1. Source of Submission (Name, Organization)

Bethany McAvoy, VeruTEK Technologies Inc

2. Identity of Reagent (Chemical Name, common name, trade name)

VeruSOL-3 Components	
CAS# 61791-12-6	Ethoxylated Castor Oil
CAS# 61791-08-0	Ethoxylated Cocamide
CAS# 61791-29-5	Ethoxylated Fatty Acid
CAS# 94266-47-4	D-limonene

3. MSDS and Technical Data Sheet for all substances in product (those with >5% are considered critical)

4. Number of Field-scale Applications to Date

53

5. Case Studies

Case studies attached

6. Brief Rationale for Inclusion in New WDR (should include duration on market, impact on groundwater quality, effectiveness, human health & safety)

Since entering the market in 2006 VeruSOL has proven to be a safe and effective product for treating source contamination when used as part of the patented Surfactant enhanced In Situ Chemical Oxidation (S-ISCO) and Surfactant Enhanced Product Recovery (SEPR) processes. The product has been implemented in over 50 sites, including four Superfund Sites, and the product effectiveness is well documented (see attached case studies).

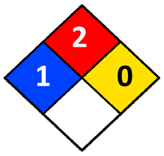
VeruSOL has been evaluated for biodegradability and toxicity. The OECD 301D biodegradability test which is the test officially recognized by the EPA, concluded VeruSOL is readily biodegradable, biodegrading 90% in 13 days (see report attached).

The product is safe for human health; the chemical components are classified as Generally Recognized as Safe by the US FDA.

MATERIAL SAFETY DATA SHEET
VeruSOL®-4

Date Issued: October 21, 2013
Revision No: 1

Section 1: PRODUCT AND COMPANY IDENTIFICATION



Manufacturer: VeruTEK® Technologies, Inc.
Address: 65 West Dudley Town Road, Suite 100, Bloomfield, CT 06002
Phone Number: (860) 242-9800

24 Hour EMERGENCY CONTACT: **ChemTel:** 1-800-255-3924

Product Name: VeruSOL-4®
Issue Date: October 21, 2013

Section 2: HAZARDS IDENTIFICATION

Emergency Overview

Appearance/Odor: Yellow to amber, slightly viscous with citrus odor.

Product is combustible.

Stability: Product is stable under normal conditions.

Slippery when spilled.

Potential Health Effects: See Section 11 for more information.

Likely Routes of Exposure: Eye contact, skin contact, inhalation.

Eye:	Causes moderate to severe irritation.
Skin:	May cause slight redness. Prolonged or repeated exposure may cause drying of the skin.
Inhalation:	May cause nose, throat, and respiratory tract irritation, coughing, headache.
Ingestion:	Not likely to be toxic, but may cause vomiting, headache, or other medical problems.

Medical Conditions Aggravated By Exposure: May irritate the skin of people with pre-existing skin conditions.

This product does not contain any carcinogens or potential carcinogens as listed by OSHA, IARC, or NTP.

OSHA Regulator Status
This material is combustible, which is defined as having a flash point between 100°F (37.8°C) and 200°F (93.3°C)

Section 3: COMPOSITION/INFORMATION ON INGREDIENTS

	Percent by wt.	CAS
d-limonene	5-40	94266-47-4
Ethoxylated Castor Oil	5-40	61791-12-6
Ethoxylated Coco Fatty Acid	5-40	61791-29-5
Ethoxylated Cocamide	5-40	61791-08-0

Section 4: FIRST AID MEASURES

Eye Contact:
Flush with water for at least 15 minutes. If irritation persists, seek medical attention.

Skin Contact:
Wash affected area with copious amounts of soap and water for at least 15 minutes. Remove contaminated clothing. If irritation develops, seek medical attention.

Inhalation:
Move to fresh air immediately. If breathing is difficult or discomfort persists, seek medical attention.

Ingestion:
Rinse mouth with water. Dilute by drinking 1 or 2 glasses of water. Do not induce vomiting. Seek medical attention immediately. Do not administer anything by mouth to an unconscious person.

Notes to Medical Doctor:
Direct contact may be minimally irritating. Treatment is by dilution and is symptomatic and supportive.

Section 5: FIRE FIGHTING MEASURES

Flash Point (Method): N/A **Explosion Limits**: Upper: N/A Lower: N/A

Suitable Extinguishing Media:
Carbon dioxide, foam, or dry chemical. Caution: Carbon dioxide will displace air in confined spaces and may create an oxygen deficient atmosphere.

Protection of Firefighters:
Vapors may be irritating to eyes, skin and respiratory tract. Firefighters should wear self-contained breathing apparatus (SCBA) and full fire-fighting turnout gear.

Section 6: ACCIDENTAL RELEASE MEASURES

Personal Precautions: Use personal protection recommended in Section 8. Product is slippery when spilled. Isolate the hazard area. Deny entry to unnecessary and unprotected personnel.

Environmental Precautions: Keep out of drains, sewers, ditches, and waterways.

Methods for Containment: Dike spill area and cap leaking containers as necessary to prevent further spreading of spilled material. Absorb spilled liquid with suitable material.

Methods for Clean Up: Eliminate all ignition sources. Use equipment rated for use around combustible materials. Oil-soaked rags may spontaneously combust; place in appropriate disposal container.

Other Information: There are no special reporting requirements for spills of this material.

Section 7: HANDLING AND STORAGE

Handling
Keep away from heat, sparks, and flame. Open container slowly to release pressure caused by temperature variations. Do not allow this material to come in contact with eyes. Avoid prolonged contact with skin. Use in well-ventilated areas. Do not breathe vapors.As with any chemical, employees should thoroughly wash hands with soap and water after handling this material

Storage

Product may be packaged in phenolic-lined, steel containers or fluorinated plastic containers. Store in well-ventilated area. Storage temperature should not exceed flashpoint for extended periods of time. Keep container closed when not in use. Air should be excluded from partially-filled containers by displacing with nitrogen or carbon dioxide. Do not cut, drill, grind, or weld on or near this container; residual vapors may ignite.

Section 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

Exposure Guidelines

Citrus Terpenes	8h TWA=30ppm (AIHA Standard)
Nonionic Surfactant	N/E (N/E - Not Established)

Nonionic Surfactant	N/E
Nonionic Surfactant	N/E

Engineering Controls:
Provide ventilation to minimize the release of vapors and mist into the work environment. Spills should be minimized or confined to prevent release from work area. Remove contaminated clothing immediately and wash before reuse. Keep away from sparks and flames.

Eye/Face Protection:
Wear chemical splash-type safety glasses or goggles. Use full face mask if severe splashing is expected during use.

Skin Protection:
Liquid proof neoprene gloves are recommended. Nitrile gloves are adequate. Wear boots, apron, or bodysuits as necessary.

Respiratory Protection:
Not normally required. If adequate ventilation is unavailable, use NIOSH approved air-purifying respirator with organic vapor cartridge or canister.

General Hygiene Considerations:
As with any chemical, wash hands thoroughly after handling. Have eyewash facilities immediately available.

Section 9: PHYSICAL AND CHEMICAL PROPERTIES

Color: Yellow to amber
Physical State: Liquid
Specific Gravity: 0.972 to 0.984 @ 77ºF (25ºC)
Flash Point: 130℉ (54.4℃)
Odor: Citrus odor.
Boiling Point: 212ºF (100ºC)
Vapor Pressure: <2mmHg @ 68℉ (20℃)
Solubility in Water: Soluble.
Volatile Organic Compound (VOC) Content: <10 to 40% by volume.

Note: These specifications represent a typical sample of this product, but actual values may vary. Certificates of Analysis and Specification Sheets are available upon request.

Section 10: STABILITY AND REACTIVITY

Stability: Stable.

Conditions to Avoid: Keep away from heat, sparks, flames, and contamination.

Incompatible Materials: Strong oxidizing agents and strong acids, including acidic clays, peroxides, halogens, vinyl chloride, and iodine pentafluoride.

Hazardous Decomposition Products: Oxides of citrus terpenes, which can result from improper storage and handling, are known to cause skin sensitization.

Possibility of Hazardous Reactions: BHT, an antioxidant, has been added to prevent oxidation. Avoid long-term exposure to air. If storing partially-filled container, fill headspace with an inert gas such as nitrogen or carbon dioxide

Section 11: TOXICOLOGICAL INFORMATION

Acute Effects
Citrus terpenes have been shown to have low oral toxicity (LD50>5 g/kg) and low dermal toxicity (LD50> 5g/kg) when tested on rabbits. Citrus terpenes also showed low toxicity by inhalation (RD50>1 g/kg) when tested on mice. Product may be a skin and eye irritant. Inhalation may cause irritation of the nose, throat, and respiratory tract.

Chronic Effects
This product is not classified as a carcinogen by OSHA, IARC, or NTP. This product has not been shown to produce genetic changes when tested on bacterial or animal cells. This product does not contain known reproductive or developmental toxins. Prolonged or repeated exposure can cause drying or dermatitis of skin. Improper storage and handling may lead to the formation of a possible skin sensitizer.

Section 12: ECOLOGICAL INFORMATION

Ecotoxicity: N/A

Persistence/Degradability: Product is expected to be readily biodegradable.

Bioaccumulation/Accumulation: No appreciable bioconcentration is expected in the environment.

Mobility in Environment: Citrus terpenes volatilize rapidly.

Section 13: DISPOSAL CONSIDERATIONS

Disposal:
Incinerate or dispose of in accordance with Local, State, and Federal Regulations. Taking regulations into consideration, waste may be incinerated or handled through EPA Spill Control Plan via landfill or dilution. Empty containers must be triple-rinsed prior to disposal. Oil soaked rags should bedisposed of properly to prevent spontaneous combustion.

Section 14: TRANSPORT INFORMATION

US DOT Shipping Classification
Proper Shipping Name: Terpene Hydrocarbons, N.O.S.
Hazard Class: 3
Identification No.: UN2319
Packing Group: III
Label/Placard: Exception §173.150(f) applies.

TDG Status: Hazardous
IMO Status: Hazardous
IATA Status: Hazardous

The listed transportation classification does not address regulatory variations due to changes in package size, mode of shipment, or other regulatory descriptions.

Section 15: REGULATORY INFORMATION

Global Inventories
The components of this product are included in the following inventories:
USA (TSCA)
Canada (DSL)
Australia (AICS)
Korea (KECL)
Philippines (PICCS)

Proposition 65: California Safe Drinking Water and Toxic Enforcement Act of 1986
This product is not known to contain any chemicals currently listed as carcinogens or reproductive toxins under California Proposition 65 at levels which would be subject to the proposition.

Section 16: OTHER INFORMATION

NFPA 704: National Fire Protection Association
Health – 1 Fire – 2 Reactivity – 0

Legend
OSHA – United States Occupational Health and Safety Administration
IARC – International Agency for Research on Cancer
NTP – National Toxicology Program
NIOSH – National Institute for Occupational Safety and Health
EPA – United States Environmental Protection Agency

Caution: The user should conduct his/her own experiments and establish proper procedures and control before attempting use on critical parts.

VeruTEK Technologies, Inc.
65 West Dudley Town Rd
Ste. 100
Bloomfield, CT 06002

April 13, 2011
Project # IA-7706
Ref # SUC0711-2

Attn: Margaret Napier

Ready Biodegradability Test

A sample was received for testing the biodegradability according to Method OECD 301 D. Essentially, the test involves determining the Chemical Oxygen Demand (COD) and then tracking the progress of a Biochemical Oxygen Demand (BOD) test series to determine when, and if, it reaches two goals. The goals are 10% of the COD and 60% of the COD; in order for the material to be regarded as biodegradable, it must reach 60% within 10 days of reaching 10%. The following data are presented:

Sample:	**VeruSOL 3**
Method:	OECD 301 D
Chemical Oxygen Demand	2,552,000 µg/g
BOD 255,200 (10%)	1 day, 10 hrs
BOD 1,531,200 (60 %)	7 days, 15 hrs
Conclusion:	Passes Test
Last reported BOD reading	13 days (90 %)

The VeruSOL 3 is biodegradable according to Method OECD 301 D.

Joseph Pickar
Analytical Chemist

Josh Rhein
IA Assistant Manager

SF Analytical Laboratories • 2345 South 170th Street • New Berlin, WI 53151
Phone: (262) 754-5300 • Toll Free: (800) 300-6700 • Fax: (262) 754-5310 • sflabs.com

Wisconsin Dept. of Trade and Consumer Protection Certified #168 • FDA Registered Laboratory #2134640
USDA Soil Permit #S-76521 • Dept. of Natural Resources State Certified Laboratory #241249360

SF
ANALYTICAL LABORATORIES

VeruTEK Technologies, Inc.
65 West Dudley Town Rd
Ste. 100
Bloomfield, CT 06002

April 13, 2011
Project # IA-7706
Ref # SUC0711-2

Attn: Margaret Napier

Ready Biodegradability Test

Scope of Report: This report covers the Biodegradability test run on your product identified as VeruSOL 3.

Specific Nature of Product Tested: It is our understanding that VeruSOL 3 is a proprietary product.

Definitions:

COD (Chemical Oxygen Demand) is the amount of Oxygen equivalent used in digesting a portion of the test product with Sulfuric/Chromic Acid. This represents a complete oxidation of the test product by chemical process.

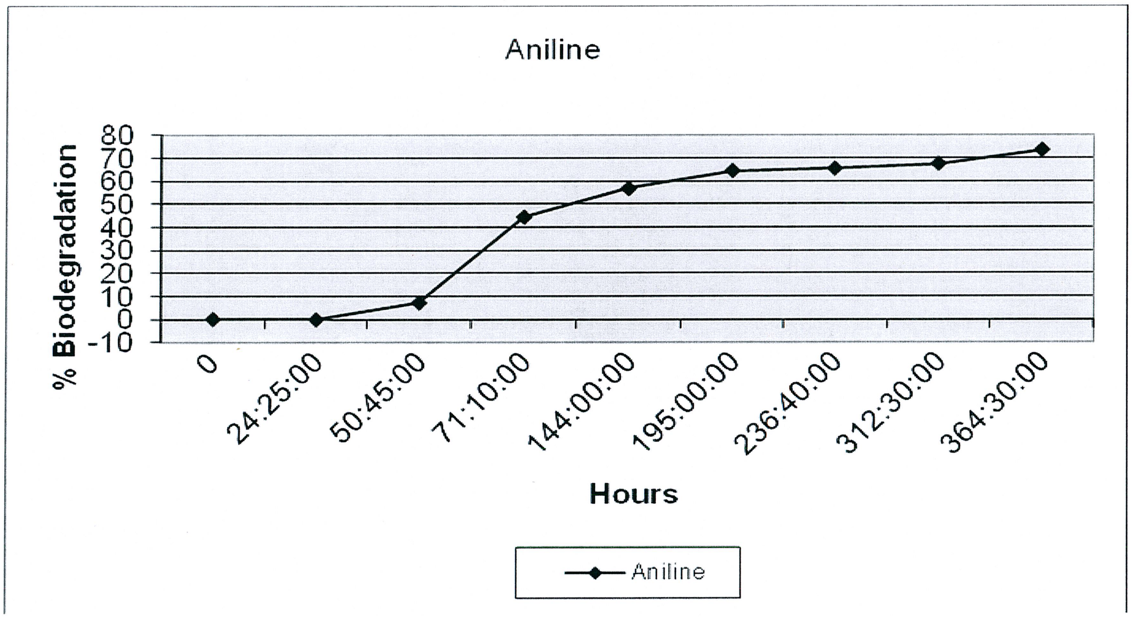
BOD (Biochemical Oxygen Demand) is the amount of Oxygen used by an inoculated bacterial population in degrading as much of the product as can be oxidized by a biological process.

Test Method: The determination of whether a product is or is not biodegradable is based on the criterion of Method OECD 301 D. This Method involves determination of the degradation of the product being tested by the depletion of Oxygen rather than by evolution of Carbon Dioxide as is the determinant in some other methods. Essentially, this is a BOD determination. Six dilutions are set up and read repeatedly at one or two day intervals. The significant data are the time at which the degradation (as revealed by the BOD) reaches 10% of the COD and the time at which the BOD reaches 60% of the COD. The essential criterion is that the time span between these events shall not exceed 10 days. The test in its entirety is not to exceed 28 days.

Praxis: The concentrations of test product in the six bottles are such that each is one-half the concentration of the previous bottle. The concentrations in the six bottles are selected so that the final bottles are expected to give readable results as the criterion is approached. Because there frequently is a "toxicity effect," or retardation of the degradation in the less dilute bottles, the BOD at any time that readings are taken is taken to be the average of the results calculated for the two most dilute bottles. BOD standards are run for each day of read-outs.

Addenda: Copies of Data Sheets, Degradation Curve and Seed Control Data Sheets are attached.

Reference: The reference used to monitor the authenticity of the procedure is Aniline. Aniline meets the criteria for ready biodegradability and is run in parallel with samples for the duration of the testing period. Aniline, like all samples, must reach 10% of the COD and 60% of the COD; for a material to be regarded as biodegradable, it must reach 60% within 10 days of reaching 10%. The degradation Curve is shown below.



Inoculum: The inoculum (seed) used for all biodegradability testing is Polyseed. Polyseed capsules containing 100 mg of specialized bacterial cultures for use in a broad range of areas involving degradation of industrial and municipal waste. The capsules are manufactured by InterLab, P.O. Box 130549, The Woodlands, TX 77393. To prepare the inoculum, one capsule is added to the test medium and mixed thoroughly. Two milliliters of seed are added to each bottle for sample testing and references.

Oxygen Measurement: All measurements of dissolved oxygen are done with a YSI 5000 Dissolved Oxygen Meter with a YSI 5010 BOD probe. The meter is calibrated daily against a Winkler titration.

Incubation: All sample and reference dilution bottles are incubated at 20°C +/- 1°C.

Data Summary:

Sample:	**VeruSOL 3**
Method:	OECD 301 D
Chemical Oxygen Demand	2,552,000 µg/g
BOD 255,200 (10%)	1 day, 10 hrs
BOD 1,531,200 (60 %)	7 days, 15 hrs
Conclusion:	Passes Test
Last reported BOD reading	13 days (90 %)

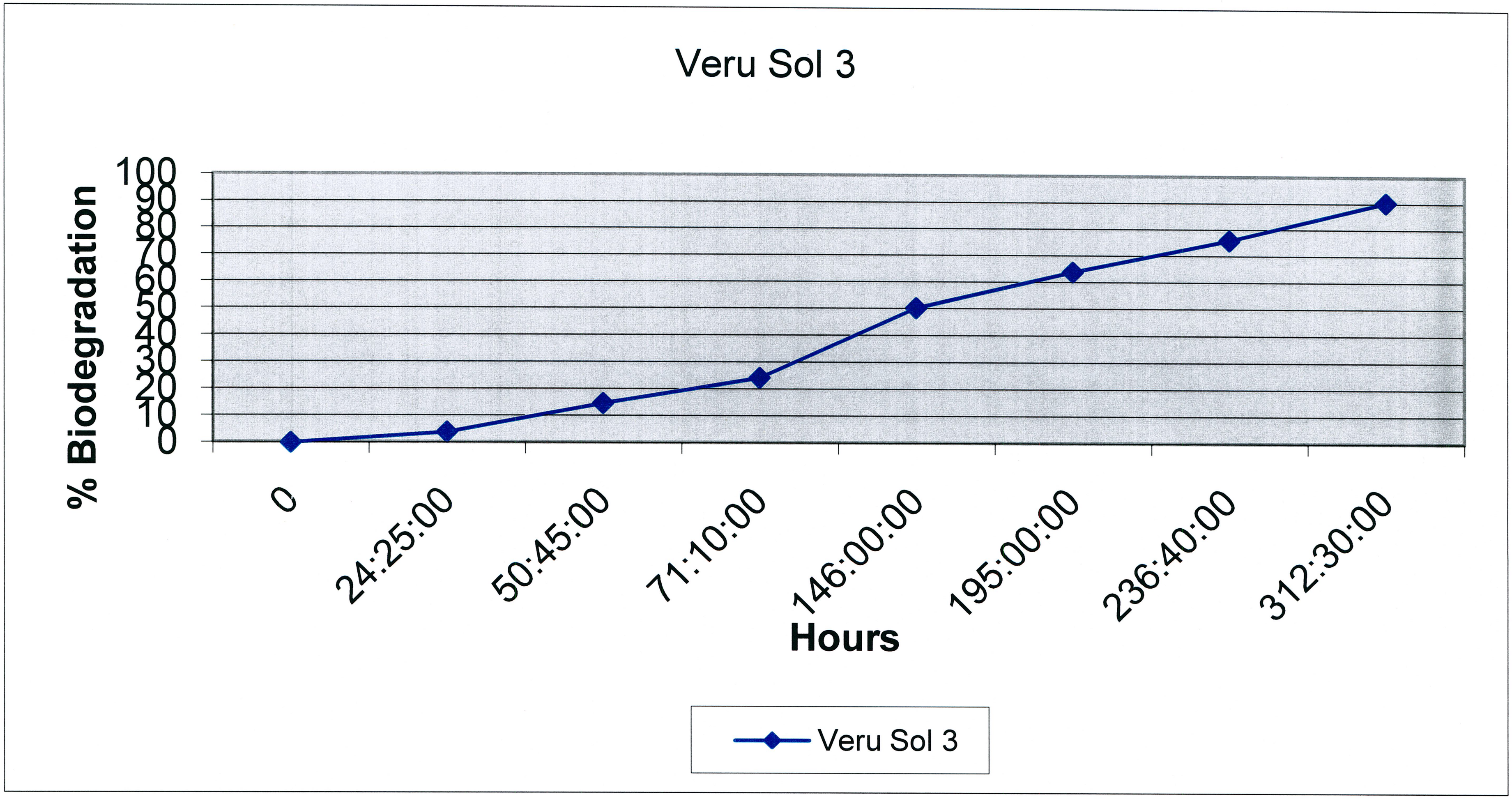
The VeruSOL 3 is biodegradable according to Method OECD 301 D.

Joseph Pickar
Analytical Chemist

Josh Rhein
IA Assistant Manager

Veru Sol 3
SUC0711-2
0.366 ---- grams of sample to (500
COD= 2,552,000

	Orig Read	Read	Blank	seed	Bottle Fac	Diluted BOD	Setup Dilution	Pre Dilution	BOD	3/22/2011 12:30			
23-Mar	7.98	7.06	0	0.05	1	0.869571429	20	1366.120219	23758.7822	3/23/2011 12:55	(time)		
	8.01	7.38	0	0.05	4	2.318285714	20	1366.120219	63341.13973	24:25:00	(total hrs)		
	8.01	7.75	0	0.05	16	3.353142857	20	1366.120219	91615.92506				
	8.01	7.24	0	0.05	1	0.719571429	40	1366.120219	39320.84309		BOD as% COD		
	8.01	7.51	0	0.05	4	1.798285714	40	1366.120219	98266.97892				
	8.03	7.85	0	0.05	16	2.073142857	40	1366.120219	113286.4949	102451.21	4.014546		
24-Mar	7.98	1.14	0	0.17	1	6.669714286	20	1366.120219	182232.6308	3/24/2011 15:15		3/22/2011 12:30	
	8.01	6.00	0	0.17	4	7.358857143	20	1366.120219	201061.6706	50:45:00		3/23/2011 12:55	24:25:00
	8.01	7.17	0	0.17	16	10.71542857	20	1366.120219	292771.2724			3/24/2011 15:15	50:45:00
	8.01	3.99	0	0.17	1	3.849714286	40	1366.120219	210366.9009			3/25/2011 11:40	71:10:00
	8.01	6.68	0	0.17	4	4.638857143	40	1366.120219	253489.4614			3/28/2011 14:30	146:00:00
	8.03	7.33	0	0.17	16	8.475428571	40	1366.120219	463138.1733	377954.7229	14.81014	3/30/2011 15:30	195:00:00
25-Mar	7.98	8.00	0	0.23	1	-0.253666667	20	1366.120219	-6930.783242	3/25/2011 11:40		4/1/2011 9:10	236:40:00
	8.01	5.22	0	0.23	4	10.22533333	20	1366.120219	279380.6922	71:10:00		4/4/2011 13:00	312:30:00
	8.01	6.74	0	0.23	16	16.58133333	20	1366.120219	453041.8944				
	8.01	2.52	0	0.23	1	5.256333333	40	1366.120219	287231.3297				
	8.01	6.06	0	0.23	4	6.865333333	40	1366.120219	375154.827				
	8.03	6.89	0	0.23	16	14.50133333	40	1366.120219	792422.5865	622732.2404	24.40173		
28-Mar	7.98	8.00	0	0.27	1	-0.285428571	20	1366.120219	-7798.594848	3/28/2011 14:30			
	8.01	8.00	0	0.27	4	-1.021714286	20	1366.120219	-27915.69087	146:00:00			
	8.01	5.11	0	0.27	16	42.15314286	20	1366.120219	1151725.215				
	8.01	8.00	0	0.27	1	-0.255428571	40	1366.120219	-13957.84543				
	8.01	2.71	0	0.27	4	20.13828571	40	1366.120219	1100452.771				
	8.03	6.14	0	0.27	16	25.99314286	40	1366.120219	1420390.32	1286057.767	50.39411		
30-Mar	7.98	8.00	0	0.41	1	-0.432333333	20	1366.120219	-11812.38616	3/30/2011 15:30			
	8.01	8.00	0	0.41	4	-1.609333333	20	1366.120219	-43970.8561	195:00:00			
	8.01	4.34	0	0.41	16	52.12266667	20	1366.120219	1424116.576				
	8.01	8.00	0	0.41	1	-0.402333333	40	1366.120219	-21985.42805				
	8.01	1.82	0	0.41	4	23.11066667	40	1366.120219	1262877.96				
	8.03	5.51	0	0.41	16	33.72266667	40	1366.120219	1842768.67	1633442.623	64.00637		
1-Apr	7.98	8.00	0	0.43	1	-0.445142857	20	1366.120219	-12162.37315	4/1/2011 9:10			
	8.01	8.00	0	0.43	4	-1.660571429	20	1366.120219	-45370.80406	236:40:00			
	8.01	3.90	0	0.43	16	58.95771429	20	1366.120219	1610866.511				
	8.01	8.00	0	0.43	1	-0.415142857	40	1366.120219	-22685.40203				
	8.01	1.47	0	0.43	4	24.45942857	40	1366.120219	1336580.796				
	8.03	5.01	0	0.43	16	41.51771429	40	1366.120219	2268727.557	1939797.034	76.01086		
4-Apr	7.98	8.00	0	0.42	1	-0.444857143	20	1366.120219	-12154.56674	4/4/2011 13:00			
	8.01	8.00	0	0.42	4	-1.659428571	20	1366.120219	-45339.57845	312:30:00			
	8.01	3.43	0	0.42	16	66.48228571	20	1366.120219	1816455.894				
	8.01	8.00	0	0.42	1	-0.414857143	40	1366.120219	-22669.78923				
	8.01	1.10	0	0.42	4	25.94057143	40	1366.120219	1417517.564				
	8.03	4.41	0	0.42	16	51.12228571	40	1366.120219	2793567.525	2305011.71	90.32178		



Veru Sol 3

% Biodegradation
100
90
80
70
60
50
40
30
20
10
0
0
24:25:00
50:45:00
71:10:00
146:00:00
195:00:00
236:40:00
312:30:00
Hours
Veru Sol 3

Mar-23

Seed	Correction	DAY=	1
Bottle	Initial	Now	Correction
Blank	8.06	8.01	
4	8.06	7.94	0.035
7	8.06	7.82	0.054286
10	8.05	7.69	0.062
		average	0.050429

Mar-24

Seed	Correction	DAY=	2
Bottle	Initial	Now	Correction
Blank	8.06	7.89	
4	8.06	7.65	0.12
7	8.06	7.25	0.182857
10	8.05	6.84	0.208
		average	0.170286

Mar-25

Seed	Correction	DAY=	3
Bottle	Initial	Now	Correction
Blank	8.06	7.80	
4	8.06	7.41	0.195
7	8.06	6.96	0.24
10	8.05	6.46	0.266
		average	0.233667

Mar-28

Seed	Correction	DAY=	6
Bottle	Initial	Now	Correction
Blank	8.06	7.61	
4	8.06	7.21	0.2
7	8.06	6.65	0.274286
10	8.05	5.99	0.322
			0.265429

Mar-30

Seed	Correction	DAY=	8
Bottle	Initial	Now	Correction
Blank	8.06	7.54	
4	8.06	6.81	0.365
7	8.06	6.07	0.42
10	8.05	5.27	0.452
		average	0.412333

Apr-01

Seed	Correction	DAY=	10
Bottle	Initial	Now	Correction
Blank	8.06	7.51	
4	8.06	6.75	0.38
7	8.06	6.00	0.431429
10	8.05	5.18	0.464
		average	0.425143

Apr-04

Seed	Correction	DAY=	13
Bottle	Initial	Now	Correction
Blank	8.06	7.40	
4	8.06	6.66	0.37
7	8.06	5.90	0.428571
10	8.05	5.01	0.476
		average	0.424857

Case Study

TREATMENT OF PCB LNAPL

CLENDENIN, WEST VIRGINIA

Summary

Figure 1: Injection Operations at the Site

VeruTEK® Technologies, Inc. (VeruTEK) successfully removed PCB-impacted fuel oil contamination from soils at a compressor station in Clendenin, West Virginia using a surfactant flushing process. The treatment consisted of injections of VeruSOL®, VeruTEK's patented biodegradable and plant-based surfactant and co-solvent mixture, which solubilized PCB-impacted oil from site soils into an immobile, fixed emulsion that was then removed for treatment.

Site Introduction

During the operation of compressors on this site in West Virginia, PCB oil used in the equipment and machinery leaked into building's basement and migrated into the gravel foundation drains surrounding the structure. Although PCB oil is no longer used, additional non-PCB oil is still being released from the basements, combining with the existing PCB-impacted oil and increasing the total volume contamination present. Both PCB and non-PCB oil within the foundation drains migrates radially toward the perimeter of the site with the flow of groundwater, eventually discharging to the sumps in this area. VeruTEK designed a surfactant flushing treatment that took advantage of this natural flow to discharge sumps.

Treatment

Prior to field implementation, laboratory tests conducted by VeruTEK demonstrated the ability of VeruSOL® to remove polychlorinated biphenyl (PCB) impacted hydraulic/motor oil contamination from Site soils. VeruSOL® is a green surfactant composed of citrus-based co-solvents and plant oil-based surfactants that are biodegradable and approved as indirect food additives for dermal contact, such as in cosmetics. These tests demonstrated that VeruSOL® increased the solubility of PCBs by seventy-five times.

Field implementation consisted of 1.5 weeks of VeruSOL® injections, accompanied by recovery of the emulsified product effluent from sump drains.

Field Results

VeruSOL® effectively created an emulsion with the hydraulic fluid in the subsurface. **Figure 2** shows the initial sump effluent before the addition of VeruSOL® and **Figure 3** shows the sump effluent, a white oil-water emulsion, after VeruSOL® injections emulsified the NAPL. **Table 1** shows the drop in interfacial tension (IFT) that correlates to the increased presence of VeruSOL® in the sump effluent. **Table 2** shows the increase in TPH (DRO) in the sump effluent corresponding to the increase in IFT (caused by the addition of VeruSOL®). This quantifies how the injection of VeruSOL® increased the solubility of the oil into the water that flowed out of the sump as effluent.

Laboratory-scale oxidation tests performed on the solubilized contaminants had rendered the PCBs completely destroyed (less than 10 µg/L remained, in comparison with the 24 µg/L that remained in the untreated control reactor) after 28 days. Although this laboratory testing demonstrated the effectiveness of VeruTEK's Surfactant-Enhanced In Situ Chemical Oxidation (S-ISCO®) technology to simultaneously solubilize and destroy Site contamination, at this particular site, the mineral properties of the soil prevented *in-situ* oxidation. Nevertheless the recovered sump effluent could be effectively treated with free-radical oxidant chemistry.

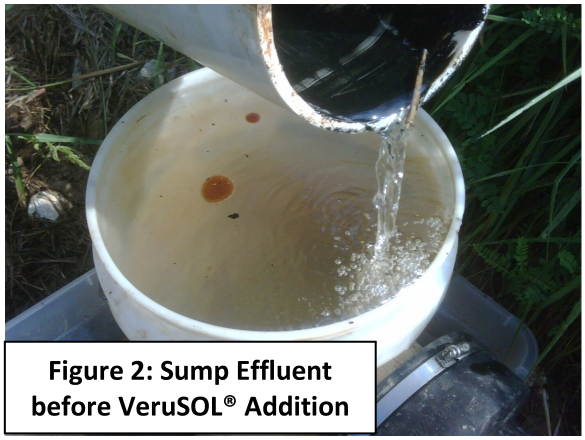


Figure 2: Sump Effluent before VeruSOL® Addition

Figure 3: Sump Effluent after VeruSOL® Addition

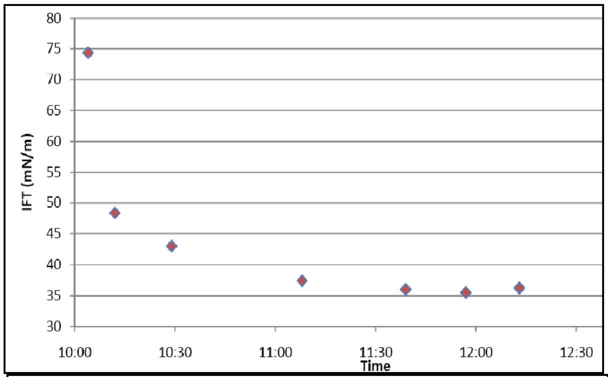


Table 1: IFT of Sump Effluent

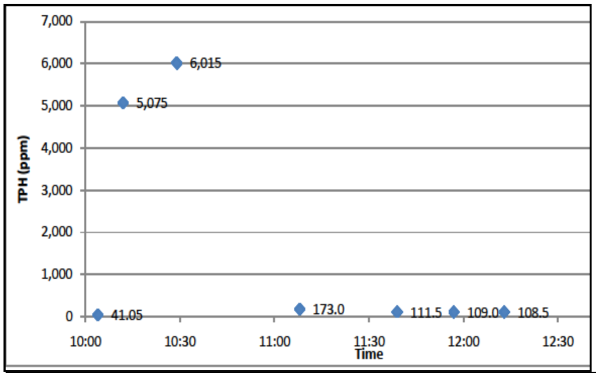


Table 2: TPH Concentration of Sump Effluent

VeruTEK®
TECHNOLOGIES

Project Facts

Site

Private Residence

Contaminants of Concern

TPH DRO from No. 2 Fuel Oil in Soil

Clean-up Objectives

- New Jersey DEP Residential Direct Contact Soil Remedial (R-DCSR) criteria;
- Site closure.

Treatment Program

VeruTEK's S-ISCO® with VeruSOL® and hydrogen peroxide

Results

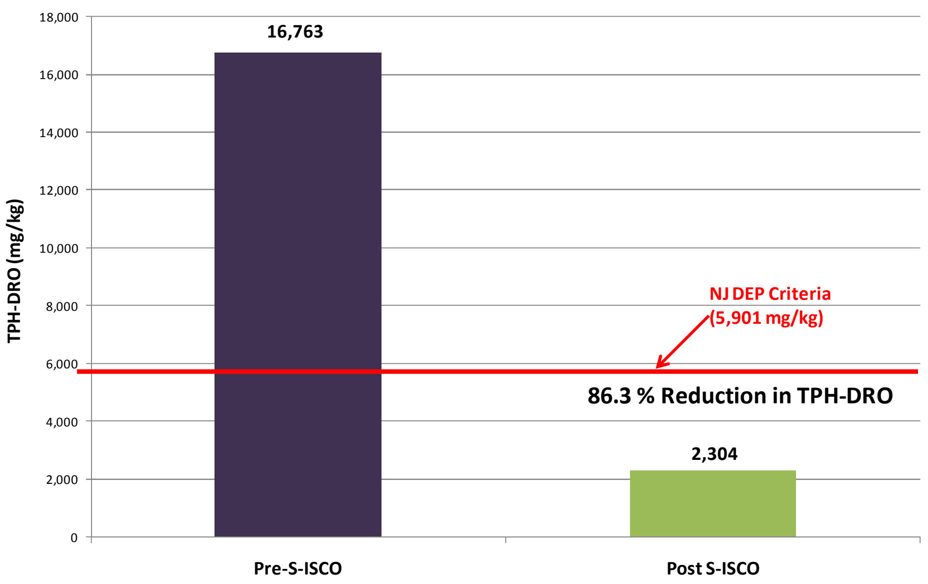
- Reduced average TPH concentration > 86 % (from 16,763 to 2,304 ppm);
- Achieved NJ DEP criteria;
- No impacts to home or residents; and
- Achieved site closure.

Case Study

S-ISCO® DESTRUCTION OF NO. 2 FUEL OIL

NEW JERSEY

Figure 1: Average Reductions in TPH DRO (ppm)



Introduction

VeruTEK® Technologies, Inc. (VeruTEK) successfully remediated TPH contamination associated with a No.2 home heating oil spill at a residence in New Jersey using its patented Surfactant-Enhanced In Situ Chemical Oxidation (S-ISCO®) technology. The S-ISCO treatment consisted of injections of VeruTEK's biodegradable and food-grade surfactant and co-solvent mixture, VeruSOL®, along with hydrogen peroxide, and destroyed TPH contamination present in site soils. As a result of the treatment, which took place within 10 feet of an occupied residence, the site attained regulatory closure and neither the residents nor their home were negatively impacted.

Background

At this site the entire contents of a damaged 1,000 gallon underground storage tank (UST) had leaked into the soils surrounding the vessel, at a distance less than 10 feet from the home. The UST was decommissioned and removed along with 62 tons of petroleum-impacted soil, and the excavation was backfilled with clean fill material.

Sampling after the UST removal indicated that significant TPH contamination remained in the soil around and below the excavation. As shown on **Figure 1,** TPH concentrations ranged as high as 20,743 mg/kg and averaged 16,763 mg/kg. Impacts were present in both the saturated and unsaturated intervals, from 14 to 22 ft below ground surface.

Traditionally a homeowner's only option to remedy the effects of a UST spill would be excavation for off-site disposal. This technique is costly; typically yields an incomplete solution since contamination can remain below and around the excavated area, as was seen at this site; has a large carbon footprint, linked to the impacts of the machinery and vehicles used to remove and transport the waste; and is detrimental to the integrity of the subsurface, which threatens a building's structure and stability.

Technology Background

S-ISCO® is one of VeruTEK's innovative and patented Coelution Technologies™ that is capable of completely or near completely destroying NAPL in soils. By combining activated *in situ* chemical oxidant systems with surfactant and surfactant-co-solvent mixtures (**VeruSOL®**), S-ISCO brings NAPL into an immobile, fixed emulsion for simultaneous destruction by a co-eluted oxidant. VeruSOL, a mixture of biodegradable, plant-based and US FDA generally recognized as safe (GRAS) components, overcomes the limitations of traditional *in situ* chemical oxidation treatments which fail to treat NAPL contamination since oxidative destruction of NAPL occurs in the aqueous phase (that is, when the NAPL is dissolved).

S-ISCO destroys NAPL and yields permanent, cost-effective and environmentally friendly solutions to challenging contamination problems.

Treatment

To remediate the fuel oil contamination at this site and provide an efficient, effective and cost-competitive solution, VeruTEK implemented S-ISCO, an on-site and in-place treatment. The S-ISCO remedy VeruTEK designed for the specific conditions and contaminants at the site included injection of a solution of VeruSOL®, and hydrogen peroxide. The iron naturally present in the soil provided adequate activation for the peroxide.

Over three days, VeruTEK used a pressurized system to inject approximately 1,800 gallons of S-ISCO solution comprised of 3% peroxide and 5 to 10 g/L of VeruSOL®. The solution was injected into 14 locations at two-foot vertical intervals.

Results

One month after the S-ISCO implementation, soil samples were collected from the treatment area, in the vicinity of pre-treatment samples. Analysis of these samples indicated that the S-ISCO treatment reduced TPH concentrations by more than 86 %, on average, and well below regulatory clean-up criteria, that is, New Jersey Department of Environmental Protection (DEP) Residential Direct Contact Soil Remedial (RDCSR) standard of 5,100 ppm for TPH DRO. This data is shown on **Figure 2.**

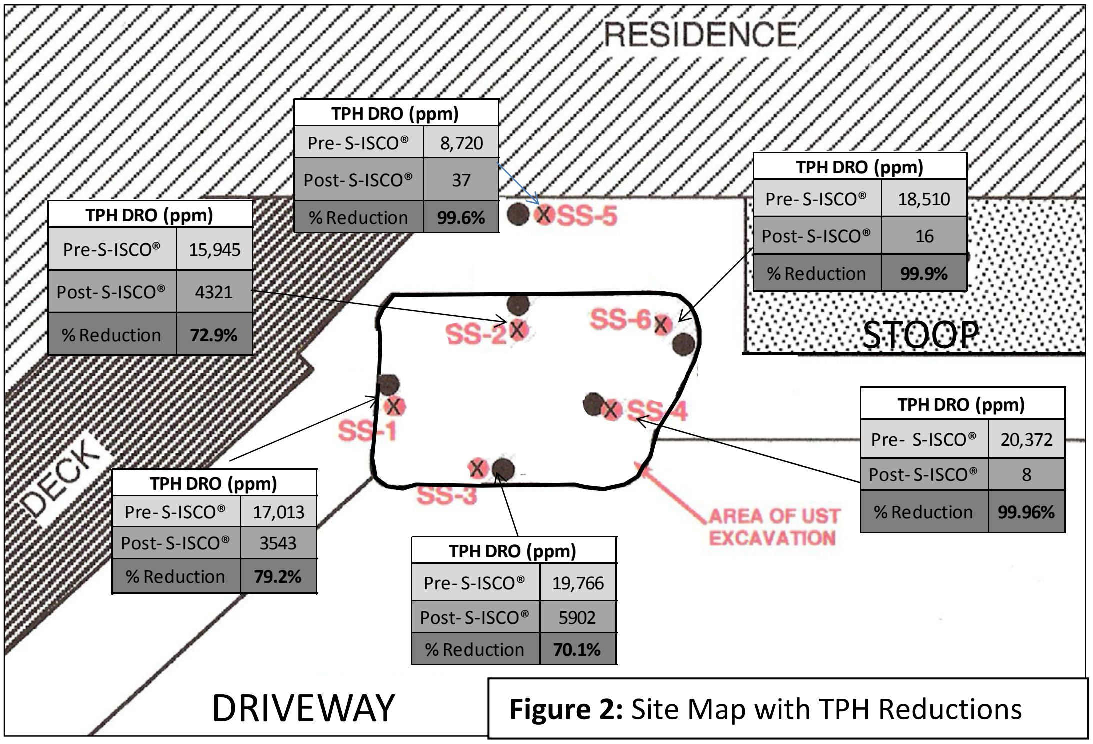


Figure 2: Site Map with TPH Reductions

Of the seven soil samples analyzed, TPH was reduced between 70 and more than 99 %. Six of the samples were below the New Jersey DEP RDCSR criteria for TPH DRO. Only one sample, SS-03, measured a DRO concentration in excess of NJ DEP criteria (5,901 ppm). In response to this exceedance, additional BN+15 analysis was performed on this sample. The results of the BN+15 analysis indicated that chrysene and pyrene were present in the sample but at concentrations below the New Jersey DEP RDCSR standards. Specifically, chrysene and pyrene measured 66 ug/kg and 1,000 ug/kg, respectively, compared to the criteria of 62 mg/kg and 1,700 mg/kg, respectively.

Implications

Based on the results achieved by the S-ISCO treatment, the New Jersey DEP issued a “No Further Action Letter” for the property, allowing the homeowner to sell the home for fair market value.

VeruTEK®
TECHNOLOGIES

Site
Former Lumber Treating Facility &
US EPA Superfund Site
Delaware

Contaminants of Concern
Creosote DNAPL

Clean-up Objectives
Remove Creosote DNAPL

Treatment Program
- VeruTEK's Surfactant Enhanced Product Recovery (SEPR) with VerEX & peroxide; and
- Surfactant-enhanced In Situ Chemical Oxidation (S-ISCO®) with VeruSOL, peroxide and alkaline-activated sodium persulfate.

Results
- *DNAPL:* Removed 88% DNAPL;
- *Technology Advancement:* Optimal extraction achieved with VerEX surfactant /co-solvent and oxidant chemistry;
- Immediately progressed to full-scale treatment.

Case Study

SEPR™ & S-ISCO® REMEDIATION OF CREOSOTE DNAPL AT DELAWARE SUPERFUND SITE

Introduction

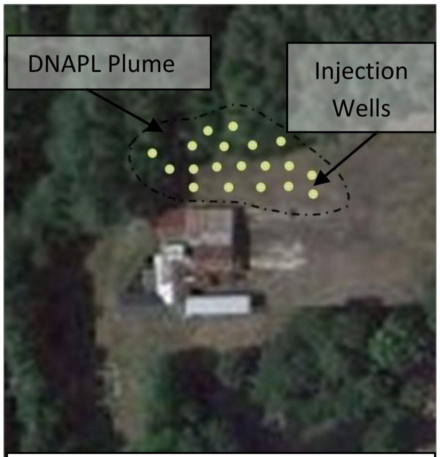


Figure 1: Treatment Area & Wells

VeruTEK Technologies (VeruTEK) successfully remediated creosote DNAPL contamination at a US EPA Superfund site in Delaware using a combination of its surfactant-enhanced technologies: Surfactant Enhanced Product Recovery (SEPR™) and Surfactant-enhanced In Situ Chemical Oxidation (S-ISCO®). Both SEPR and S-ISCO use VeruTEK's patented plant-based surfactant and co-solvent mixtures, including VerEX during the SEPR and VeruSOL during S-ISCO. During the SEPR process, injections of VerEX and peroxide formed a weak emulsion with the creosote DNAPL, enabling the product to flow to recovery wells for extraction. After SEPR removed the bulk of the DNAPL contaminant mass, S-ISCO injections of VeruSOL in combination with chemical oxidants simultaneously solubilized and destroyed residual contamination in place.

The SEPR injection and extraction process followed by S-ISCO injections at this former lumber treating facility successfully removed more than 88% of the creosote-related DNAPL identified in the treatment area. This treatment was designed as a pilot test but, based on the outstanding results achieved, the treatment area was immediately expanded and the implementation progressed directly into full scale.

Site Background

During historic lumber treatment operations at this facility between 1963 and 1986, creosote waste and condensate waste water had been gravity-fed into a 1,000 square foot unlined lagoon. The lagoon was excavated in 1986 but subsequent site investigations revealed creosote DNAPL below the excavation footprint as well as in monitoring wells and emanating from investigational test pits dug across the site.

Remedial Design

Based on previous site data, VeruTEK designed a SEPR and S-ISCO pilot test to target approximately 5,000 gallons of DNAPL in about 13,800 cu ft of soil from 6 to 11 ft below ground surface (bgs), where a confining clay aquitard was present. Prior to treatment, 19 wells were installed on a 15 ft grid pattern. Each well functioned as an injection, extraction and groundwater monitoring location. In addition, baseline soil borings were drilled in the treatment area and visually inspected for the presence of DNAPL. The results of this investigation were used to plot the vertical and horizontal extent of the contamination plume.

SEPR Implementation

The SEPR implementation took place over 18 days and consisted of a series of injections and extractions in a push-pull process that, combined with the action of the injected oxidant, facilitated DNAPL removal. The SEPR chemistry, a mixture of 0.5-1% peroxide and 10-30 g/L of VeruTEK's VerEX blend, was injected and followed by a water flush that pushed the chemistry to increase its dispersion. The buoyancy of the oxygen bubbles from the peroxide decomposition helped to loosen the DNAPL while VerEX reacted with the creosote DNAPL, forming a weak emulsion that enabled the product to flow to recovery wells. VeruTEK's patent-pending system injected the chemistry in up to 2 wells at a time, at a rate of approximately 2 gallons per minute (GPM) per well.

A vacuum pump was then connected to the injection location to remove the emulsified and free product solution. The extraction process began after several hours or up to 2 days following injection, depending on the amount of product returning to the well once the extraction pump was connected and initially activated. The extracted material was transferred to polytanks for off-site disposal.

Technology Background

Surfactant Enhanced Product Recovery (SEPR™) is one of VeruTEK's Green Chemistry-based technologies for remediation of recalcitrant environmental contaminants, including non-aqueous phase liquids (NAPL) associated with MGP coal tar and creosote oil.

SEPR combines VerEX, one of VeruTEK's patented, plant-based & biodegradable surfactant and cosolvent mixtures which is designed to form weak emulsions, , with low concentrations of peroxide in an injection-and-extraction process that facilitates removal of free-product and residual NAPL from the subsurface. The injection and extraction process increases the effective soil porosity around the well as product is removed, progressively widening that well's radius of influence for further recovery.

SEPR prepares the subsurface for VeruTEK's patented Surfactant-enhanced In Situ Chemical Oxidation (S-ISCO®) treatment. S-ISCO involves injection of higher concentrations of an activated oxidant, typically peroxide, persulfate or a combination of both, along with lower concentrations of VeruSOL, to destroy any remaining residual contamination in place. Unlike VerEX, which forms weak emulsions for product recovery, VeruSOL surfactant blends form stable micro sized emulsions which greatly increase the surface area and contact between free radical oxidants and NAPL contaminants. ***By removing gross NAPL contamination, SEPR increases the efficiency & cost-effectiveness of subsequent S-ISCO treatment at sites with heavy NAPL & free-product contamination.***

Figure 2: SEPR in Action

Pre-SEPR	Day 1	Day 2	Day 3
No Product Recovery; Clear Samples	Product + Emulsion Recovered	Increased Product Recovery	Product Flow

Both the injection and extraction processes were modified in the field based on a given well's acceptance of the chemistry and its return from pumping. The SEPR process continued until the rate of DNAPL product returning from the wells subsided and the targeted 15-ft radius of influence (ROI) around each well had been achieved. Achievement of the ROI was confirmed when overlap was seen between adjacent wells: the chemistry injected into one well was seen in the fluid extracted from a neighboring well, as shown in **Figure 5**. Overall approximately 5,000 gallons of treatment chemistry was injected and 5,000 gallons of fluid was extracted.

S-ISCO Implementation

When the SEPR process was completed VeruTEK implemented S-ISCO over the following 30 days to remove residual contamination. S-ISCO began with injections of VeruSOL at 5-10 g/L, and hydrogen peroxide at 4-8%, and, after the first week, included sodium persulfate as well. Overall, approximately 27,000 gallons of S-ISCO chemistry was injected.

Figure 4 (below) shows the full progression of the SEPR and S-ISCO treatments; **Figure** 3 shows before-and-after snapshot of S-ISCO's affect on groundwater contamination in samples from the treatment area.

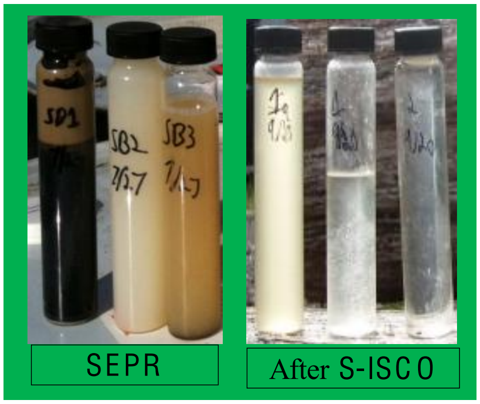


Figure 3: Before-and-after S-ISCO

Monitoring

Monitoring was conducted before, during and after the SEPR and S-ISCO processes to track the progress and performance of the injected chemistry in the subsurface, including the success of the desorption and emulsification process. Monitoring included collection of groundwater samples for analysis of process parameters including interfacial tension (IFT), an indicator of VeruSOL, oxidant concentration, TPH and oxidation-reduction potential; and observation of wells and the extracted fluid for free product.

Results

Radius of Influence

The presence of creosote DNAPL in soil pore spaces reduced the porosity and relative permeability of soil to water in the treatment area. With each round of SEPR injections and extractions, the SEPR chemistry progressively removed this confining DNAPL material in the pore spaces, enabling injection of greater volumes of chemistry which could, in turn, achieve a greater ROI. Eventually the chemistry reached the 15-foot ROI for which the well layout had been designed, and overlap was seen between adjacent wells. This process is illustrated in **Figure 5.**

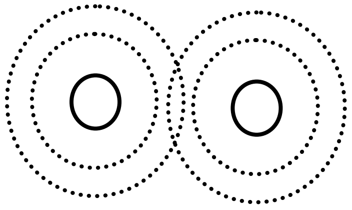


Figure 5: SEPR ROI

DNAPL Removal

During the pilot test, the SEPR chemistry was optimized to maximize recovery. As the optimal dose was reached, the amount of recovery became greater than the amount injected. Following the pilot test, soil borings were again collected from the treatment area and visually examined for the presence of DNAPL. The vertical and horizontal extent of the contamination plume was compared to the baseline. This indicated that the SEPR and S-ISCO treatment successfully removed more than 88% of the DNAPL impacts from the 6 -11 ft bgs interval. **Figure 6** depicts the reduction in the area of the DNAPL plume across the treatment interval. Specifically it shows 100% removal from 6 to 9 ft bgs, and 74% removal from 9 to 11 ft bgs.

Conclusions

The results of this pilot test have demonstrated a significant advance in remediation of subsurface DNAPL. The ability of VeruTEK's SEPR chemistry to desorb, emulsify and enable the extraction of recalcitrant DNAPL provides a safe, effective and environmentally preferable solution for similarly contaminated sites. Following the success of the pilot test, the treatment area was expanded and full-scale treatment was implemented, in early 2012. Additional site analysis will be available later in the year.

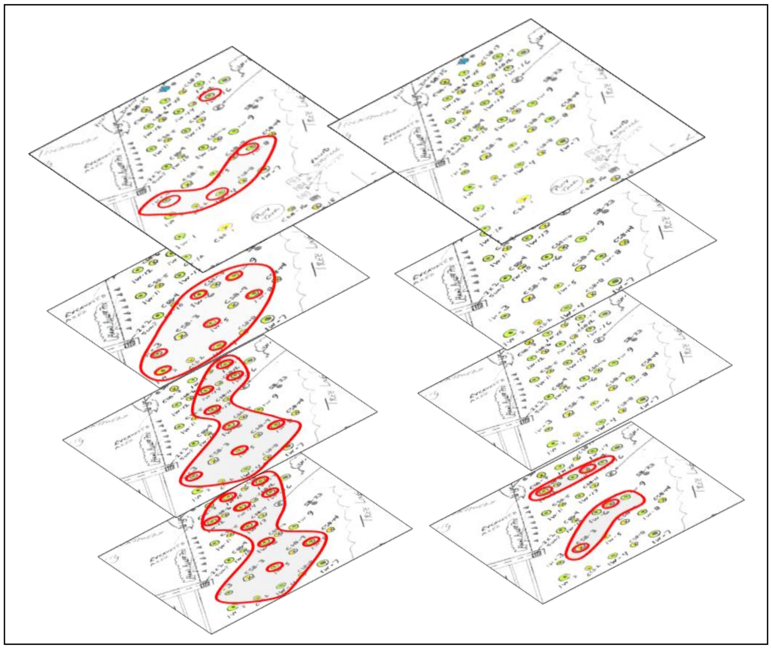


Figure 5A: Pre-treatment DNAPL plumes.	**Figure 5B:** Post-treatment DNAPL plumes.

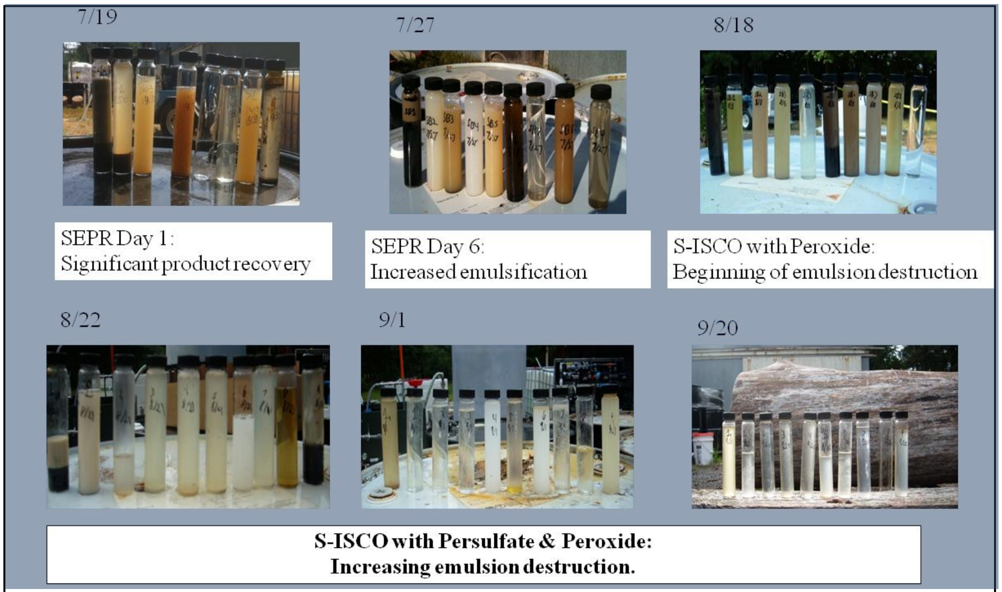


Figure 4: SEPR/S-ISCO Treatment Progression

Case Study

S-ESCO® DESTRUCTION OF DIESEL NAPL

HOLLEY, GEORGIA

Summary

VeruTEK® Technologies, Inc. (VeruTEK®) successfully remediated diesel non-aqueous phase liquid (NAPL) at a trucking facility in Holley, Georgia (the Site). Using a combination of VeruTEK®'s patented Coelution Technologies^{TM}, Surfactant-enhanced Ex Situ Chemical Oxidation (S-ESCO™), NAPL was destroyed and the Site's clean-up criteria were exceeded.

Figure 1: S-ISCO® VeruSOLVE™ Chemical Equipment

As a result of S-ESCO™ implementations at the Site, not only was visual NAPL destroyed but concentrations of diesel-range organics (DRO) were reduced to levels below the state's 1,000 ppm threshold, surpassing the treatment objectives.

Introduction

S-ESCO™ are proprietary Green Chemistry Technologies that use mixtures of biodegradable and food-grade surfactants or cosolvent/surfactant mixtures to solubilize contaminants into an immobile, fixed emulsion for immediate in-place and on Site destruction in a safe and controlled manner.

Prior to field implementation VeruTEK® completed several successful engineered destruction tests with soils and NAPL taken from the Site to determine which VeruSOLVE™ chemical formulation would most efficiently and effectively treat the diesel range NAPLs during S-ESCO™ implementations. S-ESCO™ is one of VeruTEK® 's Coelution Technology™ platforms that use natural surfactants, such as VeruSOL®, VeruTEK®'s environmentally friendly, plant-based surfactant; catalysts; builders; and oxidants to destroy NAPL and other sorbed contaminants. The results of these tests concluded that VeruSOLVE™ could significantly increase contaminant solubility and destruction.

VeruTEK® teamed with a subcontractor to implement S-ESCO™ at the former trucking terminal in Holley, Georgia. Soils at the Site consisted of micaceous sandy-silt/silty-sand saprolite derived from weathering of schist and gneiss bedrock. At the Site, a diesel NAPL plume, derived from four leaking underground storage tanks (USTs) that had been removed, existed from 3 to 11 feet below ground surface and extended beneath a portion of a building. In several monitoring wells installed after the USTs had been removed, free phase diesel NAPL measuring more than 0.5 feet in thickness was observed. The clean-up objective of the Site was to the eliminate the visual NAPL.

Field Implementation

S-ESCO™ is an innovative, green chemistry technology-based remedial process that involves excavating soils, treating them aboveground with VeruTEK®'s patented S-ISCO® chemistry and subsequently returning them to the ground. S-ESCO™ was implemented at the Site as a less expensive, more environmentally friendly alternative to proposed soil excavation and off-Site disposal followed by ongoing pump-and-treat activities using horizontal wells.

S-ESCO™ began with the removal of one to three feet of the overburden and the excavation of impacted soils to 11 to 12 feet. A total of 4,000 cubic yards of soil was removed. 80,000 gallons of contaminated water and NAPL was pumped into storage tanks and hauled off-Site by a licensed petroleum recycler. The excavated soil material was blended with VeruSOLVE™ chemistry in above-ground mixers for approximately one week of treatment.

Figure 2: Transfer of soil into cells for treatment with VeruSOLVE™.

Conclusions

Visual analysis of samples from the treatment cell showed that NAPL had been successfully treated. In addition Diesel Range Organic (DRO) analysis confirmed that levels had been reduced to below 1,000 ppm, the threshold required by the State of Georgia. This reduction amounted to a 75% destruction of NAPL. The soils were subsequently backfilled and compacted after treatment had been confirmed.

Post-S-ESCO™ monitoring has verified that no visual NAPL remains at the Site and soil samples continue to be below state regulations for DRO.

Louisiana Creosote Wood Treatment Facility Project Summary

1. Scope of Work

VeruTEK conducted a successful pilot test implementation at a creosote site in Louisiana following completion of a bench scale treatability study. The pilot scale was used as an evaluation of the SEPR (Surfactant Enhanced Surfactant Recovery) technology and demonstrated the process' cost effectiveness for full scale implementation. SEPR improved DNAPL removal from the existing recovery system by up to 17 times baseline conditions, generating approximately 1700 gallons of total recovery.

2. Description of Site and Contamination

Site Description

The Site is a 34-acre former wood treating facility that used creosote and pentachlorophenol (PCP) to treat various wood products between 1901 and 1981 (80 years). The facility was placed on the U.S. Environmental Protection Agency's (EPA) National Priorities List (NPL) in 1992 and has undergone extensive remediation, including a Recovery System. The recovery system is comprised of 28 recovery wells and trench sumps, several injection wells and injection trenches, an onsite process liquid treatment system (PLTS) and an extensive array of underground piping to convey fluids to and from the PLTS. The baseline amount of creosote oil recovered from the existing recovery system before implementing the pilot was estimated at 2 gallons per day.

Levels of contamination at the Site prior to VeruTEK's SEPR Pilot Test is summarized below:

- Total contaminated soil volume exceeding 3,000 ug/kg BaP; and
- 400,000 gallons DNAPL (estimate 50% recoverable by pumping) pooled on the upper surface of the Cockfield Formation across the entire site. Residual and free-phase creosote were observed throughout the vertical extent of the Prairie Terrace Deposits (PTD).

The soil in the pilot test area was saturated with creosote contamination. Soil concentrations in the lower PTD in the pilot test area were at 1.6 to 159 mg/kg BaP Equivalents. Prior bench-scale testing of the soils in this area identified the following concentrations:

- 5,900 mg/kg VOC (primarily as BTEX related contaminants)
- 11,041 mg/kg SVOC (primarily as PAHs)
- 30,000 mg/kg TPH

There are three primary geologic units at the Site identified as fill, Prairie Terrace Deposits and the Cockfield Formation as follows:

- Fill – is up to 10 ft thick in several places (where former wastewater impoundments were backfilled), but in most areas the fill varies in thickness from 1 to 3 ft. The fill material is characterized as mixture of dense silty clay with minor (less than 0-20 percent) amounts of crushed limestone gravel, and may contain wood debris. Visible evidence of dried, creosote stained material has been observed at depths extending from just below the surface (1 ft) to the base on this zone.

- Prairie Terrace Deposits (PTD) - extends from the base of the fill material to depths ranging from 20 – 37 ft below ground surface (bgs). The PTD are characterized as undifferentiated mixture of clay, silt, sand, and gravel. The upper portion is generally clay and silt size material grading to fine-medium silty sand with a thin layer of small gravel at the base. Groundwater occurs in the PTD (shallow aquifer) at depths between 8 and 37 feet.
- Cockfield Formation – extends from the base of the PTD to undetermined depth forming a basal confining layer beneath the Site. This unit is characterized as dense, interbedded clay, silt, and sand with some lignite. Clay and silt content decrease with depth. Groundwater occurs at depths below the contact with the PTD (deep aquifer) at depths between 45 and 60 feet. The vertical groundwater flow gradient at the Site is generally upward from the Cockfield Formation to the PTD.

Hydraulic conductivity values range between 0.002 and 0.05 ft/day for the PTD (shallow aquifer) and from 0.01 and 0.13 ft/day for the Cockfield Formation (deep aquifer).

3. Description of Remediation Activities Conducted

Prior to mobilization to the Site three new saturated zone injection wells and five new dual purpose vadose zone injection/recovery wells were installed in the pilot area. The 3 newly installed saturated zone injection wells were 2-inches in diameter and screened across the PTD while the dual purpose vadose wells screen in the lower portion of the vadose zone at depths between 9 and 19 ft.

The saturated zone pilot test injection wells were paired with seven existing recovery wells identified as R-5, R-9, R-12 (west wells), and R-10, R-15, R-17 and R-18 (east wells). The recovery wells are 4-inch diameter stainless steel wells that that are screened from the base of the PTD to the top of the water table. The screens are 10 to 15 feet in length.

The reported maximum rate of injection experienced by the existing treatment system was 8.5 gpm with the majority of this rate occurring in the trenches rather than the injection wells. Baseline quantities of creosote oil recovered from the existing Recovery System before implementing the pilot, as being verified by pre-treatment testing are estimated at a few gallons per day, or less.

The pilot study was conducted over 9 weeks from May 21st 2012 to July 19th 2012. During the pilot test a total of 31,680 gallons of SEPR chemicals were injected at the Site. A summary of the SEPR chemical injected found below.

Table 1: Pilot Test Remedial Chemistry

Treatment	Treatment Chemistry (Approximate Volume)	Oxidant	Surfactant	Activator
SEPR	31,680 gal	--	Up to20% VerEX	Up to 8% VerEX activator

The pilot study was conducted in a core area of the Site that includes 3 newly installed injection wells (IW's); and recovery wells R-5, R-9, R-10, R-12, R-15, R-17, and R-18 (see Figure 1.) The PTD in the area where the injection wells were screened was characterized as silty sand (see Figure 3.).

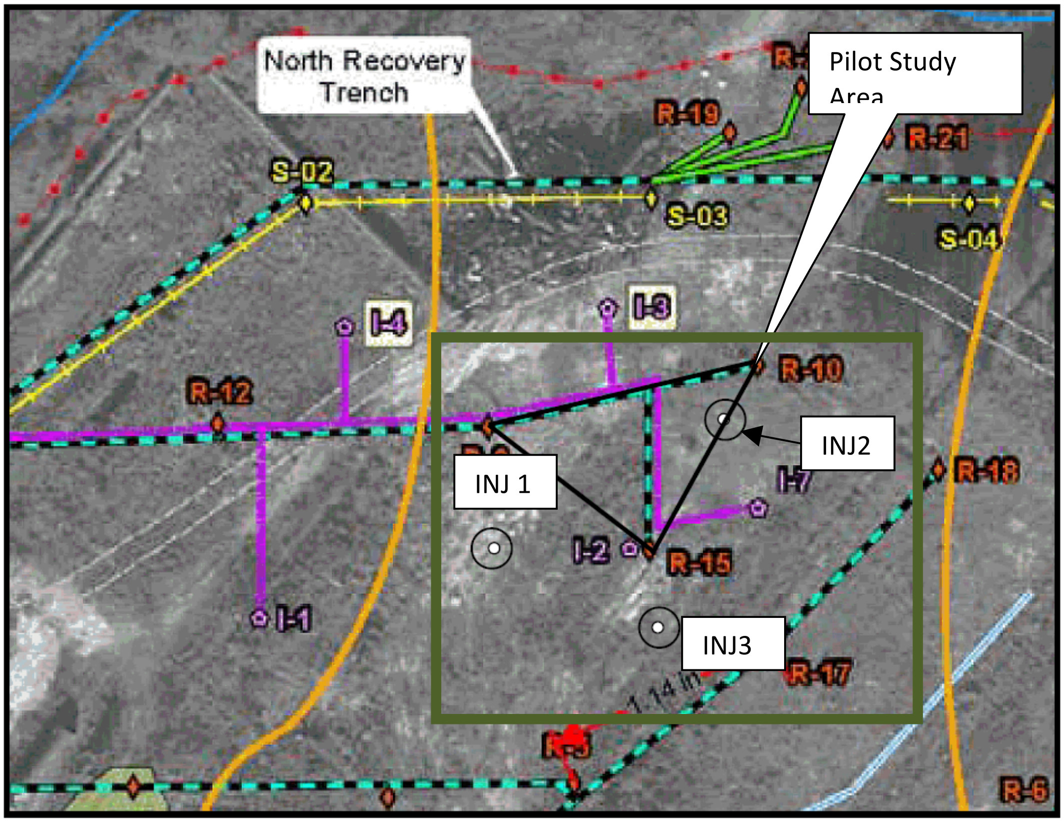


FIGURE 1: GENERAL LOCATION OF PILOT TEST AREA

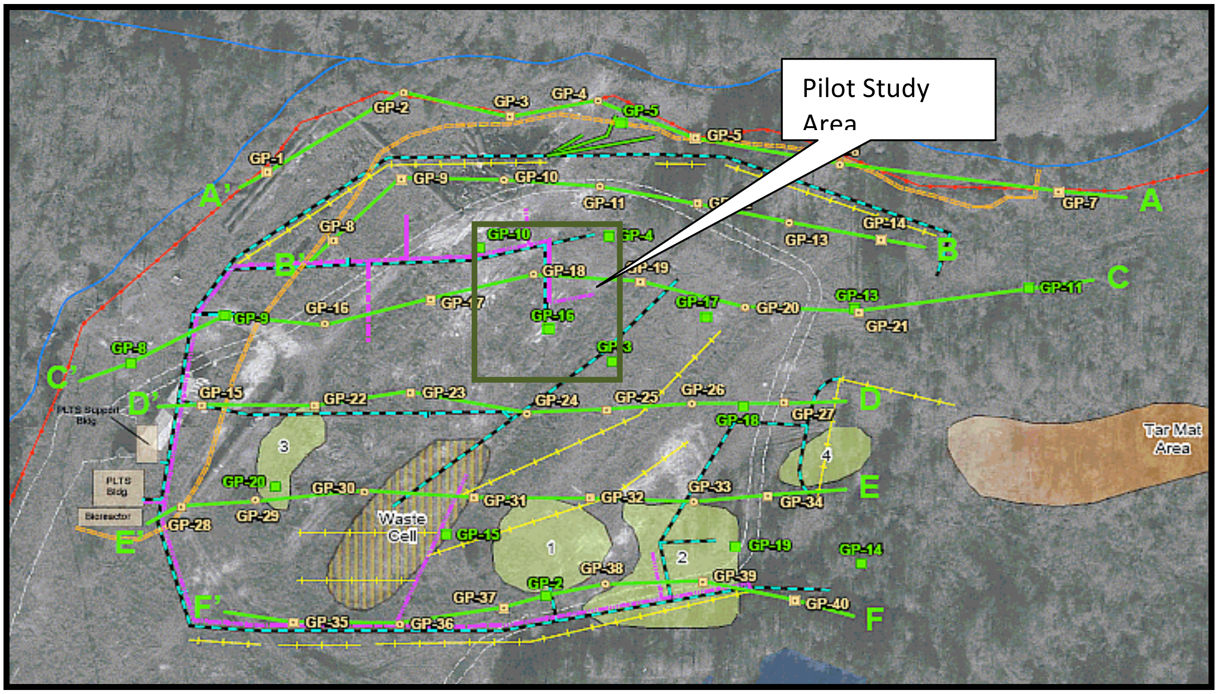


FIGURE 2: LOCATION OF X-SECTION C – C' (GP-17, GP-18, GP-19) USED TO DEFINE GEOLOGIC CHARACTERISTICS OF PILOT STUDY AREA

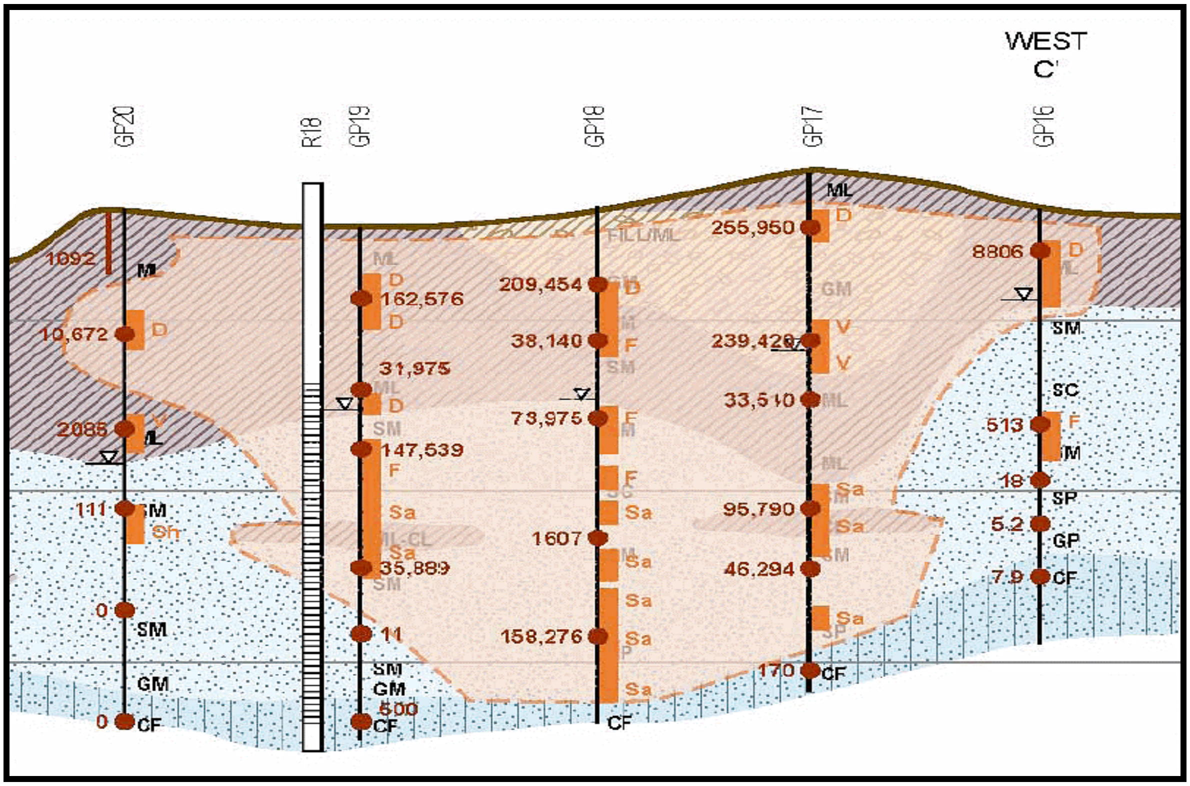


FIGURE 3: X-SECTION C-C'

4. Effectiveness of Treatment

a. Removal rates

32,800 gallons of fluids were recovered over the 60 day treatment period including approximately 1,700 gallons of DNAPL, with an increase in recovery rate of 17 times the pretreatment baseline.

b. Current state of site

The pilot test at the Site has been complete, full-scale implementation is pending client approval.

c. Cost per cubic yard of soil treated

The cost of the pilot test was ~$240,000 or $57/cubic yard of soil treated for product recovery.

Case Study

S-ISCO® DESTRUCTION OF MGP COAL TAR, *NEW YORK*

Project Facts

Site

Former MGP, New York

Contaminants of Concern

TPH and PAHs from Coal Tar

Project Objectives

Demonstrate controlled destruction of MGP contaminants

Treatment Program

VeruTEK's Surfactant-enhanced In Situ Chemical Oxidation (**S-ISCO®**), using VeruSOL®, sodium persulfate, and Fe-EDTA (activator)

Results

- Destroyed 4,000 kg TPH and PAH contamination in soil;
- Achieved sustainable reductions in soil gas contamination; and
- Did not impact nearby water resources.

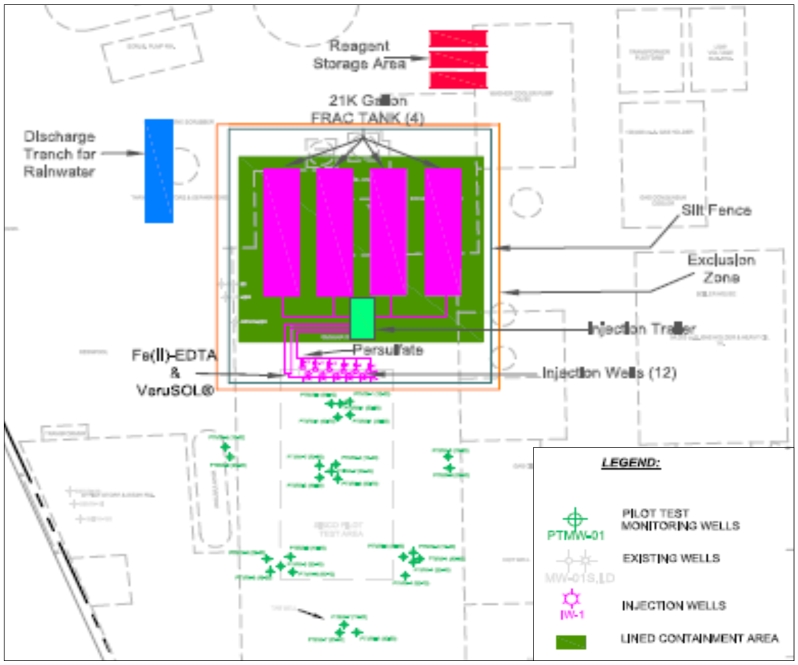


Figure 1: Site Set-Up

Introduction

Under the approval of the New York State Department of Environmental Conservation (NYSDEC) VeruTEK® Technologies, Inc. (VeruTEK) successfully demonstrated the effectiveness and safety of its patented Co-elution Technology™, Surfactant Enhanced In Situ Chemical Oxidation (S-ISCO®), to remediate contamination related to coal tar at a former manufactured gas plant (MGP) site in New York (the Site). The Site, part of a 6-acre former MGP located in a residential and commercial neighborhood, was contaminated by PAHs and TPH present in the soil, groundwater and an estuarine surface water body.

VeruTEK conducted a S-ISCO® pilot test that targeted **900 kg of PAH** and **BTEX** contamination located beneath the former Generator House, an 8,100 square foot brick building with a concrete base. The majority of the contamination was present in the upper 35 ft below ground surface (bgs) with the greatest mass between 30 and 35 ft bgs. **Figure 1** depicts the Site set-up, including the injection system, and injection and monitoring wells.

Implementation

The S-ISCO® implementation took place over 70 days and consisted of a series of injection events alternating with periods of performance monitoring. 12 injection wells, screened from 12 to 15 ft bgs, and 27 monitoring wells were used.

The S-ISCO® chemical formulation was based on the results of laboratory treatability and dosage tests VeruTEK conducted using soil and groundwater from the Site. Injections consisted of a total of 541,050 gallons of fluid, composed of the following components:

Table 1: S-ISCO® Chemistry

Chemical	Mass
Sodium Persulfate	72,674 kg
VeruSOL®	3,314 kg
Fe-EDTA	475 kg

Monitoring

Monitoring took place before, during and after injections and consisted of analysis of soil and groundwater samples for contaminants of concern (COCs), including VOCs and SVOCs; and analysis of groundwater samples for water quality and performance parameters including conductivity, temperature, oxidation-reduction potential, interfacial tension (IFT) and iron and sodium persulfate concentrations. Soil and groundwater contamination data was used to evaluate the contamination reduction achieved by the pilot test, while groundwater parameter data provided information about the movement of the chemistry in the subsurface and the success of its contact and reactions with contaminants.

Technology Background: S-ISCO® vs ISCO

S-ISCO® is one of VeruTEK's innovative and patented Coelution Technologies™ that is capable of completely or near completely destroying the amount of NAPL in soils.

Two years prior to VeruTEK's S-ISCO® implementation on the Site, an *in situ* chemical oxidation (ISCO) implementation using legacy technology failed to destroy the targeted coal tar contamination. This failure resulted in large part from the inability of the injected ISCO chemicals to contact non-aqueous phase liquids (NAPLs) since they were not in aqueous phase. S-ISCO® specifically overcomes this limitation by enabling the NAPL to become solubilized into an immobile, fixed emulsion for immediate destruction in-place, and in a safe and controlled manner, by a co-eluted oxidant. S-ISCO® incorporates biodegradable, US FDA generally recognized as safe (GRAS) surfactants and co-solvents to dissolve and oxidants to subsequently destroy contaminants.

Field Results

Coelution

The results of groundwater monitoring demonstrated that the S-ISCO® chemistry successfully travelled through the subsurface to both contact and subsequently destroy contaminants. **Figure 2** shows that the surfactant, oxidant and activator were co-eluted and moved together through the subsurface. In a controlled process, the

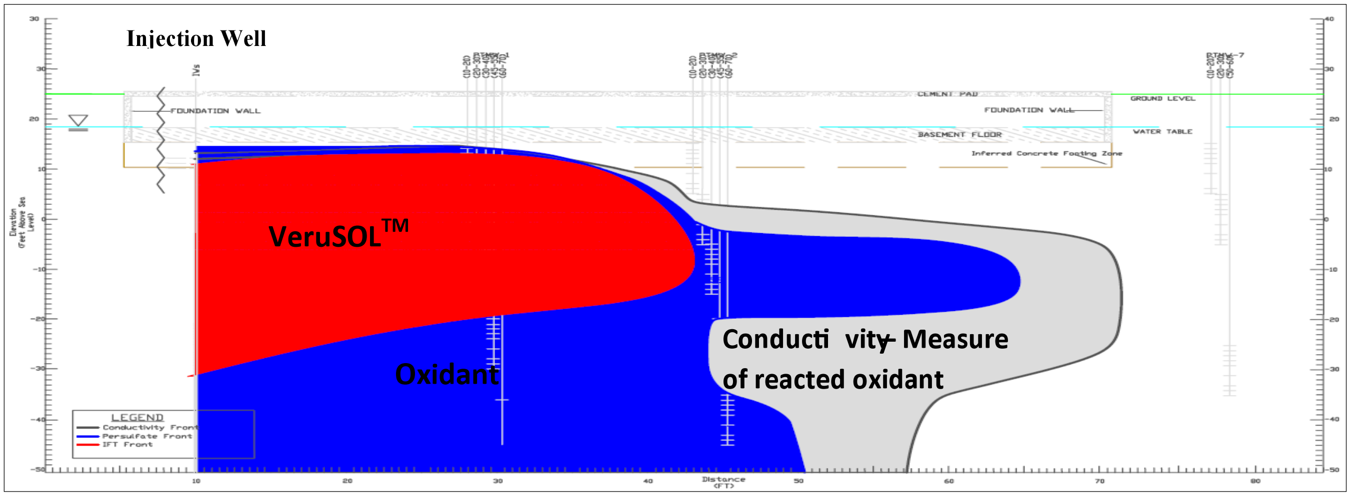


Figure 2: Controlled Movement and Coelution of the S-ISCO® Chemistry

dissolved contaminants reacted with and were destroyed in the presence of excess persulfate, as shown by the extent of the conductivity front.

Contamination Destruction

A comparison of COC concentrations in soil before and after injections shows that S-ISCO® destroyed petroleum hydrocarbons with high molecular weight (that is, solid and liquid coal tar) as well as more soluble contaminants. In addition, the concentrations of potential breakdown products of these contaminants, such as acetone, did not significantly increase during the S-ISCO® implementation, providing another measure of S-ISCO®'s safety and its ability to completely degrade breakdown products.

Figure 3: Coal Tar Removal

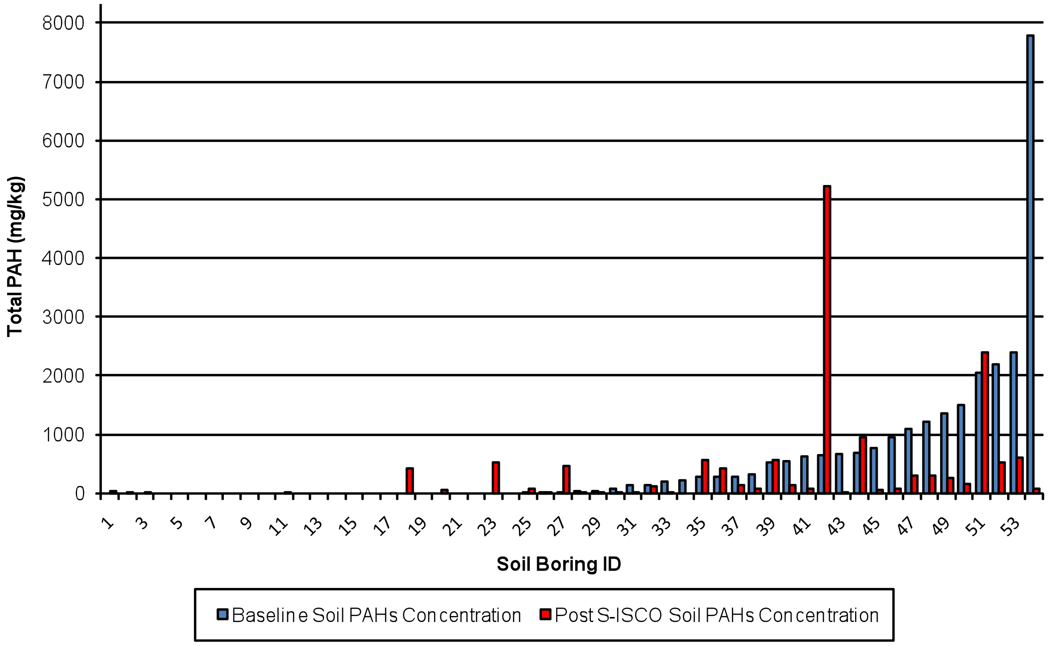
3a. Pre-treatment Stained Core

3b. Post-S-ISCO® Clean Core

Figure 3a, a petroleum-stained soil core taken before treatment and **Figure 3b,** a corresponding clean core taken after treatment, show the success of S-ISCO® in removing visible coal tar from the soil.

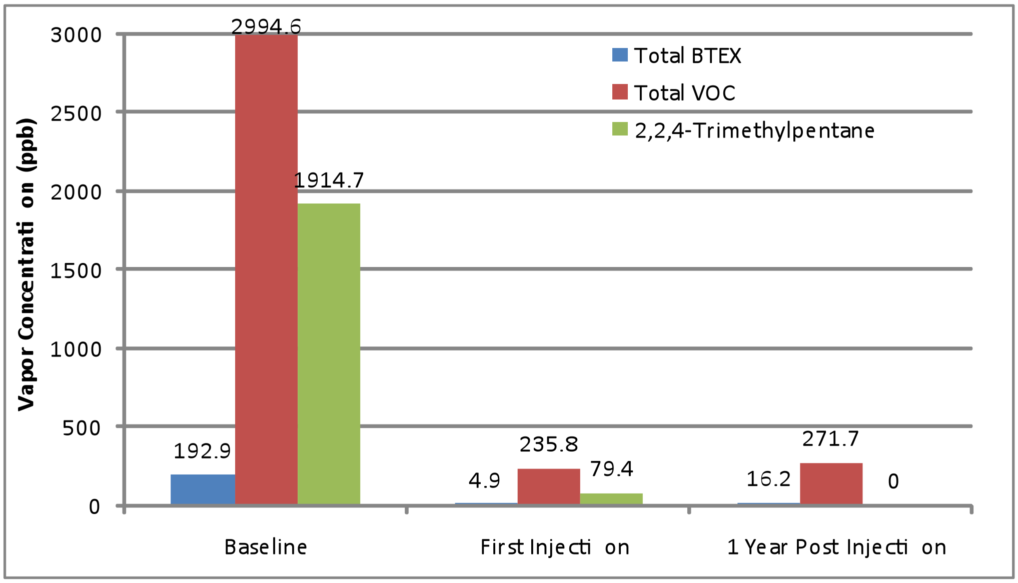
The S-ISCO® treatment destroyed **843 kg of total VOCs and SVOCs**, approximately 94% of the mass of VOCs and SVOCs the pilot test was designed to treat. In addition, the pilot test destroyed 3,600 kg of medium-range petroleum hydrocarbons (MPH), a mass of contamination in excess of the treatment's design. **Figure 4** shows pre- and post-S-ISCO® PAH concentrations, in rank order according to baseline measurements.

Figure 4: Pre and Post S-ISCO® PAHs



In addition, analytical results of soil gas samples collected approximately 20 feet from the injection wells indicate that S-ISCO® effectively and sustainably reduced contamination in soil gas vapors. These reductions are shown in **Figure 5** and include 91.6% of BTEX, 90.9% total VOCs and 100% of 2,2,4-Trimethylpentane.

Figure **5**: Soil Gas



Treatment Results

Conclusions & Implications

A third party consultant oversaw this remediation and confirmed S-ISCO® destroyed MGP contamination at the Site in a safe and controlled manner, and that S-ISCO® can achieve complete or near-complete treatment of MGP-contaminated soils .

The New York State Department of Environmental Conservation (NYSDEC), Division of Environmental Remediation approved the results of this S-ISCO® implementation and sanctioned the use of S-ISCO® for further, larger-scale application at the site. In a letter the NYSDEC stated that "…the Department is approving the use of the 'Surfactant enhanced In-Situ Chemical Oxidation Technology' for full scale implementation at the site..."

In addition, this remediation aligns with the US EPA Office of Solid Waste and Emergency Response's (OSWER) Principles for Greener Cleanups, including: minimized energy use; minimized air pollution and greenhouse gas emissions; minimized impacts to water resources; reduction and reuse of waste material; and protection of land and ecosystems.

- *Energy Use*: S-ISCO® technology enables greater efficiency of ISCO processes, minimizing the project's duration and concomitant use of equipment; the S-ISCO® chemistry travelled in the subsurface with the flow of groundwater, removing the need for re-circulating or extraction pumps; and this *in situ* remediation did not require the heavy machinery used in excavations, for example.
- *Air pollution*: Contaminated material was treated on site; no material had to be hauled to landfills or disposal facilities.
- *Impacts to Water Resources*: S-ISCO® destroyed contamination impacting groundwater. In addition, groundwater monitoring confirmed that solubilized contaminants were subsequently oxidized and not mobilized.
- *Waste Reduction*: Soil was treated in place and on site; no soil was removed for disposal.

- *Protection of Land and Ecosystems*: S-ISCO® destroyed the contaminant source (coal tar), without soil removal or disturbance, and enabled the full use of the land in subsequent redevelopment.

Case Study

S-ISCO® REMEDIATION OF COAL TAR CONTAMINATION AT NYC BROWNFIELD

QUEENS, NEW YORK

VeruTEK®
TECHNOLOGIES

Site

Former Roofing Products Manufacturer,
Queens, New York

Contaminants of Concern

VOCs (BTEX) & SVOCs (PAHs and naphthalene) related to MGP coal tar in soil & groundwater

Clean-up Objectives

- Reduce contaminant mass from 10-22 ft bgs to enable issuance of Certificate of Completion (COC);
- Reduce groundwater contaminant flux.

Treatment Program

- VeruTEK's Surfactant-enhanced In Situ Chemical Oxidation (S-ISCO®) with VeruSOL® and alkaline-activated sodium persulfate;
- Wavefront's Primawave pressure-pulsing injection enhancement process;
- RemMetrik characterization process.

Results

- *Soil:* Destroyed >90% of total contamination targeted, including 95% of naphthalene;
- *Groundwater:* Reduced on and off-site concentrations; no NAPL mobilized; adjacent river protected throughout;
- *Soil Vapor:* Significant VOC & SVOC reductions, including 100% benzene & naphthalene, and 98% BTEX;
- *Technology Fusion:* Successful combination of S-ISCO with pressure-pulse technology.

Introduction

VeruTEK Technologies (VeruTEK) successfully destroyed coal tar contamination at a former roofing products manufacturing site in New York City using Surfactant-enhanced In Situ Chemical Oxidation (S-ISCO). The urban site, surrounded by dense residential and commercial development along the shores of the East River, was contaminated with coal tar repurposed from a nearby Manufactured Gas Plant (MGP) for the roofing manufacturing process. VeruTEK conducted five months of S-ISCO injections that destroyed greater than 90% of coal tar-related contaminants including BTEX, PAHs and naphthalene in the targeted interval. The treatment consisted of injections of VeruSOL, VeruTEK's patented plant-based surfactant and co-solvent mixture, and alkaline-activated sodium persulfate that were augmented by Wavefront Technology Solutions US Inc's (Wavefront) Primawave pressure-pulsing injection enhancement technology, as well as the RemMetrik^{SM} process to quantify subsurface contamination, optimize the treatment and measure its effectiveness

S-ISCO was an integral part of the remedial implementation that will enable redevelopment of the Brownfield site as a public library and park ranger station. The New York State Department of Environmental Conservation (NYSDEC) has issued a Certificate of Completion to confirm the success of the cleanup. The successful destruction of MGP-related coal tar at the urban Brownfield site demonstrates the effectiveness of S-ISCO as a remedy for MGP-related contamination.

Site Background

Located on a bank of the East River in a densely developed residential and commercial area in New York City, this 0.73-acre parcel is part of an urban revitalization project and will be redeveloped as a public library and park ranger station. As part of the history of roofing products manufacture at the parcel, MGP coal tar that was brought onto the site leaked into the subsurface, contaminating the soil and groundwater with benzene, toluene, ethylbenzene, and total xylenes (BTEX), naphthalene, and polycyclic aromatic hydrocarbons (PAHs). Contaminant concentrations in the soil and groundwater exceeded the NYSDEC regulatory limits, including in a number of groundwater locations by orders of magnitude. The majority of contamination was present as residual non-aqueous phase liquid (NAPL) held within the pore spaces of the predominately sandy and silty soil that also included lenses of silt and silty clay. Traditionally these NAPL droplets, especially in fine soils such as the silts and clays present at this site, present a challenge to *in situ* treatments.

Technology Background

S-ISCO® is one of VeruTEK's innovative Coelution Technologies that combines biodegradable, plant-based surfactant & co-solvent mixtures (VeruSOL) with free-radical oxidant systems to desorb and destroy NAPL and other strongly sorbed contaminants. Because oxidative destruction of NAPLs only occurs in the aqueous phase, traditional in situ chemical oxidation (ISCO) is limited by the immiscibility (resistance to dissolving in water) of organic contaminants. VeruSOL overcomes this limitation by desorbing and emulsifying the NAPL for destruction by a co-injected oxidant.

The Pressure-Pulsing Process uses a sidewinder tool to generate subsurface pressure waves that open soil pore spaces. Particularly in clayey and silty soils, this enhances the uniformity of chemical dispersion and the treatment's radius of influence

The S-ISCO technology was approved as part of the Brownfield Cleanup strategy for the site after the results of VeruTEK's bench-scale treatability tests and pilot-scale field implementation demonstrated that Surfactant-enhanced In Situ Chemical Oxidation (S-ISCO) could effectively contact and destroy contamination at the site, including sorbed NAPL. The laboratory and field-scale testing indicated that a S-ISCO treatment composed of VeruSOL-3 and alkaline-activated sodium persulfate was the optimal remedy for site contaminants, while the results of the pilot test also indicated that the incorporation of Primawave pressure-pulsing with S-ISCO injections enhanced the radius of influence and uniformity of dispersion for the injected chemistry.

Implementation

S-ISCO implementation took place between October 2010 and March 2011, and consisted of injections of VeruSOL-3, sodium persulfate and sodium hydroxide[1] into 34 wells located in the areas in which the greatest contamination had been identified[2]. These wells were variably screened across 6 – 7 foot lengthss within the 10 and 22 ft bgs treatment interval. Injections took place at an average rate of 8 gallons per minute (GPM) per well to 4 wells at a time (32 GPM overall), and were augmented by the Primawave pressure-pulsing tool. **Table 1** summarizes the injection parameters.

Table 1: Injection Summary

Chemical	Amount	Injected Concentration (g/L)
VeruSOL®	29,545 kg	5 g/L
Sodium Persulfate	152,000 kg	25 - 50 g/L
Sodium Hydroxide	61,950 kg	20 g/L
Total Fluid	1,201,900 gal	--

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[1] Sodium hydroxide was injected to create alkaline conditions to activate the sodium persulfate.

[2] Additional wells were installed when interim soil sampling revealed a previously un-identified area of contamination.

Monitoring

Monitoring was conducted before, during and after S-ISCO injections to track the progress and performance of the injected chemistry in the subsurface and to confirm that the treatment was not negatively impacting sensitive receptors, such as the adjacent river. Monitoring included: continuous tracking of water quality parameters using *in situ* data loggers; collection of groundwater samples for analysis in VeruTEK's on-site laboratory; observation of all wells on and off-site for indications of NAPL; and collection of soil and groundwater samples for contaminant analysis.

Results

Contamination Destruction

Approximately 5 months after the completion of injections, when the results of groundwater monitoring indicated that the sodium persulfate reactions had subsided, VeruSOL had largely degraded and pH conditions were approaching pre-injection levels, 114 soil grab samples were collected from the treatment area and analyzed for total VOCs and SVOCs[3]. These results were used to calculate the mass of contamination remaining that was then compared to the mass calculated before treatment. This analysis indicated that the S-ISCO treatment destroyed 90.3% of the mass of total VOCs and SVOCs present before treatment, including more than 95% of the naphthalene present. Naphthalene, a principal component of coal tar, was one of the primary SVOCs affecting the site soils and groundwater; it accounted for almost 65% of the total pre-treatment contaminant mass. **Table 2** shows additional reductions for priority contaminants, including benzene, toluene, ethylbenzene and total xylenes (BTEX).

Figure 2: Contaminant Mass Reduction

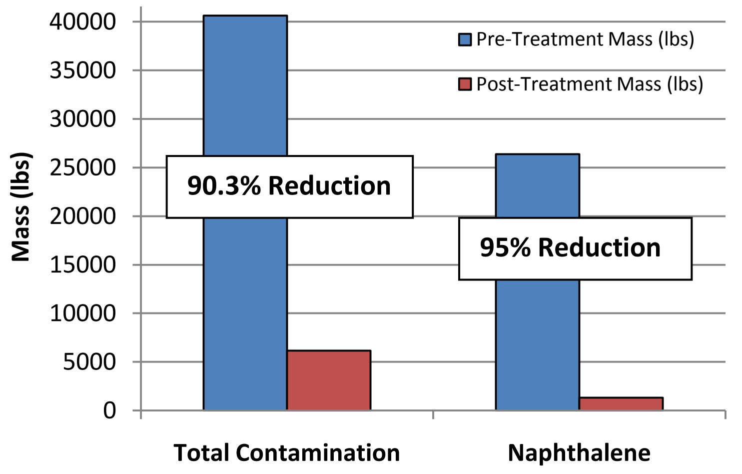

Table 2: Mass Reductions for Priority Contaminants

Contaminant	Pre-Treatment Mass (kg)	S-ISCO Reduction
Naphthalene	26,389	95 %
Benzene	30	85 %
Toluene	267	81 %
Ethylbenzene	348	75 %
Total Xylenes	1,028	60 %
BTEX	1,674	67 %
Total SVOCs & VOCs	40,621	90.3 %

Groundwater

Controlled Desorption & Destruction Process

The results of groundwater analysis for S-ISCO performance parameters[4], as well as regular inspection of all on and off-site wells for the presence of either NAPL or the injected chemistry, confirmed that the S-ISCO desorption and destruction process proceeded in a safe, controlled and effective manner. Specifically, while the injected VeruSOL desorbed and emulsified NAPL and sorbed contaminants, these contaminants were subsequently destroyed by the co-injected persulfate oxidant. **Figure 3** shows the S-ISCO process at a shallow well in the treatment area. This process is explained in greater detail in the **Attachment.**

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[3] TCL SVOCs (Method 8270) and TCL VOCs (Method 8260).

[4] S-ISCO performance parameters include interfacial tension (IFT), an indication of VeruSOL, electrolytic conductivity, and concentrations of sodium persulfate and total petroleum hydrocarbons (TPH).

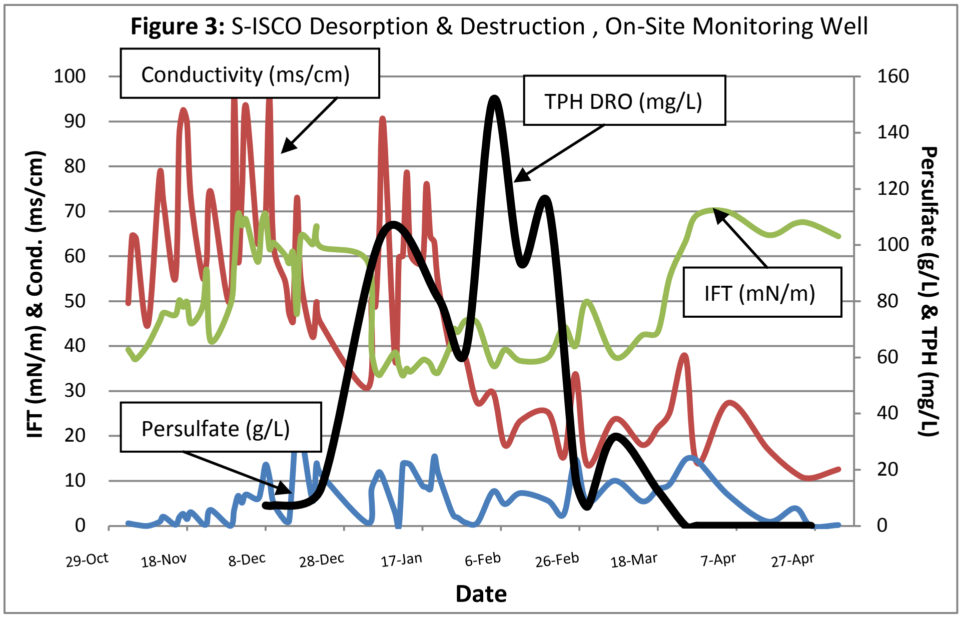
Figure 3: S-ISCO Desorption & Destruction , On-Site Monitoring Well

In addition, at no time during injections was any indication of either the injected chemistry or the targeted contamination, including NAPL, solubilized NAPL, odors or sheen, observed in off-site groundwater.

Contaminant Reductions

Groundwater samples from the nine on-site monitoring wells screened across the treatment interval (10-22 ft bgs) were analyzed before and after treatment. This data indicated that the S-ISCO treatment achieved significant VOCs reductions, including 92% for xylenes, 87% for benzene, the most toxic and mobile VOC at the site, 90% for ethylbenzene, and 91% for BTEX.

Soil Gas Contamination Reductions

Soil vapor samples collected from three areas adjacent to the site were analyzed before (October 2010) and after (April 2011) injections[5]. Because regular measurement of soil gas pressure[6] indicated that the injected oxidant was not causing any measurable increase in pressure, additional rounds of vapor sampling during injections were deemed unnecessary. Reductions in soil gas concentrations are summarized in **Table 3** and shown in **Figure 4,** and included 100% for benzene, ethylbenzene, naphthalene and TCE. Improvement in soil gas contamination included reductions at a sampling location more than 100 feet from the southeastern corner of the injection area, indicating that the effects of the treatment extended far beyond the immediate injection area.

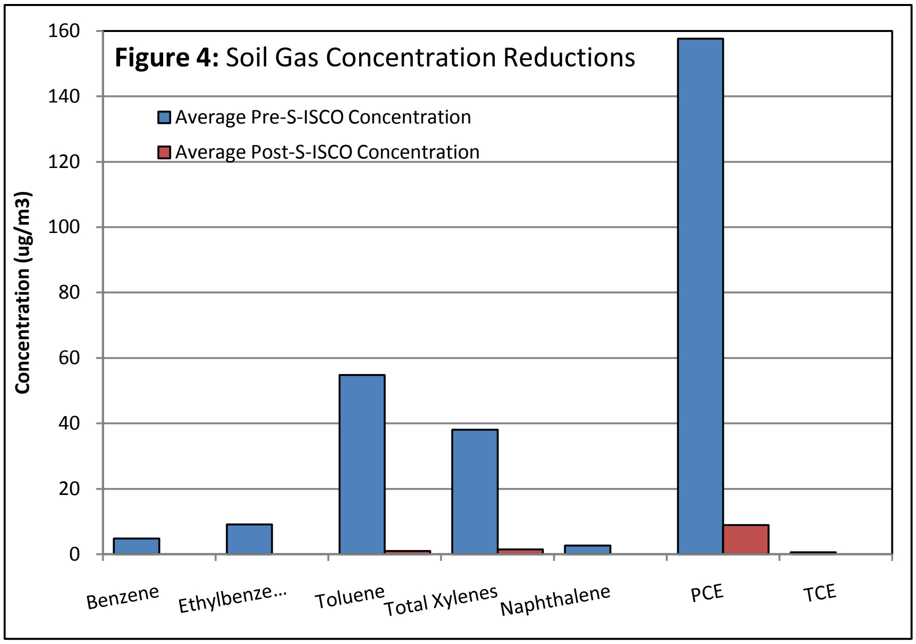
Figure 4: Soil Gas Concentration Reductions

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[5] Samples were collected from the 4 to 6 ft bgs interval and analyzed using Method TO-15 plus naphthalene.

[6] 4,440 soil gas readings were taken throughout the injection process.

Table 3: Soil Gas Concentration Reductions			
Contaminant	Pre-S-ISCO Average	Post-S-ISCO Average	% Reduction
Benzene	4.83	ND	100%
Ethylbenzene	9.10	ND	100%
Toluene	54.80	0.97	98%
Total Xylenes	38.10	1.43	96%
Naphthalene	2.67	ND	100%
PCE	157.67	8.90	94%
TCE	0.56	ND	100%

Conclusions

The successful destruction of MGP-related coal tar at this urban Brownfield site demonstrates a clear success for S-ISCO and its safety and effectiveness as a remedy for MGP-related contamination. The five month S-ISCO treatment successfully contacted, desorbed and destroyed NAPL contaminants and reduced soil vapor contamination in a controlled process without impacting the adjacent water body (the East River) or the local community.

Attachment

Tracking Desorption and Destruction

Implementations of S-ISCO include comprehensive groundwater monitoring programs designed to track the progress and performance of the injected chemistry and ensure the success of the desorption and destruction process. This monitoring includes laboratory analysis of groundwater samples for parameters including interfacial tension (IFT), conductivity and concentrations of oxidant (such as persulfate and peroxide) and TPH.

- ***Increased oxidant concentrations*** indicate effective transport and sufficient dosage of the oxidant.
- ***Increased conductivity measurements*** indicate the presence of oxidative reactions, and also that the oxidant has been successfully activated and is entering into reactions with contaminants.
- ***Reductions in IFT*** indicate the presence and effective transport of VeruSOL.
- Accompanied by ***increases in TPH concentration***, decreases in IFT indicate that VeruSOL has desorbed and solubilized immiscible contaminants.
- Subsequent ***decreases in TPH,*** in the presence of elevated conductivity, indicate that the desorbed contaminants have been oxidized.

Figure 3 (above) shows the results of groundwater monitoring conducted during S-ISCO treatment. This shallow well, screened from 11 to 21 feet bgs, was down-gradient to four injection wells into which VeruSOL and alkaline-activated sodium persulfate were injected during the period from October 2010 to the end of February 2011.

At the start of injections, the persulfate (blue) and conductivity (red) fronts arrive, indicating the presence of the injected oxidant (persulfate) and its entrance into reactions with dissolved contaminants present. The activity of the persulfate also indicates its successful activation. The VeruSOL front (green) follows, shown by the drop in IFT in early January. The rise in TPH that accompanies this decrease in IFT indicates that the VeruSOL is successfully desorbing and solubilizing contamination into the aqueous phase. The corresponding spike in conductivity and subsequent reduction in TPH indicates that the solubilized TPH is reacting with the activated persulfate. The IFT remains low as VeruSOL injections continue and the surfactant continues to desorb and emulsify additional TPH contaminants. As injections end, the persulfate remains in the subsurface but its reactions with the dissolved contamination slow as the alkaline conditions used for its activation become more acidic. Nevertheless, continued elevations in conductivity as well as continued decreases in TPH indicate that oxidative reactions are on-going.

VeruTEK® TECHNOLOGIES

Green Chemistry Technologies for the Environment

Site

Former MGP, Hartford, CT

Contaminants of Concern

TPH, SVOCs and VOCs

Treatment Program

- VeruTEK's Surfactant-enhanced In Situ Chemical Oxidation (S-ISCO®) and Surfactant-enhanced Ex Situ Chemical Oxidation (S-ESCO®).
- VeruSOL®, sodium persulfate, hydrogen peroxide, and sodium hydroxide.

Results

- 2,750 tons of contaminated soil were treated by S-ESCO™ aboveground;
- 1,900 tons of contaminated soil were treated by S-ISCO® in the subsurface;
- TPH concentrations in *ex situ* soils were reduced by as much as 95%, from 4,183 ppm to 182 ppm;
- Contaminant concentrations *in situ* and *ex situ* were reduced below I/C RSRs (Remediation Standard Regulations) established by the Connecticut DEP;
- Plans for site redevelopment could proceed.

Project Cost

$178,000 or $38/ton of soil

Case Study

S-ISCO® & S-ESCO™ DESTRUCTION OF TPH, VOCS AND SVOCS

HARTFORD, CT

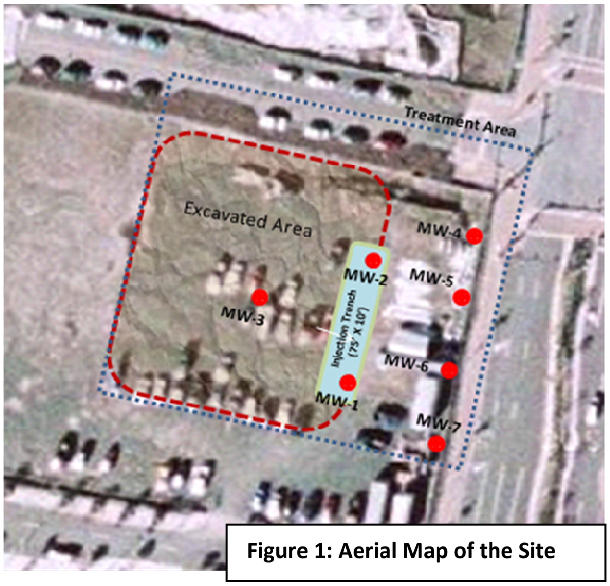


Figure 1: Aerial Map of the Site

Introduction

VeruTEK® Technologies, Inc. (VeruTEK) successfully remediated MGP-related contamination, including petroleum hydrocarbon, semi-volatile organic compounds (SVOCs) and volatile organic carbons (VOCs), present in soil at a former Manufactured Gas Plant (MGP) site in Hartford, Connecticut (the Site). This remediation enabled developers to include the Site in a large-scale urban redevelopment project. **Figure 1** presents an aerial map of the Site during treatment. **Figure 2** presents a frontal view of the commercial development that proceeded on the Site following treatment.

Figure 2: Redeveloped Site

Site Background

MGP-related contaminants had leaked to the subsurface from an abandoned gas holder and related piping, infiltrating the unsaturated zone (fine-grained glacial and alluvial sediments) and the upper fractured bedrock. The upper 10 feet of contaminated soil had been excavated but contamination at levels that exceeded Connecticut industrial/commercial (I/C) criteria remained below the excavation area, shown in red on **Figure 1.** Contamination was also present beneath the sidewalk and street adjacent to the Site that were not accessible to excavation, as well as in the aboveground piles of excavated soil. Specific soil contaminants of concern included: Benz(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Fluoranthene, Fluorene, Naphthalene, Dibenz(a,h)anthracene, Phenanthrene and total petroleum hydrocarbons (TPH). Soil contaminant levels and relevant criteria are shown in **Tables 1** and **2**, and on **Figure 6.**

To meet both the *in situ* and *ex situ* requirements of the Site, VeruTEK implemented two of its Coelution Technologies™, Surfactant-enhanced In Situ Chemical Oxidation (S-ISCO®) and Surfactant-enhanced Ex Situ Chemical Oxidation (S-ESCO™). S-ISCO targeted approximately 1,900 tons of contaminated soil *in situ* while S-ESCO targeted approximately 1,200 tons of contaminated soil *ex situ.*

Technology Background

S-ISCO and S-ESCO are two of VeruTEK's innovative and patented Coelution Technologies™ that are capable of completely or near completely destroying the amount of NAPL in soils. Using VeruSOL, proprietary mixtures of biodegradable, US FDA generally recognized as safe (GRAS) surfactants and co-solvents, along with free-radical oxidant systems, S-ISCO and S-ESCO effectively, efficiently and sustainably destroy both subsurface and above-ground contamination. Note that 'coelution' refers to the fact that the separate treatment streams—oxidant, surfactant and activator, are injected together into the treatment area to desorb, emulsify and oxidize contaminants.

Figure 3: Site Trench

Field Implementation

S-ISCO

S-ISCO treatment took place over the course of two weeks and consisted of injections of VeruSOL, sodium persulfate, and its activator, sodium hydroxide, that targeted approximately 3,800 lbs of contamination. VeruSOL served to desorb and emulsify the VOC, SVOC and TPH contaminants present for their destruction, in place, by activated persulfate. The treatment formulation and dosage were based on the results of bench-scale solubilization and oxidation tests VeruTEK conducted using Site soils prior to field implementation.

The S-ISCO chemistry was injected on the up-gradient edge of the excavation area into a stone-filled trench that measured 75 feet long, six feet wide and five feet deep (from approximately 11 to 16 feet below ground surface). The VeruSOL, persulfate and hydroxide were delivered in individual streams at a cumulative flow rate that ranged from 10 to 20 gallons per minute (gpm) during 10 to 12 hours each day.

Overall, the S-ISCO treatment consisted of the following:

- 7,560 lbs of persulfate, injected at 20 g/L;
- 380 lbs of VeruSOL, injected at 1.5 g/L; and
- 800 lbs of sodium hydroxide, injected at 1.5 g/L.

Figure 4: S-ESCO Application

Seven groundwater monitoring wells, shown on **Figure 1**, were installed and sampled before, during and after injections to track the progress and performance of the treatment chemistry. Groundwater was measured for pH, inter-facial tension (an indicator of VeruSOL), turbidity, conductivity, oxidation reduction potential (ORP), and persulfate and hydroxide concentrations. Monitoring of these parameters confirmed that injected chemistry was successfully moving through the subsurface and reacting with contaminants. Hydraulic head was also monitored to confirm hydraulic control during the injection process.

S-ESCO^{TM}

S-ESCO implementation consisted of applying S-ISCO chemistry to aboveground soils. The process took five days and treated approximately 1,660 cubic yards of contaminated soil that had been excavated from the area around the former gas holder. During S-ESCO, VeruSOL, sodium persulfate and hydrogen peroxide were applied to the soil as it was deposited into a pugmill. As shown in **Figure 4**, the soil was thoroughly mixed with the chemistry before it was deposited into stockpiles to react. The treatment dosage and chemical formulation were based on the results of bench-scale tests conducted prior to field implementation, and consisted of:

- 4,500 gallons of 27% hydrogen peroxide,
- 4,600 gallons of sodium persulfate, applied at a concentration of 300 g/L, and
- 534 pounds of VeruSOL, applied at a concentration ranging from 5 to 20 g/L.

Figure 5 shows the reactions taking place in the stockpiles of soil during the three days of treatment. The reactions are evidenced by the foaming and bubbling seen in the second and third views. **Table 3** of the Appendix contains pre- and post-S-ESCO soil analytical data for VOCs and SVOCs. **Figure 6** shows graphically the pre- and post-S-ESCO soil analytical data for TPH.

Field Results

Following S-ISCO, analysis of soil samples collected from the treatment area indicated that the necessary clean-up criteria (CT RSR for I/C sites) had been achieved and the client's remedial objectives had been met. Results of the *in situ* treatment were provided to the state Department of Environmental Protection to document remedial compliance of the Site and re-development of the brownfield parcel was able to proceed.

As a result of S-ESCO treatment, five out of the six soil stockpiles met or exceeded regulatory criteria for VOCs, and five out of six stockpiles met or exceeded criteria for SVOCs, as shown in **Table 2.** Reductions in VOCs included a more than

27% reduction in naphthalene in SP-NW, while reductions in SVOCs ranged from more than 26% (benz(a)anthracene in SP-SW) to 100% (dibenz(a,h)anthracene in SP-NE, SP2-S, SP-SE and SP2-N).

From the baseline TPH concentration, 4,183 ppm, TPH concentrations were reduced by as much as 96% (to 182 ppm in SP-SE), and on average by almost 92%, after three days of *ex situ* treatment. These results are shown in **Figure 6**.

Figure 5: S-ESCO Reactions

Treatment Cell Dosed with S-ISCO® Chemistry

Treatment Cell Reacting

Treatment Cell, Day 3

Implications

These successful S-ISCO and S-ESCO implementations treated 4,650 tons of soil at a cost of approximately $178,000 ($38/ton). In addition, this project embodied US EPA's Office of Solid Waste and Emergency Response's (OSWER) Principles for Greener Cleanups, including decreased energy use; reduced generation of air pollution; reduced waste generation; and protection of land and ecosystems. **Table 3** describes these principles in greater detail.

Lastly, as a result of these S-ISCO and S-ESCO treatments, the Site was approved for development and productive use as part of a large-scale urban revitalization project. The site was not longer a blight and liability but rather an asset that was repurposed for the city's benefit.

Appendix

Table 1: Pre-S-ISCO® Soil Data

Sample Type	CT Soil Criteria	Soil	Soil	Soil	Soil
Sample ID	I/C	MW2 10-12'	MW2 12-13'	MW3 12-13'	MW3 10-12'
SVOCs		mg/kg	mg/kg	mg/kg	mg/kg
Benz(a)anhracene	7.8	ND	ND	**840**	**760**
Benzo(a)pyrene	7.8	ND	ND	**540**	**570**
Benzo(b)fluoranthene	7.8	ND	ND	**610**	**640**
Fluoranthene	2500	ND	ND	**1,500**	**1,300**
Fluorene	2500	ND	ND	**1,100**	**1,000**
Naphthalene	2500	1,900	1,800	**13,000**	**17,000**
Phenanthrene	2500	590	ND	**3,100**	**2,600**
Total SVOCs	**--**	**3,180**	**1,800**	**26,890**	**29,980**

Only exceedances are shown.

Table 2: Pre- and Post-SESCO™ Soil Analytical Data, VOCs and SVOCs

Sample Type	CT Soil Regulations, I/C	Soil	Soil	Soil	Change	% Change	Soil	Soil	Soil	Change	% Change	Soil	Soil	Change	% Change
Date		18-Oct	22-Oct	29-Oct			18-Oct	22-Oct	29-Oct			22-Oct	29-Oct		
VeruTEK ID		SP-NW	SP-NW	SP-NW			SP-NE	SP-NE	SP-NE			SP2-S	SP#2S		
VOCs	mg/kg	mg/kg	mg/kg	mg/kg			mg/kg	mg/kg	mg/kg			mg/kg	mg/kg		
Naphthalene	5.60	6.60	4.8	--	-1.80	**-27.3**	2.4	9.2	--	6.8	283.3	22.0	--	--	--
SVOCs	mg/kg	mg/kg	mg/kg	mg/kg			mg/kg	mg/kg	mg/kg			mg/kg	mg/kg		
Benz(a)anthracene	7.80	--	7.8	4.5	-3	**-42.3**	--	7.8	4.6	-3.2	**-41.0**	6.8	4.0	-2.8	**-41.2**
Benzo(a)pyrene	7.80	--	8.7	6.0	-3	**-31.0**	--	9.2	4.9	-4.3	**-46.7**	7.2	4.5	-2.7	**-37.5**
Benzo(b)fluoranthene	7.80	--	10.0	7.0	-3	**-30.0**	--	10.0	6.0	-4.0	**-40.0**	9.1	4.9	-4.2	**-46.2**
Dibenz(a,h)anthracene	1.00	--	1.5	0.9	-1	**-42.7**	--	1.4	ND (<0.81)	-1.4	**-100.0**	1.0	ND (<0.78)	-1.0	**-100.0**
Total SVOCs	--	--	90.1	**57.2**	**-33**	**-36.5**	--	100.6	60.4	-40.2	**-40.0**	86.4	**52.3**	-34.1	**-39.5**

Sample Type		Soil	Soil	Soil	Change	% Change	Soil	Soil	Soil	Change	% Change	Soil	Soil	Change	% Change
Date		18-Oct	22-Oct	29-Oct			18-Oct	22-Oct	29-Oct			22-Oct	29-Oct		
VeruTEK ID		SP-SW	SP-SW	SP-SW			SP-SE	SP-SE	SP-SE			SP2-N	SP2-N		
SVOCs	mg/kg	ug/kg	ug/kg	ug/kg			ug/kg	ug/kg	ug/kg			ug/kg	ug/kg		
Benz(a)anthracene	7.8	--	9	6	-2	**-26.7**	--	4.8	2.6	-2.2	**-45.8**	4.0	2.3	-1.7	**-42.5**
Benzo(a)pyrene	7.8	--	11	8	-3	**-30.9**	--	6.6	2.9	-3.7	**-56.1**	4.8	2.7	-2.1	**-43.8**
Benzo(b)fluoranthene	7.8	--	13	9	-4	**-30.8**	--	7.2	3.6	-3.6	**-50.0**	5.6	3.2	-2.4	**-42.9**
Dibenz(a,h)anthracene	1	--	2	1	-1	**-31.3**	--	0.9	ND (<0.75)	-0.9	**-100.0**	0.8	ND (<0.78)	-0.8	**-100.0**
Total SVOCs	--	**--**	129	79	-50	**-38.4**	**--**	88.9	33.5	-55.4	**-62.3**	51.9	30.7	-21.2	**-40.9**

Note: Only exceedances are shown.

Figure C: S-ESCO™ Soil TPH Reductions

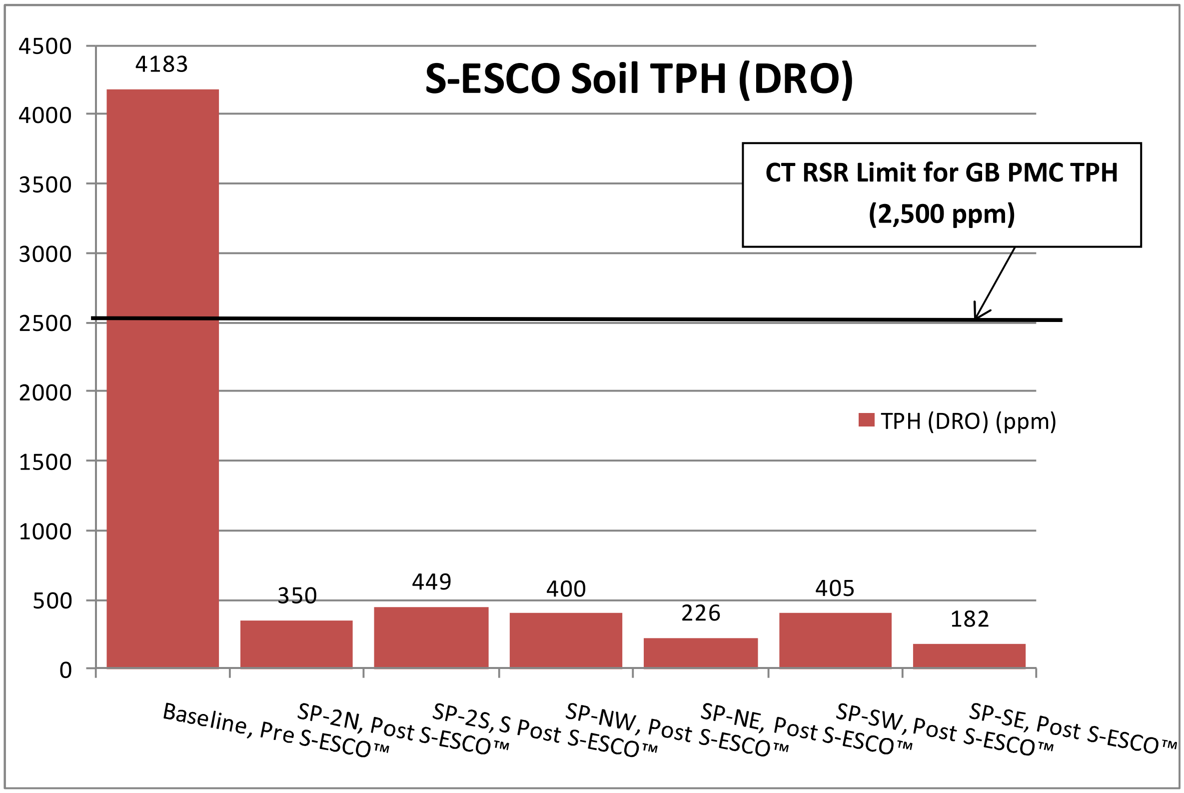
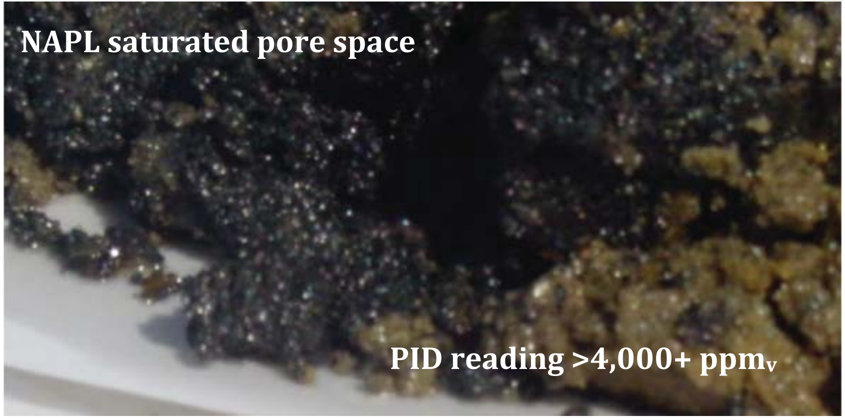


Table 3: US EPA's OSWER Principles for Greener Cleanups	
Energy Use	S-ISCO® technology enables greater efficiency of ISCO processes, minimizing the amount of time a project is implemented and equipment is run; S-ISCO® chemistry travelled in the subsurface with the flow of groundwater, removing the need for re-circulating or extraction pumps; and *in situ* remediation does not require the heavy machinery used in excavations, for example.
Air pollution	All materials were treated on site; no material had to be hauled off-site to landfills or disposal facilities.
Impacts to Water Resources	S-ISCO® destroyed contamination impacting groundwater and reduced contaminant concentrations in groundwater. In addition, groundwater monitoring confirmed that all solubilized contaminants were subsequently oxidized and not mobilized.
Waste Reduction	Excavated soil was treated on site (by S-ESCO™) and beneficially re-used on-site.
Protection of Land and Ecosystems	S-ISCO® destroyed the contaminant source, enabling the full use of the land in redevelopment, and enabled treatment of the site without further soil removal or disturbance.

IN-SITU CHEMICAL OXIDATION CASE STUDY

- **Problem: Persistent recurrence of ephemeral LNAPL in monitor wells was preventing regulatory closure.**
- **Cause: Petroleum NAPL sequestered within interstitial pore space at the lower vadose zone seasonally resulted in measureable LNAPL presence in groundwater monitoring wells.**
- **Solution: Remove petroleum sequestered in soil from the smear zone; NAPL in particular. A VeruTEK® patented Surfactant Enhanced chemical oxidation (SISCO)® treatment train specifically designed for this site was implemented as a cost-effective, permanent solution.**

A pipeline pumping station in Texas has transported diesel and gasoline for over 60 years, resulting in soil and groundwater contamination. The site is under the regulatory jurisdiction of the Texas Commission on Environmental Quality. A high vacuum extraction system was in operation over ten years. LNAPL persistently recurred in monitor wells near the property border preventing regulatory closure. A Field Pilot Test was performed evaluating the effectiveness of a Surfactant Enhanced In-Situ Chemical Oxidation treatment train. Those results are presented in this case study.



Soil sampled from the lower vadose zone (25 – 25.5 ft bgs) prior to treatment exhibited free NAPL from highly weathered diesel and gasoline. Monitor well MW-25 was installed in this borehole for performance monitoring. Four injection wells were installed approximately 10 ft. radially from MW-25. Pre-treatment soil analytical results are as follows:

Total Petroleum Hydrocarbon
C6-C12 = 36,000 mg/Kg
C12 – C28 = 28,000 mg/Kg
C28 – C35 = <1250 mg/Kg (U)
C6 – C35 = 60,000 mg/Kg

Benzene = 21.000 mg/Kg
Toluene = 240.000 mg/Kg
Ethylbenzene = 210.000 mg/Kg
Xylenes (m, o & p) = 800.000 mg/Kg
BTEX = 1,271 mg/Kg

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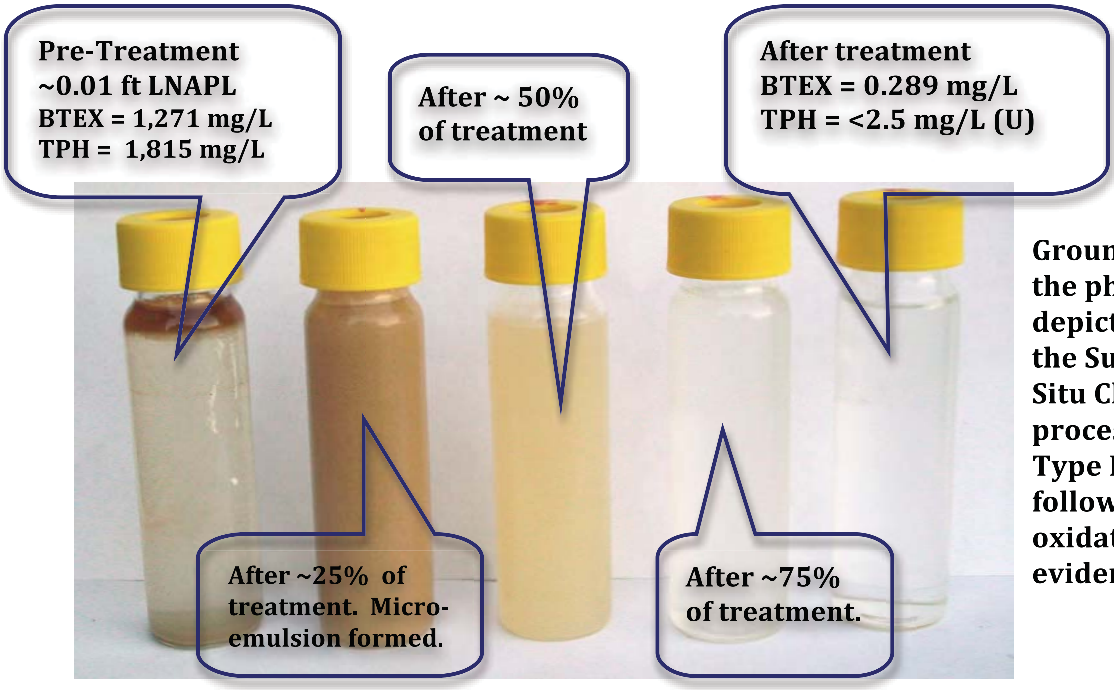
IN-SITU CHEMICAL OXIDATION CASE STUDY

Transitioning non-aqueous phase organics into an aqueous phase and producing persistent contact between the organic contaminant and the oxidant reagent is critical for achieving adequate NAPL destruction. The treatment area was inoculated using **VeruSolve-HP™** aqueous reagent as a Surfactant-Enhanced In-Situ Chemical Oxidation (S-ISCO™) Co-elution Technology™ manufactured by **VeruTEK Technologies, Inc.**

VeruTEK's stabilized surfactant-cosolvent/oxidant blend achieves Winsor Type I solubilization, where the contaminant is solubilized as a single-phase micro-emulsion and dissolution of constituents occurs without mobilization. This allows for the destruction of the contaminants that are currently in a non-aqueous phase. (i.e. the source term). The resulting REDOX reaction will occur over time. Reaction kinetics are controlled, sustaining a highly oxidative environment for weeks. Extended persistence greatly increases the contaminant-oxidant contact persistence, thereby producing very favorable results.

The treatment area was inoculated with four 500-gallon batches of VeruSolve HP reagent separated by one week per batch. Step-wise inoculation with three interim 7-day non-injection periods was a critical component to overall contaminant destruction efficiency. Groundwater quality was continually monitored for oxidation-reduction potential, dissolved oxygen, temperature, specific conductance and pH. Groundwater piezometric surface was continuously monitored in the treatment area during injection allowing for injection flow rate and pressure modulation to insure optimal subsurface distribution.



Pre-Treatment
~0.01 ft LNAPL
BTEX = 1,271 mg/L
TPH = 1,815 mg/L

After ~ 50% of treatment

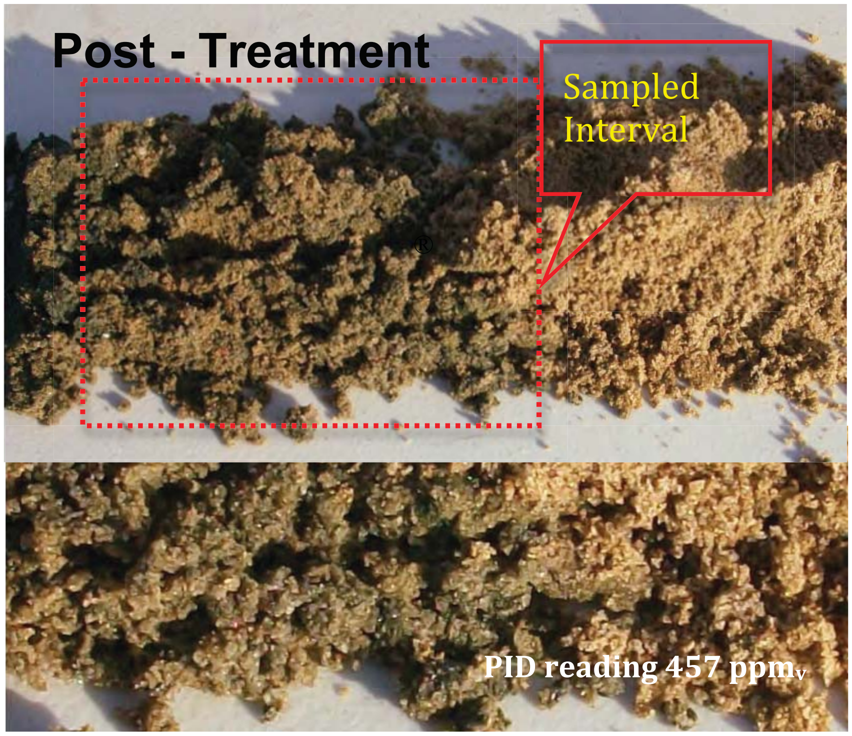
After treatment
BTEX = 0.289 mg/L
TPH = <2.5 mg/L (U)

After ~25% of treatment. Micro-emulsion formed.

After ~75% of treatment.

Groundwater samples in the photo to the left visually depict different stages of the Surfactant-Enhanced In-Situ Chemical Oxidation process. Initial Winsor Type I solubilization followed by sustained oxidation kinectics is evident.

IN-SITU CHEMICAL OXIDATION CASE STUDY



After SISCO® treatment, a soil boring was installed within 18 inches of MW-25. No NAPL is detectable. The previously sampled soil interval (25 – 25.5 ft bgs) was re-sampled. Post - treatment soil analytical results are as follows:

Total Petroleum Hydrocarbon

C6-C12 = 152 mg/Kg
C12 – C28 = 280 mg/Kg
C28 – C35 = <12.9 mg/Kg (U)
C6 – C35 = 432 mg/Kg

Benzene = <0.005 mg/Kg (U)
Toluene = <0.005 mg/Kg (U)
Ethylbenzene = 0.3939 mg/Kg
Xylenes (m, o & p) = 0.1520 mg/Kg
BTEX = 0.5459 mg/Kg

In-Situ Chemical Oxidation Results

The site has three specific regulatory based clean-up goals that must be met in order to obtain closure:

1. Eliminate measurable LNAPL re-occurrence in groundwater monitor wells
2. Reduce soil TPH GRO, DRO and Benzene concentrations below risk-based closure goals
3. Reduce groundwater TPH GRO, DRO and Benzene concentrations below risk-based closure goals

The Field Pilot Study demonstrated Surfactant-Enhanced In-Situ Chemical Oxidation (S-ISCO™) sufficiently achieved the following goals:

- **Separate Phase Hydrocarbons: the source for ephemeral LNAPL was eliminated.**
- **COC concentrations were reduced as follows:**

SOIL	PRE-TREATMENT	REMEDIAL GOAL	POST-TREATMENT
TPH GRO (C6 – C12)	36,000 mg/Kg	≤ 2,640 mg/Kg	152 mg/Kg
TPH DRO (C12 – C28)	28,000 mg/Kg	≤ 14,700 mg/Kg	280 mg/Kg
Benzene	21.000 mg/kg	≤ 2.56 mg/Kg	<0.005 (U) mg/Kg
GROUNDWATER	**PRE-TREATMENT**	**REMEDIAL GOAL**	**POST-TREATMENT**
TPH GRO (C6 – C12)	1,000.00 mg/L	≤ 16.1 mg/L	<2.5 (U) mg/L
TPH DRO (C12 – C28)	810.00 mg/L	≤ 149.1 mg/L	<2.5 (U) mg/L
Benzene	2.000 mg/L	≤ 0.083 mg/L	0.062 mg/L

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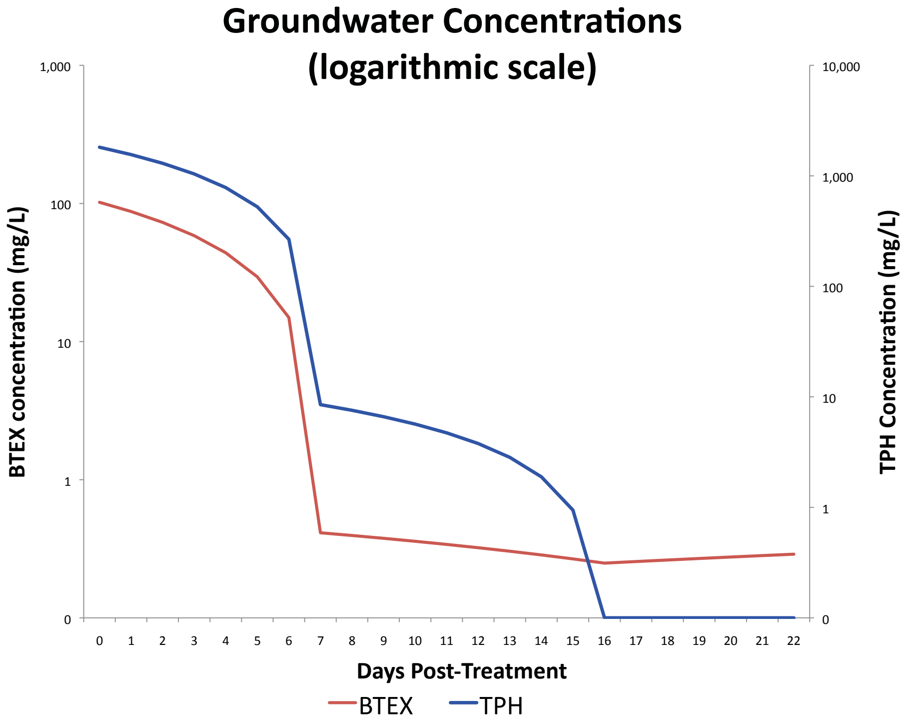
IN-SITU CHEMICAL OXIDATION CASE STUDY



The Field Pilot Study clearly demonstrated each regulatory closure goal was exceeded using Surfactant-Enhanced In-Situ Chemical Oxidation (S-ISCO™) tailored to site-specific conditions under properly guided and monitored application procedures.

Soil

- **All detectable NAPL was removed from interstitial pore space**
- **TPH (C6 – C35) reduced 99.33%**
- **BTEX reduced 99.96%**

Groundwater

- **LNAPL removed. No sheen remains**
- **TPH reduced >99.93%**
- **BTEX reduced 99.72%**

This In-Situ Chemical Oxidation Field Pilot Case Study was a collaborative effort between:

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