

REMEDIATION ACTION PLAN FOR THE AEROBIC BIOREMEDIATION OF HYDROCARBONS USING INVENTURES TECHNOLOGIES INC. gPRO[®] HP 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 aerobic bioremediation of petroleum hydrocarbons using inVentures Technologies Inc. gPRO HP 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 site to remediate groundwater contaminated with various constituents of concern including BTEX, MTBE, TBA, PAHs and other aromatic and aliphatic hydrocarbons. This methodology may be adapted to any compound that is subject to bioremediation under aerobic 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; national, 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

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. To stimulate 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 dissolved oxygen with the gPRO[®] HP System is an effective technology to stimulate degradation of petroleum hydrocarbons in groundwater. Efficient delivery of dissolved oxygen electron acceptor to ground water is essential to insure that an abundance of oxygen is available for the bioremediation process safely and at a reasonable cost. The gPRO[®] HP 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. Oxygen gas is supplied from a compressed gas cylinder or oxygen generator through a pressure regulator. A gas flow control system is built into the gPRO HP unit. Gas fills the hollow fibers of the gPRO module(s) and pressurized water flows past the hollow fibers effecting efficient mass transfer of gas to water. For a gas such as oxygen, 25-150 mg/l of dissolved oxygen can be produced and dissolved gas levels can be adjusted to suit site specific conditions. A distribution header is used to connect amended water lines to ground water recharge wells.

The oxygen rich water disperses around the delivery well into the adjacent groundwater forming a treatment zone where 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 oxygen
- Injecting an alternative water supply amended with oxygen
- Developing recirculating groundwater treatment cells with a series of extraction and recharge 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 oxygen 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 oxygen demand may require tighter spacing of injection or delivery wells. The treatment area developed around a gPRO® HP delivery well will depend on oxygen demand, water recharge rate, and dissolved oxygen concentration. In addition to oxygen delivery, additional nutrients, pH control and bioaugmentation with petroleum degrading bacteria species may be required to optimize bioremediation. Control of dissolved iron in extracted groundwater may be necessary to prevent system and recharge well fouling.

Scope of Work for gPRO® HP System Design and Installation

The main components of the gPRO® HP system include:

- Water system for oxygen infusion including extraction wells and a source water header tank or direct pump feed system
- gPRO® HP units (number of required modules depending on system design, oxygen demand and water flow)
- Two stage low-flow oxygen regulator (gauge reading 0-100 PSI)
- Industrial grade oxygen supply
- 1/2" clear braided PVC hose rated for 200 psi for oxygen supply line with fittings
- Injection wells with well head assemblies and related materials
- An above ground storage area (ventilated shed, trailer or security cage) for gPRO® HP units gas regulator and cylinders
- Power supply
- Required safety signage

Items supplied by inVentures Technologies per gPRO HP include:

gPRO® HP unit
gPRO® HP Manual
Oxygen generator (specific systems)

Design Plans and Specifications

(Identify gPRO HP design plans and drawings)

Necessary Figures for a gPRO HP system RAP may include:

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

gPRO® HP 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. gPRO® HP system installation requirements and guidance will be available on www.gproinfo.com.

(Include an installation schedule)

gPRO® HP System Monitoring

Following startup of the oxygen 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® HP 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. Where gas generators are used generator system monitoring procedures will be followed.

Remediation Waste Management

The gPRO[®] HP 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 (BOD₅) 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.

gPRO[®] HP 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
- Oxygen 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 weekly first month and then monthly
- Gas usage and tank rental or gas generator
- 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. Hincbee, 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