transfer to groundwater without sparging. The treatment area established by Co-inFusion wells can be designed as a grid to treat source areas or as a treatment curtain or fence of treatment wells to cut off plume migration.

In an aerobic cometabolic bioremediation application, the iSOC® saturates the treatment well with dissolved oxygen (DO), typically 40-200 PPM depending on the immersion depth of the iSOC® in groundwater. A natural convection current and a designed release bubble from the top of the iSOC® mixes the water column in the well resulting in a relatively uniform DO concentration. The alkane or alkene gas is delivered to the iSOCs intermittently, either to dedicated cometabolic gas delivery wells or alternately switching gases at the oxygen delivery wells. A curtain of dissolved gas rich water around and downgradient of the treatment well is formed by diffusion, advection and dispersion, forming a treatment zone where enhanced bioremediation removes target contaminants.

The cometabolic gas/nitrogen mixture is added intermittently by manually switching with a gas manifold system or by a mechanical system controlled by a timer as shown in the following schematic.

Co-metabolic Gas Management System with Timer



Using a dilute mixture cometabolic gas supply limits the dissolved concentration of the cometabolic gas to target concentrations. The recommended gas mixtures are also non-flammable and are stored in high pressure cylinders, ideal for gas delivery to iSOC treatment wells. Where necessary the treatment well can be actively vented via an air flow exhaust blower operated on a 12 volt rechargeable battery system which can also serve to operate the solenoid valves on the timer controlled gas management system.

Placement of injection wells depends on site-specific conditions and treatment objectives as described further below. Treatment well screens typically span the full thickness of the contaminated groundwater zone with the iSOC unit placed near the bottom for maximum hydraulic head. The iSOC® system is installed in a few hours to days depending on the number of treatment wells. iSOC® units are easily moved from well to well to optimize performance and remediation strategies.

The iSOC® unit is constructed of high quality SS316 stainless steel and a proprietary structured polymer mass transfer device. iSOC® is 1.62" (41 mm) in diameter and 12.65" (321 mm) long with a barb connector for 0.167" (or 4 mm) ID polyurethane tubing. The housings for the pressure and flow control unit and the drain plug are made from nylon. iSOC® has a lifting ring for connecting to a suspension line for insertion in 2" (50 mm) or larger treatment wells. High flow well screen is recommended for treatment wells. The units are connected to regulated supplies of industrial-grade compressed oxygen and the cometabolic substrate specialty gas.

Experience in the field has shown that in each treatment well where an iSOC® is installed, high levels dissolved oxygen levels of can easily be achieved with concentration depending on the head of the water in the well and groundwater flow velocity. Each atmosphere of pressure allows for an approximately 40 ppm of dissolved oxygen. The solubility of an example alkane cometabolic substrate, 4.5% propane gas mixture, is approximately 2.7 mg/L propane at one atmosphere of pressure. Oxygen and the alkane gas mixture are intermittently infused into the aquifer at a rate of 15 to 20 cubic centimeters/minute.

Treatment Strategy

(Specify treatment strategy)

The right strategy for a particular site will depend on site-specific conditions and site constraints. Strategies for applying the technology include:

- Locating the infusion wells within and immediately upgradient of the source area of the plume to enhance attenuation of contaminants in the source area,
- Creating a biobarrier by locating the infusion wells along a cross-gradient line downgradient of the source of the plume and up gradient of the point of compliance,
- Hotspot treatment by installing treatment wells immediately upgradient and within high concentration areas,
- Creating a protective fence on the upgradient side of a property or sensitive receptor, and
- A combination of the above technology deployments.

Treatment areas that exhibit higher oxygen demand may require tighter spacing of treatment wells. The treatment area developed around an iSOC® treatment well is typically 10 to 15 feet wide and dissolved oxygen may be distributed over a larger area depending on oxygen demand, groundwater velocity and sediment type. The arrangement of biobarrier wells should consider the potential for seasonal variation in groundwater flow. The use of double rows of treatment wells may be appropriate in high oxygen demand environments. Were appropriate, existing monitoring wells may be converted to treatment wells to enhance natural attenuation.

iSOC® gas infusion technology works at both high and low permeability sites. Sites dominated by silts and clays may take considerably more time to see results at downgradient monitoring wells due to the low groundwater flow velocities.

In addition to oxygen and alkane gas delivery, nutrient addition and bioaugmentation with contaminant degrading bacteria may be required to optimize bioremediation.

Remedial Action Objectives

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

Scope of Work for Remedial Design and Installation

iSOC® System Design

An iSOC® system does not require electrical power, does not generate any noise and requires little maintenance. The main components of iSOC® systems are:

- iSOC® units (one unit per treatment well)
- Two stage low-flow gas regulators (gauge reading 0-100 PSI)
- Industrial grade oxygen and specialty alkane/alkene-nitrogen mixtures in cylinders (gas consumption: 1 cu ft/per day/per iSOC®)
- Polyurethane tubing (6mm OD x 4mm ID - SMC part# TU0604 or 0.250" OD x 0.167" ID (SMC part # TIUB07 or equal)
- Conduit for tubing, well head valve boxes and related materials
- Separate above ground storage areas for oxygen and alkane gas storage (sheds, trailer or security cage for regulator & cylinders)
- Gas switching valves for alternate delivery of oxygen and dilute alkane/alkene gas
- Wellhead ventilation system where necessary

Items supplied by inVentures Technologies per iSOC® include:

- iSOC® unit
- iSOC® tool for use when opening drain plug (1 per distribution header)
- Distribution header complete with regulator connector
- Bleed valve and iSOC® valve connections
- Snoop Liquid Leak Detector (1 per distribution header)
- 1 filter
- 1 iSOC® repair kit: 1 iSOC® flow-control valve, 1 stainless steel snap ring, 1 direction sheet

Pictures of each or these items is available at www.isocinfo.com

Design Plans and Specifications

(Identify iSOC® design plans and drawings)

Necessary plans for installation of an iSOC® system may include:

- Treatment wells layout and construction details and/or selection of properly screened existing monitoring wells for treatment
- Trenching diagram from gas storage location to treatment wells
- Well head iSOC® connection diagram

iSOC® System Installation
Site installations will be installed according to site specific plans prepared by a qualified professional and manufacturer's specifications. All system components should be leak tested.

iSOC® system installation requirements and guidance are also available at www.isocinfo.com

(Include an installation schedule)

iSOC® System Monitoring
Following startup of the Co-infusion system, cylinder gas pressures should be monitored to verify expected usage. Each iSOC® unit uses approximately 2 cubic feet of gas per day. Cylinders are not always 100% full, and flow may vary slightly. Pressure settings on the regulator will be set per the manufacturers specifications. (see www.isocinfo.com website)

During each site visit the remaining cylinder pressure will be recorded along with iSOC® regulator pressure settings. The estimated number of days to cylinder replacement will be calculated based on gas consumption since the last reading.

iSOC® water and particulate filters will be inspected at a minimum on a quarterly schedule and drained of accumulated water as necessary.

Remediation Waste Management
The iSOC® system does not produce any wastes.

Performance Monitoring
Groundwater sampling events will be conducted on a quarterly some other scheduled 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, bacteria densities and dissolved propane. Sampling will be done in accordance with the approved methodology including **(specify requirements)**.

Baseline Sampling
Prior to system implementation, a one or more baseline sampling events will be conducted on a minimum of 2 wells within the plume. A summary of proposed analyses is shown below:

Groundwater Analyses

Indicator	**Analyses**
Contaminant	VOCs
Microbial Activity	Heterotrophic bacteria and specific degraders (CFU/mL)
Field parameters	Dissolved Oxygen (DO) Oxidation-Reduction Potential (ORP) Temperature, pH, conductivity
Dissolved gases	Propane, methane, ethene
Redox indicators, oxygen demand and nutrients	Total and dissolved iron and manganese, nitrate, phosphate and sulfate, TOC, DOC, BOD

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

iSOC® 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
  - Infusion Well Installations
  - Gas Infusion Equipment
  - Miscellaneous (Baseline Sampling Event)
- Construction Engineering
  - Construction Labor & Equipment Rental
  - Engineering Oversight
  - Utility Clearance & Mobilization
  - Proposal Preparation
  - Construction Drawings & Specifications
  - Bid Package Solicitation & Evaluation
  - RA Startup Report (Includes As-Builts)
  - Permitting & Mobilization
  - Professional Surveying

The system O&M costs will consist of

Analytical costs
Quarterly Monitoring Reports
System checks – 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.

Daniel J. Arp, Chris M. Yeager and Michael R. Hyman. (2001). Molecular and Cellular Fundamentals of Aerobic Cometabolism of Trichloroethylene. *Biodegradation* **12**: 81 - 103.

EPA 542-R-00-008. July 2000. Engineering Approaches to In Situ Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications (www.cluin.org/download/remed/engappinsitbio.pdf)

McCarty, P.L. and Semprini, L. (1993). Ground-water Treatment of Chlorinated Solvents. In Handbook of Bioremediation, Lewis Publisher Inc., Chelsea, MI, pp. 87–116.

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

Use of Cometabolic Air Sparging to Remediate Chloroethene-contaminated Groundwater Aquifers. ESTCP Cost and Performance Report Environmental Security Technology Certification Program (ESTCP), Arlington, VA. 73 pp, Aug 2001 http://www.estcp.org/documents/techdocs/199810.pdf