Injection of Oxygen in Deep Horizontal Wells for the Biostimulation of PAH Degradation at a Former Wood Treating Superfund Site

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Oxygen Injection Systems

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ESCAMBIA WOOD TREATING SITE

Background

- Former wood treating facility in Pensacola, FL that operated from 1942 to 1982
- Primary products were pressure treated utility poles.
- Primary contaminants are coal tar creosote compounds, PCP and dioxin
- Site is 26-acres, with over 60 acres of adjacent neighborhoods acquired.

Active Wood Treating Plant circa 1975
Escambia Treating Co.
Site

Level Surface

60 - 70 feet below level surface

90 - 100 feet below level surface

180 - 190 feet below level surface

LEGEND

NAPHTHALENE
> 7,000 parts per billion (ppb)

NAPHTHALENE
140-7,000 parts per billion (ppb)

NAPHTHALENE
< 140 parts per billion (ppb)
ESCAMBIA WOOD TREATING SITE – JAN 2009

Relocation of Mount Dioxin and Source Area Locations
Notes: Geology was taken from sonic boring logs, and is therefore conceptualized between borings; core was restricted to the screened zones at HW2-PMW and HW3-PMW.
RDCPT07 was a advanced with a CPT probe coupled with tar-related green optical scanning tool (TarGOST).
Solid Waste Management Unit (SWMU)10 has been enlarged to the west and excavated to the water table.

SZ = Surficial Zone
LPZ = Low Permeability Zone
MPZ = Main Producing Zone
NAPL = Non-Aqueous Phase Liquid

J = estimated
VFG = very fine-grained
ug/L = micrograms per liter
SVOC = semi-volatile organic compounds
Source Zone DNAPL

Adjacent confirmatory sonic bore; cores and plastic sleeves stained dark brown to black; strong naphthalene odor.

DNAFL at 70 ft bgs

Adjacent test well screened 70 to 75 ft bgs with free flowing creosote DNAPL.
Biosparge Pilot Test Setup
BIOSPARGE PILOT TEST GOALS

1. Demonstrate viability of directional drilling under railroad yard
2. Compare the effectiveness of different well materials
3. Evaluate the ability to disperse oxygen effectively through a horizontal well
4. Determine design basis for flows and pressures
5. Measure and assess dissolved oxygen dispersion outward and upward from the horizontal wells
6. Identify changes in microbial activity due to oxygenation of the plume
NAPHTHALENE PLUME

Source Zone

Dissolved Plume in the Low Permeability Zone

Wood Treating Site

HDD Well

Scale in Feet

0 500
LAYOUT OF IN SITU BIOSPARGE PILOT TEST
Performance Monitoring Wells

HW-3 Performance Monitoring Array

Railroad Switching Yard

Directional Drilled Well

HW-3A (91 ft bgs)
HW-3B (71 ft bgs)
HW-3C (55 ft bgs)
In Situ Biospargage Pilot Study Components

**Bundle of 3 Injection Wells**

**Air Conversion to >90% Pure O₂**

**Horizontal Directional Rig drilling the 1,450 ft long bore to 100 ft bgs, and installing the bundle of three (3) injection well screens.**

**O₂ Injection Trailer**

**Railroad Switching Yard with 20 Parallel Tracks**

**Three bundled well screens @ 170’ per screen = 510’ of total screen length**
Pilot Scale Biosparge Wall Design

- Determine Flux Rate of SVOCs
- Determine $O_2$ Injection Requirement
- Select Screen Length and Diameter
- Plume Geometry
- Select Slot Spacing
  - Open Area Calculation
- Select Slot Size
  - Grain Sieve Analysis
- Select $O_2$ Injection Flow Rate
- Select Well Materials
  - Minimize Siltation
  - Non-Corrosive
  - Flexible
- Prepare Bore Plan and Assembly Plan

- Determine Friction Losses
  - Consider Siltation/Blockage
BioSparge Well Construction

Screen Construction
ADS piping is air cut microslits on 1-foot centers that delivers 0.2 scfm per foot of pipe (opens at 5 psig).

- HDPE Riser
- 12-inch Borehole
- 8-inch Casing (Withdrawn)
- SS Riser
- 2-Inch Stainless Steel Screen Slot
- 2-Inch ADS HDPE DR-11 Air Diffusion Pipe
- 2-Inch Stainless Steel Screen Slot
- 8-inch DIA steel carrier casing
- Two 1 ⅞-inch DIA HDPE tremie pipes
- 2-inch DIA HDPE
- 2-inch DIA HDPE casing and stainless screen
- 2-inch Stainless steel
Oxygen Injection Trailer

• The Matrix Oxygen Injection System produces **O2 gas on-site for pulse injection** into groundwater contaminant plumes at controlled rates or volumes.
• DO saturation levels up to **40 mg/L**.
• Dispersion of oxygen with control of radius of influence and oxygen mass transfer
• Used at over 250 remediation sites over 14 years.
• U.L. certified PLC control system with touch screen display and remote access
• Pressure swing adsorption oxygen generator and rotary screw compressor
• License to operate under U.S. Patent No. 5,874,001.
Oxygen Injection Flow Schematic

Ambient Air

Rotary Screw Air Compressor and Refrigerated Dryer

Pressure Swing Adsorption Oxygen Generator

Compressed Air, Clean & Dry

~90% Oxygen Pulsed Into Groundwater

Nitrogen Gas (Purged)

Oxygen Storage Tanks for Pulse Injection

Oxygen Gas

Oxygen Delivery Manifold
Naphthalene Aerobic Degradation Pathway

Source: Dr. Larry Wackett, University of Minnesota, 2009 based upon the work of Eaton et al., 1992
Results
LAYOUT OF IN SITU BIOSPARGE PILOT TEST

- NAPL Source Area
- Former Wood Treating Site
- Railroad Switching Yard
- Horizontal Injection Well with Three Screen Intervals
- Two Sets of Three Monitoring Wells at Different Depths to Gauge Pilot Test Performance
- GW Flow

Scale in Feet: 0 - 250
Phase 1 and 2 Pilot Scale Oxygen Feed Rates

- **O₂ Injection Rate (lbs./day)**

Phase I
- 07/24/09 - 08/06/09
- 08/06/09 to 08/22/09
- 08/22/09 to 06/17/10
- 06/17/10 to 07/21/10
- 07/21/10 to 09/14/10

Phase II

- **Goal**

• *In situ* DO target = 10 mg/L (minimum goal of 5 mg/L)
Phase 1 and 2 Pilot Scale Flow Results

• 0.03 to 0.1 scfm/foot of screen
• Pressures ranged from 30 to 53 psig
Performance Monitoring

What Results are Indicators of Increased Oxygen Influence?

• Increases in DO and ORP
• Changes in metal chemistry/mobility due to:
  ➢ Changes in oxidation states (e.g., Fe$^{+2} \rightarrow$ Fe$^{+3}$)
  ➢ Decreases in natural organic matter (and potential increased metal mobility)
• Decreases in TOC or COD

What Results are Indicators of Biological Degradation?

• Increases in naphthalene degrading bacteria
• Increased CO₂ from aerobic respiration
• Decreased concentrations of naphthalene
Verification of Dissolved Oxygen Front

Used stable luminescent optical dissolved oxygen probes

- Continuous downwell monitoring with Trolls for 30-days in the 6 performance monitoring wells for DO, ORP, pH, conductivity, and temperature.

- DO Measurement a critical parameter

- Oxygen is not consumed as part of an electrochemical reaction, and optical sensors do not require sample flow or stirring for accurate readings

- Accuracy from:
  - 0 to 20 mg/L (±0.1 to 0.2 mg/L)
  - 20 to 50 mg/L (±10%)

Oxygen Solubility
Performance Monitoring Wells

HW-3 Performance Monitoring Array

- HW-3A (91 ft bgs)
- HW-3B (71 ft bgs)
- HW-3C (55 ft bgs)

Railroad Switching Yard
Directional Drilled Well

Scale in Feet

Note: The diagram depicts a performance monitoring array with directional drilled wells labeled HW-3A, HW-3B, and HW-3C, each with specific locations in feet below ground surface (bgs). The surrounding area includes a railroad switching yard. The scale is marked in feet.
Phase 1 and 2 Pilot Scale DO Results – HW3

Phase 1 Monitoring
- Phase 1 = 30 days injection

Phase 2 Monitoring
- Phase 2 = 89 days injection

DISSOLVED OXYGEN AT HW3

- DO Goal

• Phase 1 = 30 days injection
• Phase 2 = 89 days injection
Phase 1 and 2 Pilot Scale DO Results – HW2

- Phase 1 = 30 days injection
- Phase 2 = 89 days injection
Phase 1 and 2 Pilot Scale ORP Results

- Phase 1 = 30 days injection
- Phase 2 = 89 days injection
Naphthalene Aerobic Degradation Pathway

Source: Dr. Larry Wackett, University of Minnesota, 2009 based upon the work of Eaton et al., 1992
Sampling for *In Situ* Microbial Population

**Bio-Flo Samplers**
- Field sample collection
- Used to record baseline & post-pilot test populations of degraders
- 1 to 2 Liters
- Microbes live on solid surface

**Bio-Trap® Samplers**
- Contains beads of activated carbon with high surface area for microbial growth
- ~30-day incubation
- Unique sampling matrix, bio-sep beads, which mimics environmental conditions
- Can be analyzed using a variety of molecular based approaches (DNA, RNA and PLFA)
Microcosm study consisted of Bio-Trap cylinders installed in 3 wells for one month (07/25/09 to 08/25/09)

Baseline results from Bio-Flo Sampler

NAH = Naphthalene Dioxygenase
NAH Indicator Gene Populations by qPCR

Bio-Flo Sampling
NAH = Naphthalene Dioxygenase

Phase 1 O₂ Injection
Phase 2 O₂ Injection

05/27/09 07/26/09 09/24/09 11/23/09 01/22/10 03/23/10 05/22/10 07/21/10 09/19/10

NAH (cells/ml)

HW2-71 NAH
HW3-71-NAH
HW2-91 NAH
HW3-91 NAH
Phase 1 Pilot Scale Respirometry Data

- Wellhead CO$_2$ Analysis
- 500 ppmv is background value in air
Conclusions and Lessons Learned

• Directional drilling of 1450-ft long and 100-foot deep cluster biosparge well was quite successful.
• ADS Sparge pipe proved effective.
• Additional performance monitoring wells would greatly enhance determination of the lateral influence of dissolved oxygen and naphthalene-consuming bacteria.
• Vertical biosparging wells would serve to compare the HDD effectiveness and cost for full-scale operation.
• The optical DO downwell probes on the trolls maintained calibration through 90 days of operation.
• Good convergence of data for pilot test success:
  ✓ Analytical results  ✓ Bacterial microcosm results
  ✓ Field DO and ORP data  ✓ Respirometry
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