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 bioremediation of petroleum hydrocarbons 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 petroleum hydrocarbon impacted site to remediate groundwater contaminated with various constituents of concern including but not limited to gasoline constituents, benzene, toluene, ethylbenzene, total xylenes (BTEX), and typical gasoline oxygenates such as methyl tertiary butyl ether (MTBE) and tertiary butyl alcohol (TBA), acetones, alcohols, etc.

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

Enhanced Bioremediation Overview
The in situ groundwater bioremediation process relies on microorganisms (soil bacteria) that are stimulated through the control of environmental factors to reduce contaminant concentrations in groundwater. These soil bacteria utilize petroleum hydrocarbons as a source of carbon for biomass production and energy. In aerobic processes, terminal electron acceptors such as dissolved oxygen and where necessary other essential nutrients can be delivered to groundwater to enhance natural attenuation of fuel related hydrocarbons, including gasoline constituents benzene, toluene, ethylbenzene and total xylenes (BTEX), methyl tertiary butyl ether (MTBE) and tertiary butyl alcohol (TBA), polycyclic aromatic hydrocarbons (PAH) and a variety of other hydrocarbons. In-situ bioremediation technology has been extensively studied and applied since the mid 1980's.

Delivery of Oxygen with the iSOC® System for Hydrocarbon Bioremediation
Enhanced bioremediation stimulated by the infusion of dissolved oxygen has been proven to be an effective technology to reduce all forms of dissolved hydrocarbons in groundwater. The efficient delivery of dissolved oxygen into ground water is essential to

insure that an abundance of oxygen is available for the bioremediation process at a reasonable cost.

The iSOC® gas delivery system is 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 that provides an enormous surface area for mass transfer - in excess of 7000 m2/m3. It is hydrophobic and therefore excludes water. The system efficiently delivers gas to liquid by mass transfer without sparging.

In an aerobic bioremediation application, the iSOC® supersaturates the treatment well with low decay 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® fills the well with uniform DO. The supersaturated DO curtain of water disperses around the well into the adjacent groundwater forming a treatment zone and enhanced bioremediation removes target contaminants. 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. 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.

iSOC® is constructed of high quality SS316 stainless steel using the latest manufacturing equipment 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 monitoring wells. The unit is connected to a regulated supply of industrial-grade compressed oxygen.

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, depending on the height of the water column in the well. Each atmosphere of pressure allows for a maximum of 40 ppm of dissolved oxygen. Oxygen is continuously infused into the aquifer over a period of several months to up to several years, as needed. During this time, a large and continuous supply of oxygen is infused into the groundwater system to provide significant enhanced degradation of hydrocarbons, including BTEX and MTBE/TBA. Oxygen is infused from the iSOC® into the monitoring well at a typical rate of 15 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 dissolved oxygen biobarrier by locating the infusion wells along a 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, and
- A combination of the above three technology deployments.

Generally source areas exhibit higher oxygen demand and may require tighter spacing of treatment wells. The effective treatment area developed around an iSOC® treatment well is typically 10-15 feet wide, depending on oxygen demand, groundwater flow 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 due to the low groundwater flow velocities. In addition, typically high and organic carbon content of silts and clays may exert a large oxygen demand.

In addition to oxygen mineral nutrients may be required to optimize bioremediation.

Enhanced bioremediation does not work well in the presence of liquid phase hydrocarbons (LPH). LPHs should be removed from the target area before bioremediation commences. However, downgradient biobarrier approaches are effective for containing plumes during source area remediation.

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 oxygen regulator with ¼" NPT female outlet (gauge reading 0-100 PSI)
- Industrial grade oxygen in cylinders (consumption: 1 cu ft/per day/per iSOC®)
- Polyurethane tubing (0.250" OD x 0.167" ID - SMC part # TIUB07) or (6mm OD x 4mm ID - SMC part# TU0604) or equal)
- Conduit for tubing, well head valve boxes and related materials
- An above ground storage area (shed, trailer or security cage for regulator & cylinders) or
- A ground vault storage arrangement (regulator & cylinder storage at wellhead)

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
- 2 black hose clamps used at iSOC® barb connections (1 spare)
- Nylon collar with stainless steel hose clamp used at distribution header barb connection
- 1 iSOC® repair kit: 1 iSOC® flow-control valve, 1 stainless steel snap ring, 2 plastic hose clamps, 1 direction sheet

Pictures of each or these items is available at www.isocinfo.com (include latest link to iSOC® Installation Procedures)

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 vault cylinder storage diagram
- Well head iSOC® connection diagram

iSOC® System Installation

Site installations will be installed according to site specific plans and diagrams and manufacturers specifications.

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

(Include an installation schedule)

iSOC® System Monitoring

Following startup of the oxygen infusion system, groundwater DO concentrations in the infusion wells will be monitored with a high range DO meter to assure target DO levels are reached. DO in treatment wells should reach equilibrium within the first 24 hours. DO monitoring will then be performed after one month of operation and thereafter quarterly along with the groundwater sampling events. The dissolved oxygen concentration increases with immersion depth of the iSOC® infusion unit below the water table. The unit should always sit as close to the bottom of the well as practical.

Head (feet)	1	10	16	25	50
DO Concentration (ppm)	40	53	60	70	100

Each iSOC® unit uses approximately 1 cubic foot of oxygen 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).

If concentrations above are not attained, it may be due to higher than expected groundwater flow or a large oxygen demand. The regulator pressure can be increased to increase dissolved oxygen concentrations. The gas usage will then increase and should be assessed for expected usage and tank change out scheduling.

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

iSOC® water 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
Sampling events will be conducted on a quarterly basis. Each of the quarterly sampling events will consist of collecting groundwater samples for analysis of the constituents of concern and indicator parameters. Sampling will be done in accordance with the approved methodology including (specify requirements).

Baseline Sampling
Prior to system implementation, a baseline sampling event will be conducted on a minimum of 2 wells within the plume. Field tests for geochemical parameters include pH, dissolved oxygen (DO), oxygen-reduction potential (ORP), temperature and conductivity. In addition, total iron and dissolved iron (Fe^{+2}) (reduced) should be measured using Hach colorimetric field kits or laboratory methods. Ferric iron (Fe^{+3}) (oxidized) can be determined by subtracting the ferrous iron result from the total iron. These indirect indicators should be measured every quarter during the quarterly monitoring events.

Enhanced bioremediation baseline samples should also include the contaminants of concern as well as nitrate and sulfate, macronutrients: orthophosphate-phosphate and ammonia as nitrogen. Oxygen demand in the groundwater samples includes five-day biological oxygen demand (BOD_5) and chemical oxygen demand (COD). Total inorganic carbon should also be evaluated. Additional analyses include total organic carbon, total dissolved solids, and alkalinity (speciated). Total heterotrophic plate count and specific hydrocarbon degraders should be quantified. A summary of proposed analyses is shown below:

Direct Indicator	Analyses
Contaminant	TPHg, TPHd, BTEX, MTBE, TBA, etc.

Indirect Indicators	Analyses
Microbial Activity	Total Heterotrophic Plate Count Specific Hydrocarbon Degraders
Macronutrients	Ammonia as nitrogen Ortho-phosphate

Terminal Electron Acceptors	Oxygen, measured as dissolved oxygen (DO) in field Nitrate (lab analysis) Ferrous iron (Fe^{+2}) and Total iron (field kits) Sulfate (lab analysis)
Total Oxygen Demand	Sediment oxygen demand (SOD, lab) Water oxygen demand: Chemical Oxygen Demand (COD, lab) Biological Oxygen Demand (BOD_5, lab)
REDOX, Field Parameters	Dissolved Oxygen (DO) (downhole meter) Oxidation-Reduction Potential (ORP) (downhole meter) Temperature, pH, conductivity (field meter)
Carbon Status	Total organic carbon (TOC, lab) Total inorganic carbon (TIC, lab) Speciated Alkalinity (lab)
Other Analyses	Total dissolved solids (TDS, lab)

This data will be used to assess whether sufficient nutrients exist at the site to provide the necessary conditions for biodegradation and to monitor geochemical conditions. If it is concluded that adequate levels do not exist, then an optimum nutrient mix should be determined and regulatory approval obtained prior to any addition of nutrients.

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 and engineering are listing

- Groundwater Treatment System
  - Infusion Well Installation
  - Oxygen Infusion Equipment
  - High range DO meter
  - 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
  - Oversight

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.

Norris, R.D. 1994. "In-situ Bioremediation of Soils and Groundwater Contaminated with Petroleum Hydrocarbons." in R.D. Norris, R.E. Hinchee, R.A. Brown, P.L. McCarty, L. Semprini, J.T. Wilson, D.H. Kampbell, M. Reinhard, E.J. Bower, R.C. Borden, Handbook of Bioremediation. Boca Raton, FL: CRC Press.

MTBE Treatment Case Studies presented by the USEPA Office of Underground Storage Tanks. www.epa.gov/swerust1/mtbe/mtberem.htm

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

Interstate Technology and Regulatory Council In Situ Bioremediation Documents http://www.itrcweb.org/gd_ISB.asp