SUPPLEMENTAL REMEDIAL INVESTIGATION WORK PLAN
FORMER CHARLTON CLEANERS FACILITY
FOREST AVENUE SHOPPERS TOWN
STATEN ISLAND, NEW YORK
VCP SITE ID NO. W3-0891-01-06

APPENDIX III

HYDROGEN RELEASE COMPOUND ADVANCED® (HRCA) TECHNICAL REFERENCES

The reader is referred to the manufacturer's website pages which describe Hydrogen Release Compound Advanced® (HRCA) in detail:

Regenesis Home Page: http://www.regenesis.com/

Case Studies: http://www.regenesis.com/resources/casestudies/hrcadv.aspx

Technical Bulletins: http://www.regenesis.com/resources/bulletins/hrc.aspx

3-D Microemulsion (3DMe)™
MATERIALS SAFETY DATA SHEET

Last Revised: March 26, 2007

Section 1 – Material Identification

Supplier:

REGENESIS

1011 Calle Sombra
San Clemente, CA 92673

Phone:	**949.366.8000**
Fax:	**949.366.8090**
E-mail:	**info@regenesis.com**
Chemical Name(s):	• Glycerides, di-, mono [2-[2-[2-(2-hydroxy-1-oxopropoxy)-1-oxopropoxyl]-1-oxopropoxy]propanoates] • Propanoic acid, 2-[2-[2-(2-hydroxy-1-oxopropoxy)-1-oxopropoxy]-1-oxopropoxy]-1,2,3-propanetriyl ester • Glycerol
Chemical Family:	**Organic Chemical**
Trade Name:	**3-D Microemulsion (3DMe)™**
Synonyms:	**HRC Advanced™ HRC-PED (Hydrogen Release Compound – Partitioning Electron Donor)**
Product Use:	**Used to remediate contaminated groundwater (environmental applications)**

Section 2 – Chemical Identification

CAS#	**Chemical**
823190-10-9	**HRC-PED**
61790-12-3 or **112-80-1**	**Fatty Acids (neutralized)**
201167-72-8	**Glycerol Tripolylactate**
56-81-5	**Glycerol**

Section 3 – Physical Data

Melting Point:	**Not Available (NA)**
Boiling Point:	**Not determined (ND)**
Flash Point:	**> 200 ºF using the Closed Cup method**
Density:	**0.9 -1.1 g/cc**
Solubility:	**Slightly soluble in acetone. Insoluble in water.**
Appearance:	**Amber semi-solid.**
Odor:	**Not detectable**
Vapor Pressure:	**None**

Section 4 – Fire and Explosion Hazard Data

Extinguishing Media:	**Use water spray, carbon dioxide, dry chemical powder or appropriate foam to extinguish fires.**

Water May be used to keep exposed containers cool.

For large quantities involved in a fire, one should wear full protective clothing and a NIOSH approved self contained breathing apparatus with full face piece operated in the pressure demand or positive pressure mode as for a situation where lack of oxygen and excess heat are present.

Section 5 – Toxicological Information

Acute Effects:	**May be harmful by inhalation, ingestion, or skin absorption. May cause irritation. To the best of our knowledge, the chemical, physical, and toxicological properties of the 3-D Microemulsion have not been investigated. Listed below are the toxicological information for glycerol, lactic acid and fatty acid.**	
RTECS#	**MA8050000** **Glycerol**	
Irritation Data:	**SKN-RBT 500 MG/24H MLD** **EYE-RBT 126 MG MLD** **EYE-RBT 500 MG/24H MLD**	**85JCAE-,207,1986** **BIOFX* 9-4/1970** **85JCAE-,207,1986**

Section 5 – Toxicological Information (cont)

Toxicity Data:	ORL-MUS LD50:4090 MG/KG	FRZKAP (6),56,1977
	SCU-RBT LD50:100 MG/KG	NIIRDN 6,215,1982
	ORL-RAT LD50:12,600 MG/KG	FEPRA7 4,142,1945
	IHL-RAT LC50: >570 MG/M3/1H	BIOFX* 9-4/1970
	IPR-RAT LD50: 4,420 MG/KG	RCOCB8 56,125,1987
	IVN-RAT LD50:5,566 MG/KG	ARZNAD 26,1581,1976
	IPR-MUS LD50: 8,700 MG/KG	ARZNAD 26,1579,1978
	SCU-MUS LD50:91 MG/KG	NIIRDN 6,215,1982
	IVN-MUS LD50:4,250 MG/KG	JAPMA8 39,583,1950
	ORL-RBT LD50: 27 MG/KG	DMDJAP 31,276,1959
	SKN-RBT LD50: >10 MG/KG	BIOFX* 9-4/1970
	IVN-RBT LD50: 53 MG/KG	NIIRDN 6,215,1982
	ORL-GPG LD50: 7,750 MG/KG	JIHTAB 23,259,1941

Target Organ Data: Behavioral (headache), gastrointestinal (nausea or vomiting), Paternal effects (spermatogenesis, testes, epididymis, sperm duct), effects of fertility (male fertility index, post-implantation mortality).

Only selected registry of toxic effects of chemical substances (RTECS) data is presented here. See actual entry in RTECS for complete information on lactic acid and glycerol.

Fatty Acids

Acute oral (rat) LD50 value for fatty acids is 10000 mg/kg. Aspiration of liquid may cause pneumonitis. Repeated dermal contact may cause skin sensitization.

Section 6 – Health Hazard Data

One should anticipate the potential for eye irritation and skin irritation with large scale exposure or in sensitive individuals. Product is not considered to be combustible. However, after prolonged contact with highly porous materials in the presence of excess heat, this product may spontaneously combust.

Handling: Avoid continued contact with skin. Avoid contact with eyes.

In any case of any exposure which elicits a response, a physician should be consulted immediately.

First Aid Procedures

Inhalation: Remove to fresh air. If not breathing give artificial respiration. In case of labored breathing give oxygen. Call a physician.

Ingestion: No effects expected. Do not give anything to an unconscious person. Call a

physician immediately. DO NOT induce vomiting.

Section 6 – Health Hazard Data (cont)

Skin Contact:	**Flush with plenty of water. Contaminated clothing may be washed or dry cleaned normally.**
Eye Contact:	**Wash eyes with plenty of water for at least 15 minutes lifting both upper and lower lids. Call a physician.**

Section 7 – Reactivity Data

Conditions to Avoid:	**Strong oxidizing agents, bases and acids**
Hazardous Polymerization:	**Will not occur.**
Further Information:	**Hydrolyses in water to form lactic acid, glycerol and fatty acids.**
Hazardous Decomposition Products:	**Thermal decomposition or combustion may produce carbon monoxide and/or carbon dioxide.**

Section 8 – Spill, Leak or Accident Procedures

After Spillage or Leakage:	**Neutralization is not required. The material is very slippery. Spills should be covered with an inert absorbent and then be placed in a container. Wash area thoroughly with water. Repeat these steps if slipperiness remains.**
Disposal:	**Laws and regulations for disposal vary widely by locality. Observe all applicable regulations and laws. This material may be disposed of in solid waste. Material is readily degradable and hydrolyses in several hours.**

No requirement for a reportable quantity (CERCLA) of a spill is known.

Section 9 – Special Protection or Handling

Should be stored in plastic lined steel, plastic, glass, aluminum, stainless steel, or reinforced fiberglass containers.

Protective Gloves:	**Vinyl or Rubber**
Eyes:	**Splash Goggles or Full Face Shield. Area should have approved means of washing eyes.**
Ventilation:	**General exhaust.**
Storage:	**Store in cool, dry, ventilated area. Protect from incompatible materials.**

Section 10 – Other Information

This material will degrade in the environment by hydrolysis to lactic acid, glycerol and fatty acids. Materials containing reactive chemicals should be used only by personnel with appropriate chemical training.

The information contained in this document is the best available to the supplier as of the time of writing. Some possible hazards have been determined by analogy to similar classes of material. No separate tests have been performed on the toxicity of this material. The items in this document are subject to change and clarification as more information becomes available.

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Advanced Technologies for Groundwater Resources

Wednesday, May 07, 2008

Products Services Resources Company Worldwide Search Order Contact

3-D Microemulsion (3DMe)™ (HRC Advanced®)

Overview

Overview

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Products Overview » Enhanced Anaerobic Bioremediation » 3-D Microemulsion (3DMe)™ Overview

Achieve Rapid and Cost-Effective Chlorinated Contaminant Treatment through Wide-Area Application and Three Donor (3-D) Release Profile

Product Attributes

Low-Cost (< $0.40 per pound as applied)
Less money spent on electron donor material equals more money for other project costs or to the bottom line.

High Volume, Microemulsion Application
Increases contact with contaminants and reduces number of injection points required for treatment (saves time and money).

Enhanced Distribution through Micellar Transport
Unlike oil products, 3DMe forms micelles which are mobile in groundwater and significantly enhance electron donor distribution after injection.

Persistent and Long Lasting Hydrogen Source
Provides free lactic acid, controlled release lactic acid and long release fatty acids for effective hydrogen production for periods up to 5 years.

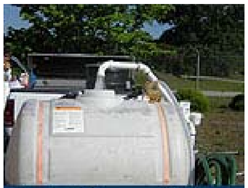
Incorporates Proven (HRC®) Technology
Successfully applied on over 1,000 sites worldwide.

Product

3-D Microemulsion (3DMe)™, a form of HRC Advanced®, is a revolutionary new product offering the most advanced hydrogen releasing technology available - at a price point equal to that of lesser performing simple commodity products. 3DMe is a product designed specifically for the low-cost in-situ treatment of chlorinated solvent based contaminants.


The 3-D Microemulsion is conveniently made on-site by mixing delivered 3DMe concentrate and water.

3DMe incorporates the proven Hydrogen Release Compound (HRC®) patented technology in addition to an entirely new and unique patented molecule (patent pending) that is specifically designed to time release a combination of highly efficient electron donors. Additionally, 3DMe was designed with a relatively high hydrophilic/lipophilic balance (HLB), allowing dilute suspensions to be well distributed across contaminant plumes without the high injection costs.


The 3-D Microemulsion is prepared in-high volumes for maximum subsurface distribution.

Upon application to the subsurface, 3DMe immediately begins to produce hydrogen and to distribute hydrogen generating compounds to the subsurface through a series of hydration and fermentation reactions. This process provides for an immediate as well as time-release supply of hydrogen to fuel the demands of the anaerobic reductive dechlorination process. Typical longevity for 3DMe is up to 2 years or more on a single injection and up to 4 years or more under optimal conditions.


The material is then injected into the treatment area through mobile direct-injection or permanent points.

Application Options

As with any injectable substrate, effective subsurface distribution is key, thus 3DMe was designed to be applied in concentrated form and in high volume. Concentrated applications are similar to that of standard HRC and involve use and injection of the product straight out of the container. High volume applications are different in that the 3DMe is mixed with water on-site, then injected into the subsurface dramatically increasing the volume and distribution of the material throughout the contaminated aquifer.

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Wednesday, May 07, 2008

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3-D Microemulsion (3DMe)™ (HRC Advanced®)

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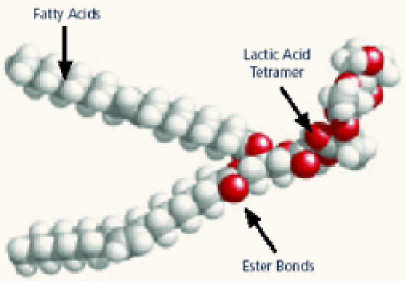
Functionality

This specially formulated product has a molecular structure (patent applied for) which time-releases a combination of lactic acid and fatty acids. This structure (Figure 1.) allows for a continuum in the release profile providing an immediate, medium range and long term, controlled-release supply of hydrogen to fuel the natural, reductive dechlorination process.

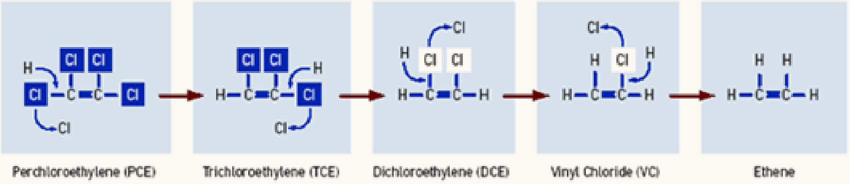
FIGURE 1:
THE 3DMe MOLECULAR STRUCTURE



Reductive dechlorination (Figure 2.) results in the step-by-step biological degradation of chlorinated contaminants. 3DMe can be used to degrade a range of chlorinated compounds including: degreasing agents (PCE, TCE, TCA and their breakdown products), carbon tetrachloride, chloroform, methylene chloride, certain pesticides/herbicides, perchlorate, nitrate, nitroaromatic explosives and dyes, chlorofluorocarbons, certain metals and radionuclides.

3DMe is supplied and shipped as a liquid concentrate. It can be applied to the subsurface via direct-injection in either its delivered, concentrate form or in an emulsified, high-volume form (recommended). The emulsified, high-volume material offers a unique micro-emulsion/ micelle suspension (refer to 3DMe Tech Bulletin 2.0 for more on micelles) which maximizes subsurface distribution by impacting a large volume of the targeted aquifer pore space immediately upon injection. 3DMe enhances transport in the subsurface through micelle formation and the release of soluble lactate fractions affecting an increasing volume of aquifer over time with a single injection.

FIGURE 2. REDUCTIVE DECHLORINATION OF PCE



3-D Microemulsion (3DMe)™

INSTALLATION INSTRUCTIONS

High-Volume, Wide-Area, Micro-Emulsion Application

Introduction

3-D Microemulsion (3DMe)™, a form of HRC Advanced®, should ONLY be applied as a high-volume, micro-emulsion. In this form it offers greater physical distribution of the 3DMe material across a larger potential radius from a single injection point. The production of a 3DMe emulsion involves the on-site, volumetric mixing of 10 parts water with 1 part delivered 3DMe concentrate to form the injection-ready 3DMe micro-emulsion. This micro-emulsion suspension can then be injected directly or further diluted to a predetermined ratio of 3DMe to water. The following instructions provide details in the production and installation of the 3DMe micro-emulsion.

Material Overview Handling and Safety

3DMe concentrate is shipped and delivered in 4.25-gallon buckets. Each bucket has a gross weight of approximately 32 pounds. Each bucket contains 30 pounds of 3DMe concentrate (net weight) and a nominal volume of 3.7 gallons. At room temperature, 3DMe concentrate is a liquid material with a viscosity of approximately 500 centipoise, roughly the equivalent of pancake syrup. The viscosity of 3DMe is not temperature sensitive above 50 ºF (10 ºC). However, below 50 ºF the viscosity may increase significantly. If the user plans to apply the product in cold weather, consideration should be given to heating the material to above 60 ºF so that it can be easily handled. 3DMe concentrate should be stored in a warm, dry place that is protected from direct sunlight. It is common for stored 3DMe concentrate to settle somewhat in the bucket, a quick pre-mix stir by a hand held drill with a paint or "jiffy mixer" attachment will rapidly re-homogenize the material. 3DMe concentrate is non-toxic, however field personnel should take precautions while handling and applying the material. Field personnel should use appropriate personal protection equipment (PPE) including eye protection. Gloves should be used as appropriate based on the exposure duration and field conditions. A Material Safety Data Sheet is provided with each shipment. Personnel who operate field equipment during the installation process should have appropriate training, supervision, and experience and should review the MSDS prior to site operations.

Micro-Emulsion Production 3DMe to Water Ratio

3DMe concentrate should be mixed with water on a volume to volume (v/v) basis to produce a micro-emulsion starting at 10 parts water: 1 part 3DMe. Although micro-emulsions can be easily produced using greater water volumes than 10 parts, e.g. 20 to 50 parts water to 1 part 3DMe, the initial micro-emulsion should never be produced below a ratio of less than 10 parts water: 1 part 3DMe v/v. **WARNING: Do not attempt to produce a micro-emulsion at less than 10 parts water to 1 part 3DMe ratio v/v. This will produce an undesirable and unstable solution.**

The field production of 3DMe micro-emulsion is a very simple procedure; however, it is critical that the user follow the mixing directions outlined below. Never attempt to add water to the 3DMe as this will produce an undesirable and unstable large emulsion. Always add the 3DMe to a large volume of water.

As indicated previously the 10:1 ratio of water to 3DMe v/v is the minimum water ratio that can be used, a greater ratio (more dilute solution) can easily be achieved and is governed by: A) the volume of 3DMe required to treat the estimated contaminant mass, B) the pore volume in which the material is applied, C) the time available for installation (gallons/pump rate), and C) the estimated volume of 3DMe micro-emulsion that the target zone will accept over the time period allocated for installation.

Conceptually, although a higher volume of water to volume of 3DMe will produce a larger volume of the suspension, it will lower the concentration of 3DMe per gallon of solution. Thus, the benefit of using a high water/3DMe v/v ratio in order to affect a greater pore volume of the subsurface aquifer is offset by the dilution of the 3DMe per unit volume of suspension as well as by the limitations of the subsurface hydraulic conductivity and effective porosity (capacity of the aquifer to accept the volume of 3DMe micro-emulsion).

It is important that the user plan in advance the v/v 3DMe/water ratio to be employed at a project site. The resulting volume of solution will dictate the site water requirements and the time required for injection, etc. If upon injection of greater than 10:1 3DMe micro-emulsion, the subsurface does not readily accept the volume of solution as designed, the user can adjust downward the v/v water to 3DMe ratio until a more concentrated suspension is produced (this solution should never drop below the required 10 parts water:1 part 3DMe v/v production ratio). For more information on designing a 3DMe/water ratios to meet specific site conditions, please contact Regenesis Technical Services.

Direct Push Application Requirements

One of the best methods to deliver the 3DMe micro-emulsion into the subsurface is to pressure inject the solution through direct-push rods using hydraulic equipment, or to pressure inject/gravity feed the micro-emulsion into the dedicated injection wells. The use of low cost push points or temporary injection points allows the applier to more cost effectively distribute the 3DMe material across shallow sites by employing multiple points per site. In the case of treating deep aquifer sites, the use of the micro-emulsion applied via dedicated injection wells is likely to be the most cost effective remediation approach. Please note that this set of instructions is specific to direct-push equipment. Please contact Regenesis Technical Services to assist you with dedicated injection well applications.

In general, Regenesis strongly recommends application of the 3DMe micro-emulsion using an injection pump with a minimum delivery rate of three gallons per minute (gpm) and a pressure rating of between 150 to 200 pounds per square inch (psi). **Note: the <u>injection pump requirements are different than the requirements of the mixing pump</u> (see Mixing to Generate 3DMe Micro-emulsion).** High pressure, positive displacement pumps and progressive cavity pumps are appropriate for injecting 3DMe. For low permeability lithologies (clay, silt) higher pressure pumps (800-1600 psi) may be necessary, while for more permeable lithologies (gravel, sand) a lower pressure pump may be adequate. Examples of appropriate pumps are: Rupe Models 6-2200, 9-1500 and 9-1600 (positive displacement), Geoprobe® GS-2000 (positive displacement) and DP-800 (progressive cavity), Yamada (air diaphragm), Moyno (progressive cavity), and Wilden (air diaphragm). Delivery rate is a critical factor in managing installation time and costs. Generally, higher delivery rates (>6 gpm) are more cost effective for these types of applications but pump selection should be on a site specific basis and account for the volume of 3DMe solution and specific aquifer conditions present at the site.

The installation of the 3DMe micro-emulsion should span the entire vertical contaminated saturated thickness. If the vertical extent of the application is confined to a limited interval, then the micro-emulsion should be placed across a vertical zone extending a minimum of one-foot above and one-foot below the screened interval of monitoring wells that are being used to evaluate the performance of the project.

Producing the 3DMe Micro-Emulsion

The application of 3DMe requires the creation of a micro-emulsion. Technically the optimal suspension is an 3DMe-in-water suspension containing micro-emulsions. Before beginning the mixing procedure the user should have in mind the desired water to 3DMe ratio v/v desired.

It is critical that the micro-emulsion be produced using a high-shear apparatus such as a high speed centrifugal pump. The shearing provided by the vanes in these types of pumps is sufficient to form and maintain a homogeneous milky emulsion. **<u>This pump will be a different pump than that used to inject the 3DMe micro-emulsion into the subsurface</u>.** If the user is uncertain as to requirements for the pump or the applicability of a certain pump, please contact Regenesis Technical Services. Regenesis typically suggests using a water trailer/pump apparatus commonly found at equipment rental facilities. Regenesis recommends using a Magnum Products LLC model MWT500 or equivalent water trailer (fitted with centrifugal recirculation pump). This “trash pump” or transfer pump is an ideal high shear pump and the water tank (400 gallons) serves as an excellent mixing tank.

<u>To ensure that proper micro-emulsion suspension is generated Regenesis suggests a two-step process that simply requires mixing at least 10 parts water to 1 part 3DMe concentrate using water at a temperature ≥ 60°F.</u>

Step 1) Regenesis recommends that the 3DMe concentrate in each bucket be re-homogenized using a drill equipped with a paint or “jiffy” mixer attachment as minor settling may have occurred during shipment.

Step 2) to calculate the volume of water necessary to produce a 10:1 v/v micro-emulsion, each bucket of 3DMe concentrate containing 3.7 gallons of material should be mixed with 37 gallons of water.

Example: 6 buckets x 3.7 gallons 3DMe concentrate/bucket yields a total of 22.2 gallons of 3DMe concentrate. Thus, a 10:1 v/v solution will require 222 gallons of water (22.2 gallons 3DMe concentrate x 10 gallons water yields 222 gallons of water). A nominal total volume micro-emulsion would result from the summation of the 3DMe concentrate volume (22.2 gallons) and the water volume (222 gallons). This yields a total fluids delivery volume of approximately 244 gallons.

The previously calculated water volume (222 gallons) should be transferred into an appropriately sized mixing tank. The water should be circulated by the high shear centrifugal pump and each of the six 3DMe buckets slowly poured into the tank. Each bucket of 3DMe concentrate should be poured at a slow rate (approx. 1 minute per bucket) and the contents of the tank continually recirculated using the high hear centrifugal pump. A period of 1-2 minutes should be allowed between addition of each subsequent bucket of 3DMe concentrate to allow the centrifugal pump to continue to shear and mix the water/3DMe concentrate. Upon addition of the entire volume of 3DMe concentrate the pump should remain on to allow the solution mixture to recirulate. The recirculation of the 3DMe micro-emulsion should continue until the material is injected to maintain micro-emulsion consistency.

Application of Micro-Emulsion Using Direct-Push Methods

1) Prior to the installation of the micro-emulsion, any surface or overhead impediments should be identified as well as the location of all underground structures. Underground structures include but are not limited to: utility lines, tanks, distribution piping, sewers, drains, and landscape irrigation systems.

2) The planned installation locations should be adjusted to account for all impediments and obstacles.

3) Pre-mark the installation locations, noting any points that may have different vertical application requirements or total depth.

4) Set up the direct-push unit over each specific point and follow the manufacturer’s standard operating procedures (SOP). Care should be taken to assure that probe holes remain vertical.

5) For most applications, Regenesis suggests using drive rods with an O.D. of at least 1.25-inches and an I.D. of at least 0.625-inches I.D (Geoprobe or equivalent). However, the lithologic conditions at some sites may warrant the use of larger 2.125-inch O.D./1.5-inch I.D. drive rods.

6) The most typical type of sub-assembly currently being used is designed for 1.25-inch direct-push rods and is manufactured by Geoprobe. Other brands of drive rods can also be used but require the fabrication of a sub-assembly that allows for a connection between the pump and drive rod.

7) For mixing large volumes of the micro-emulsion, Regenesis recommends using a Magnum Products LLC model MWT500 water trailer (fitted with centrifugal recirculation pump) or equivalent unit. However, single large volume poly tanks are adequate. We suggest filling the tank with an appropriate quantity (e.g. from the example above 222 gallons) of water before start of mixing operations. The tank should be configured so that both a hose and a fire hydrant or larger water tank can be connected to it simultaneously and filled with water quickly and easily. This will dramatically reduce the time needed to fill the tank with mixing water.

8) Regenesis highly recommends preparing the micro-emulsion before pushing any drive rods into the subsurface. NOTE: it is best if the micro-emulsion is produced a single day application volumes.

9) After the micro-emulsion mixing/shearing step has been completed as described above, the micro-emulsion is ready to be applied. Check to see if a hose has already been attached to the inlet side of the centrifugal pump. If this has not been done, do so now.

10) If a non-water trailer tank is being used for mixing the micro-emulsion a stand alone centrifugal pump and hose system should be used for the shearing and mixing operations.

11) Advance drive rods through the ground surface, as necessary, following SOP.

12) Push the drive rod assembly with an expendable tip to the desired maximum depth. Regenesis suggests pre-counting the number of drive rods needed to reach depth prior to starting injection activities to avoid any miscalculations.

13) After the drive rods have been pushed to the desired depth, the rod assembly should be withdrawn three to six inches. The expendable tip can be dropped from the drive rods, following SOP.

14) If an injection tool is used instead of a direct-push rod with an expendable tip, the application of material can take place without any preliminary withdrawal of the rods.

15) In some cases, introduction of a large column of air may be problematic. This is particularly the case in deep injections (>50 ft) with large diameter rods (>1.5-inch O.D.). To prevent the injection of air into the aquifer during the application, fill the drive rods with 3DMe emulsion after they have been pushed to the desired depth and before the disposable tip has been dropped or before the injection tip is operational.

16) Transfer the appropriate quantity of the micro-emulsion from the water trailer to the working/application pump hopper or associated holding tank.

17) A volume check should be performed prior to the injection of the micro-emulsion. Determining the volume discharged per unit time/stroke using a graduated bucket and stopwatch or stroke counter.

18) Start the pump and use the graduated bucket to determine how many gallons of micro-emulsion are delivered each minute or stroke per unit volume.

19) Connect the 1.25-inch O.D., 1-inch I.D. delivery hose to the pump outlet and the appropriate sub-assembly. Circulate the micro-emulsion through the hose and the sub-assembly to displace any air present in the system.

20) Connect the sub-assembly to the drive rod. After confirming that all of the connections are secure, pump the micro-emulsion through the delivery system to displace any water or other fluids in the rods.

21) The pump engine RPM and hydraulic settings should remain constant throughout the day to maintain a constant discharge rate.

22) The material is now ready to be installed in the subsurface. Use the pumps discharge rate as calculated in step 18 to determine the withdrawal rate of the drive rods needed for the application.

23) Slowly withdraw the drive rods using Geoprobe Rod Grip or Pull Plate Assembly (Part AT1222-For 1.25-inch drive rods). While slowly withdrawing single lengths of drive rod (three or four feet), pump the pre-determined volume of micro-emulsion into the aquifer across the desired treatment interval.

24) Remove one or two sections of the drive rod at a time. The drive rod may contain some residual material so Regenesis suggests placing it in a clean, empty bucket and allowing the material to drain. Eventually, the material recovered in the bucket should be returned to the pump hopper for reuse.

25) Observe any indications of aquifer refusal such as “surfacing” around the injection rods or previously installed injection points. If aquifer acceptance appears to be low, allow enough time for the aquifer to equilibrate prior to removing the drive rod.

26) Repeat steps 19 through 25 until treatment of the entire contaminated vertical zone has been achieved.

27) Install an appropriate seal, such as bentonite, above the micro-emulsion injection zone. The seal should span across the entire vadose zone. Depending on soil conditions and local regulations, a bentonite seal using chips or pellets can be used. If the injection hole remains open more than three or four feet below the ground surface sand can be used to fill the hole and provide a base for the bentonite seal. The installation of an appropriate seal assures that

the micro-emulsion remains properly placed and prevents contaminant migration from the surface. If the micro-emulsion continues to "surface" up the direct-push borehole, an oversized disposable drive tip or wood plug/stake can be used to temporarily plug the hole until the aquifer equilibrates and the material stops surfacing.

28) Remove and clean the drive rods as necessary.

29) Finish the borehole at the surface as appropriate (concrete or asphalt cap, if necessary).

30) Periodically compare the pre- and post-injection discharge rates of the micro-emulsion in the pump hopper or holding tank using any pre-marked volume levels. If volume level indicators are not on the pumps hopper or holding tank use a pre-marked dipstick or alternatively temporary mark the hopper or holding tank with known quantities/volumes of water using a carpenter's grease pencil (Kiel crayon).

31) Move to the next probe point, repeating steps 11 through 29.

Helpful Hints

1) *Application in Cold Weather Settings*

As discussed in the Material Overview, Handling, and Safety section, cold weather tends to increase the viscosity of 3DMe as well as decrease the ease of micro-emulsion formation. To optimize an application in cold weather settings Regenesis recommends maintaining the 3DMe concentrate and the associated water at a temperature ≥60°F (16°C). The following procedures can be used to facilitate the production and installation of a 10:1 v/v 3DMe micro-emulsion.

- Raise and maintain the temperature of the HRC-A to at least 60°F (16°C) prior to mixing with water. A hot water bath can be used to heat up the 3DMe concentrate buckets. A Rubbermaid fiberglass Farm Trough Stock Tank (Model 4242-00-GRAY) has been used for this process. This trough can hold up to 16 buckets of 3DMe concentrate.
- Hot water (approximately 130-170°F or 54-77°C) should be added to the tank after the buckets of 3DMe have been placed inside. The hot water should be delivered from a heated pressure washer (Hotsy® Model No. 444 or equivalent) or steam cleaner unit.
- It is equally critical that a moderate water temperature (>60°F or 16°C) be used in the production of the micro-emulsion. If on-site water supply is below 60°F use a hot water or steam cleaner to generate a small volume (e.g. 5-10% of total water volume) of hot water (130–170°F/54-77°C). This small volume of hot water should be added to remaining cold water volume to raise the total volume temperature to >60°F. When the 3DMe concentrate and water each reach a minimum temperature of 60°F or 16°C the two materials are ready for mixing.
- Upon achieving a minimum temperature of 60°F or 16°C (approximately 10-20 minutes). When the 3DMe and the associated water volumes have reached a minimum temperature of 60°F or 16°C (approximately 10-20 minutes) they are ready for mixing.
- In exceptionally harsh winter temperature settings use of a separate insulated pump containment structure and insulated delivery hoses may be necessary.

- Use a pump with a heater unit.
- Periodically check the temperature of the material in the hopper.
- Re-circulate the 3DMe micro-emulsion through the pump and hose to maintain temperature adequate temperatures.
- Care should be taken to avoid the re-circulation of material volumes that exceed the volume of the pump hopper or holding tank.

Table 1: Equipment Volume and 3DMe Micro-Emulsion Weight per Unit Length of Hose (Feet)

Equipment	Volume	Product Weight
1-inch OD; 0.625-inch ID hose (10 feet)	0.2 gallon	1.6 lbs.
1.25-inch OD; 0.625-inch ID drive rod (3 feet):	0.05 gallon	0.4 lbs.
1.25-inch OD; 0.625-inch ID drive rod (4 feet):	0.06 gallon	0.5 lbs.

2) Pump Cleaning

For best results, use a heated pressure washer to clean equipment and rods periodically throughout the day. Internal pump mechanisms and hoses can be easily cleaned by re-circulating a solution of hot water and a biodegradable cleaner such as Simple Green through the pump and delivery hose. Further cleaning and decontamination (if necessary due to subsurface conditions) should be performed according to the equipment supplier's standard procedures and local regulatory requirements.

NOTE:

Before using the Rupe Pump, check the following:

- Fuel level prior to engaging in pumping activities (it would be best to start with a full tank)
- Remote control/pump stroke counter LCD display [if no display is present, the electronic counter will need to be replaced (Grainger Stock No. 2A540)]

Monitor pump strokes by observing the proximity switches (these are located on the top of the piston).

3) *Bedrock Applications*

When contaminants are present in competent bedrock aquifers, the use of direct-push technology as a delivery method is not possible. *Regenesis is in the process of developing methods for applying 3DMe via boreholes drilled using conventional rotary techniques.* To develop the best installation strategy for a particular bedrock site, it is critical that our customers call the Technical Services department at Regenesis early in the design process.

The micro-emulsion can be applied into a bedrock aquifer in cased and uncased boreholes. The micro-emulsion can be delivered by simply filling the borehole without pressure or by using a single or straddle packer system to inject the material under pressure. Selection of the appropriate delivery method is predicated on site-specific conditions. The following issues should be considered in developing a delivery strategy:

- Is the aquifer's hydraulic conductivity controlled by fractures?
- Backfilling may be the better delivery method in massive, unfractured bedrock. This is particularly true in an aquifer setting with high permeability and little fracturing (such as that found in massive sandstone).
- Down-hole packer systems may be more advantageous in fractured bedrock aquifers.
    - In this case the fracture type, trends, and interconnections should be evaluated and identified.
- Are the injection wells and monitoring wells connected by the same fractures?
- Determine if it is likely that the injection zone is connected to the proposed monitoring points.
- If pressure injection via straddle packers is desired, consideration should be given to the well construction. Specific issues to be considered are:
    - Diameter of the uncased borehole (*will casing diameter allow a packer system to be used under high pressures*?).
    - Diameter of the casing (*same as above*).
    - Strength of the casing (*can it withstand the delivery pressures?*).
    - Length of screened interval (*screened intervals greater than 10 feet will require a straddle packer system*).

For further assistance or questions please contact Regenesis Technical Services at 949-366-8000.

3-D MicroEmulsion™
HRC ADVANCED®

HRC TECHNICAL BULLETIN # 1.1.2

Hydrogen Release Compound HRC®

Biological Reductive Dechlorination of CAHs

Reductive dechlorination is the most prominent mechanism by which chlorinated aliphatic hydrocarbons (CAHs) are biologically degraded under anaerobic conditions. CAHs, commonly used as degreasing solvents (see TB 1.1.1), are hydrocarbons whose hydrogen atoms have been replaced, or substituted, with chlorine atoms. It is in this chlorinated state that these hydrocarbons are considered toxic in groundwater. In order to remedy this problem the chlorine atoms must be removed.

Reductive dechlorination is the process by which anaerobic microorganisms substitute hydrogen (H+) for chlorine on CAHs. Hydrogen, resulting from the breakdown of HRC, acts as a source of electrons which provide the reducing conditions necessary for dechlorination of CAHs, as shown in the Figure 1.

$$\boxed{RCl + H^+ + 2e^- \longrightarrow RH + Cl}$$

Figure 1

Through this process, CAHs can be degraded to form vinyl chloride, and even ethene, as depicted in Figure 2.

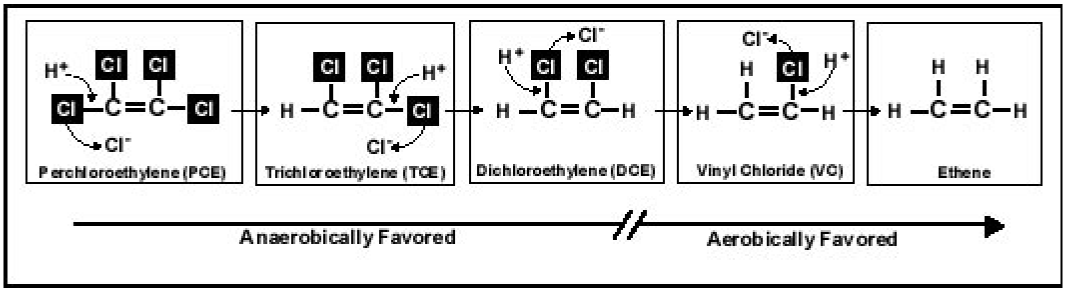


Figure 2

While the degradation rates of PCE and TCE are highest under anaerobic conditions, vinyl chloride will degrade up to four times faster under aerobic conditions (Figure 2). Therefore, optimal results for CAH remediation with HRC may be achieved by combined treatment with Oxygen Release Compound (ORC®) to enhance aerobic bioremediation of vinyl choride.

NOTE: For a complete discussion on reductive dechlorination of CAHs, see the RABITT document (1).

References:

1. Morse, J.M. and B.C. Alleman; Gossett, J.M. and S.H. Zinder; Sewell, G.W.; Vogel, C.M. 1997. A Treatability Test for Evaluating the Potential Applicability of the Reductive Anaerobic Biological In Situ Treatment Technology (RABITT) to Remediate Chloroethenes. ESTCP Technical Protocol.

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HRC TECHNICAL BULLETIN # 1.1.3

Hydrogen Release Compound HRC®

Using Organic Substrates to Promote Biological Reductive Dechlorination of CAHs

The use of organic substrates has been proven to enhance the bioremediation of Chlorinated Aliphatic Hydrocarbons (CAHs). The effect of the addition of organic acids and alcohols on the reductive dechlorination of tetrachloroethylene (PCE) is described by Gibson and Sewell (1). In this process, the acids and alcohols are metabolized by one group of organisms to yield hydrogen which in turn is used by another group of organisms to effect reductive dechlorination.

HRC, once deposited into the subsurface, slowly releases lactic acid. The resulting lactic acid acts as a nutrient source for anaerobic bacteria which metabolize the lactic acid as illustrated in Figure 1.

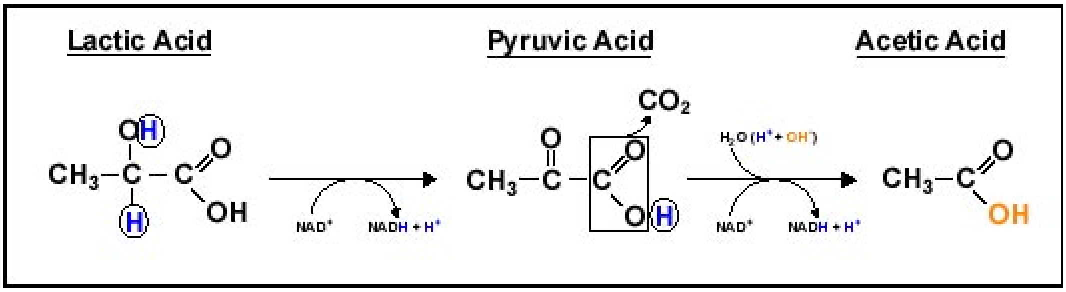

Figure 1

During the process, in which hydrogen atoms are taken up by NAD+ to form NADH , lactic acid is first degraded to pyruvic acid, which is in turn degraded to acetic acid. The driving force for fermentation of lactic acid to acetic acid is the generation of ATP during glycolysis. To make this possible, the microbe must first regenerate NAD+ by releasing the hydrogen from NADH. This is facilitated through the use of an enzyme called hydrogenase via the following reaction:

$$\mathrm{NADH} + \mathrm{H^+} \xrightarrow[\text{Hydrogenase}]{} \mathrm{NAD^+} + \mathrm{H_2}$$

Typically, in the conversion of lactic acid to acetic acid by acetogens, one mole of lactic acid produces two moles of hydrogen as H_2. The hydrogen is then available for conversion of CAHs to dechlorinated aliphatic hydrocarbons (see TB 1.1.2).

References:

1. Gibson, S.A. and G.W. Sewell. April 1992. Applied and Environmental Microbiology. 58(4): 1392-1393.

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HRC TECHNICAL BULLETIN # 1.3.1

Hydrogen Release Compound HRC®

Environmentally Safe

Hydrogen Release Compound, HRC, is a polylactate ester that is a food-grade substance. Lactic acid occurs naturally in milk and foods (such as sauerkraut), and is also formed in muscles during exercise. In the subsurface environment, lactic acid products are eventually completely removed either as methane or CO_2 and water, leaving no residue.

The only other ingredient in HRC is food grade magnesium phosphate ($MgPO_4$). Magnesium phosphate is a naturally occurring mineral and is used in fertilizers. Magnesium phosphate has even been used medically as a laxative. In the function of the product phosphorous from the phosphate helps the metabolism of the lactic acid to produce the hydrogen used in reductive dechlorination.

In a review of all of 40CFR141 there is no reference to MCLs for lactic acid or its derivatives pyruvic acid, propionic acid, and acetic acid (see HRC technical bulletin #1.3.2). As with all chemicals, safe handling practices should be used to avoid any excess exposure to skin and any exposure to eyes. A full MSDS is provided with the product. As indicated in the MSDS, there is the potential for skin irritation with large scale exposure or with sensitive individuals. It is recommended that vinyl or rubber protective gloves be worn during handling of the product. Contact with eyes will cause irritation and the use of splash goggles or some other form of eye protection should be considered mandatory.

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HRC TECHNICAL BULLETIN # 2.4.4

Hydrogen Release Compound HRC®

Simple Field Pilot Test Designs

In the initial stages of HRC testing, the efficacy of HRC was studied in single monitoring wells. HRC was placed in PVC canister measuring four feet in length and three inches in diameter. These small scale field studies were designed to observe the immediate impact of HRC on water passing through the monitoring well. Each study consisted of five rounds of sampling over a period of twelve weeks. Sampling was fairly intensive, consisting of the following parameters:

1. EPA method 8260 (chlorinated VOCs)
2. Gases (methane, ethane, and ethene)
3. Nutrients, electron acceptors, and inorganics (nitrogen, nitrate, phosphorous, sulfate, sulfide, iron, chloride, and manganese)
4. Volatile organic acids (lactic acid, pyruvic acid, acetic acid, and propionic acid)
5. Alkalinity, TOC, and conductivity
6. DO, redox potential, pH, and temperature
7. Microbial (total anaerobes and sulfate reducing bacteria)

The sampling intensity that was utilized over the twelve weeks of testing was crucial in determining the early performance characteristics of HRC. In all studies the initial impact of HRC was the reduction of redox potential and DO levels in the well as lactic acid was released from HRC. Over time pyruvic and acetic acid concentrations increased as the lactic acid underwent metabolism by indigenous microorganisms. At the same time electron acceptors (nitrate and sulfate) were reduced as indicated by concentration decreases. This initial process can collectively be called "driving" the aquifer anaerobic.

Once the aquifer was driven to a reduced, anaerobic state, reductive dechlorination of the CAHs began occurring, as described in Technical Bulletin 1.1.2. At some sites reduction of CAHs began to occur within the first two weeks of application, while at other sites appropriate reducing conditions were not reached until after eight weeks of application. This was mostly due to initial aquifer conditions, in which aquifers with highly positive redox potentials, measurable levels of DO, and high levels of competing electron acceptors took much longer to be driven to anaerobic, reducing conditions. Results from one representative study are discussed in detail in technical bulletin 3.1.2.

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HRC TECHNICAL BULLETIN H-2.7.4

Hydrogen Release Compound HRC™

The Formation of Vinyl Chloride Using HRC

We have sometimes been asked "will the use of HRC on chlorinated ethene compounds lead to the formation of vinyl chloride (VC)?" The answer is basically yes, but only as a transitional state as the dechlorination proceeds ultimately producing ethene. In all of the applications of HRC accomplished to date, not one of the sites created a buildup of vinyl chloride that persisted or moved off-site. In the event that there was such a site, a simple ORC oxygen barrier could be installed to degrade the vinyl chloride before leaving the treatment area.

VC is Produced Naturally

VC formation is a natural process. In the scope of natural attenuation, by all chemical processes both biotic and abiotic (reduction by metals), VC will form. Now, if we add organic substrates to the aquifer to accelerate natural attenuation – a sensible and cost effective strategy – we will accelerate the dechlorination process, temporarily forming VC from DCE as the degradation proceeds to ethene. Note that this is true for all organic substrates not just HRC, however, if one uses HRC with its consistent generation of low hydrogen concentrations, then the enhanced rate of VC formation will be minimized. This will effectively give the rate of VC degradation to ethene a chance to keep pace with the formation of VC itself.

VC Degrades Rapidly with Oxygen

As mentioned above, HRC has never been shown to stimulate a significant or permanent buildup of VC. However, in cases where site conditions do not allow the VC to have an adequate residence time in contact with the HRC, it is conceivable that the vinyl chloride could move off-site without conversion to ethene. In this rare case Regenesis recommends that a down gradient passive ORC oxygen barrier be installed, which will stimulate the rapid and complete mineralization of the vinyl chloride moving across the barrier zone. The use of ORC to rapidly degrade vinyl chloride is well documented and is summarized in TB 2.2.2.3 as well as others.

HRC TECHNICAL BULLETIN H-2.8.1

Hydrogen Release Compound HRC®

HRC Performance Characteristics - Longevity

General Background

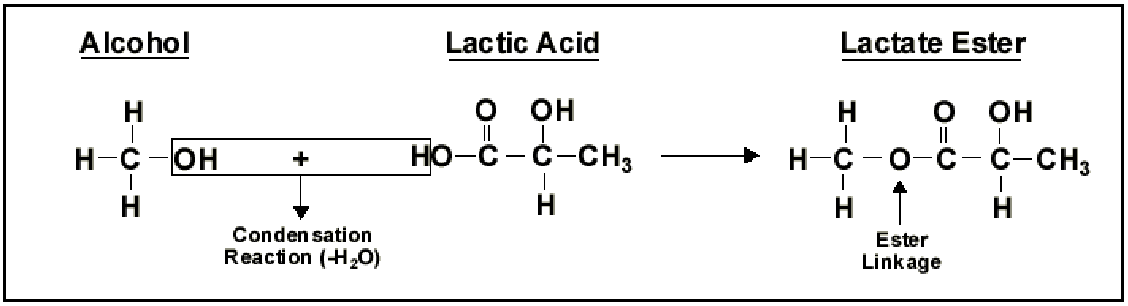
Since Hydrogen Release Compound (HRC®) is a time-release product, one of the central issues in site design and one of the most frequently asked questions is "How long does it last"? The short answer is that the basic HRC now sold, specifically defined as a formulation of Glycerol Polylactate (GPL), diluted with glycerol to a viscosity of 20,000 centipoise (cP), is estimated to stimulate reductive dechlorination within the aquifer for about 12 months. The longevity is a function of basic product chemistry and certain biological and geochemical features of the aquifer. HRC has been shown to have a direct effect on contaminants resulting from the lactic acid release and other secondary effects, related to the formation of other organic acids that "borrow hydrogen" and recycled biomass, that have a more prolonged effect on aquifer conditions.

Theoretical Considerations

Longevity as a Function of HRC Chemical Characteristics

Hydrogen Release Compound is a specific article of commerce as described. The "active ingredient", Glycerol (tri) Polylactate (GPL), is one of a family of polylactate esters, defined by our patent, that upon hydration break down to release lactic acid. The exact chemical nature of a specific polylactate ester, such as GPL, is a major factor in product longevity. In essence, the structure and degree of esterification determine viscosity and viscosity is a critical factor in longevity.

Structurally, an ester is the product of a reaction between an organic acid (COOH group) and an alcohol (OH group). In this reaction as shown in Figure 1, the two groups react and water drops out forming the ester linkage, noting that the amount of water removed in esterification can affect viscosity. The example used shows methyl alcohol reacting with lactic acid to form a simple lactate ester (methyl lactate).



$$CH_3OH + HO-C(=O)-CH(OH)-CH_3 \longrightarrow CH_3-O-C(=O)-CH(OH)-CH_3$$

Figure 1. Formation of an Ester.

Polylactate esters are formed from the combination of certain alcohols with a unique lactic acid complex serving as the organic acid group. The alcohols used are compounds such as glycerol (3 OH groups), xylitol (5 OH groups) and sorbitol (6 OH groups). These "foundation" molecules are then esterified with a polylactic acid complex as illustrated in Figure 2.

One of the unique features of the polylactic acid complex is that lactic acid is esterified to itself. This is possible because lactic acid, as shown in Figure 1, has both an OH and a COOH group. As a result we can typically produce trimers or tetramers of lactic acid and create a "polylactic acid complex" or "polylactate complex", which is in turn esterified to the foundation OH donor as described.

The Glycerol (tri) Polylactate (GPL) component of the HRC in commerce is specifically the molecule in Figure 2. However, GPL itself can vary as a function of how many OH positions are actually esterified, so that one could have glycerol (tri) polylactate if all 3 are filled or glycerol (di)polylactate if just 2 are filled. The GPL in HRC is the Glycerol (tri) polylactate ester

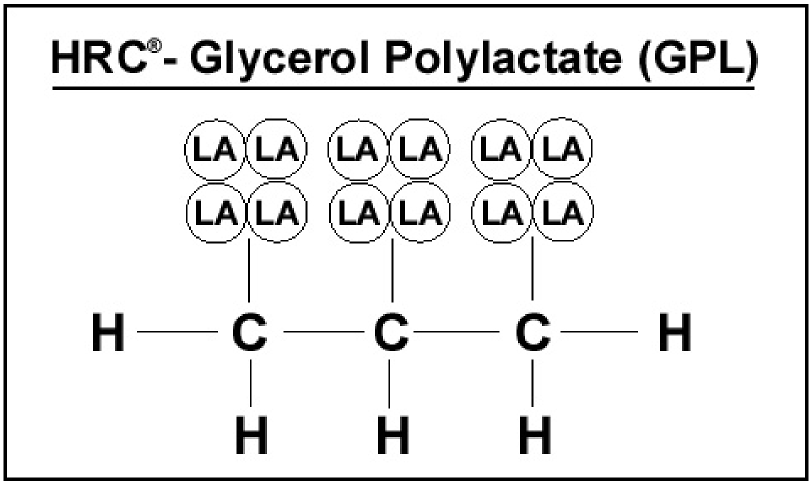


Figure 2. Structure of Glycerol (tri) Polylactate (GPL)

The point of this is to emphasize that the degree of complexity and esterification of the molecule control its viscosity and hence a major component of its reactivity. This in turn controls product longevity under a uniform set of conditions. For example, the (tri)polylactate form of GPL would be more viscous that the (di)polylactate form. Further, a molecule built with tetramers of lactic acid would be more viscous than one made with trimers. As a final example a sorbitol polylactate ester is more viscous than a glycerol polylactate ester, because it is based on 6 carbons rather than 3 carbons.

Viscosity becomes a dominant issue in longevity because it is a measurement of resistance to flow. As a result, viscosity controls the evolution of surface area over time and the speed at which HRC becomes soluble in water. Therefore, if a polylactate formulation becomes less viscous it will spread more, thus exposing more sites to chemical and biological attack. The latter case, involving the enzymatic action of microorganisms, is a particularly powerful mechanism and this will be expanded on later. In essence, "thicker lasts longer", which one would intuitively gather for the reaction of any solute with a solvent.

Returning to viscosity for a moment, we said that it is a measure of resistance to flow and can be measured in a viscometer. In a viscometer, the substance being tested is placed between two plates, one being stationary and one being movable. The amount of force applied to overcome resistance to the movement of the moveable plate is the key variable. Consequently, the units of viscosity in SI units are force-based, e.g., dyne-sec/cm^2 or Poise (P). Typically we measure the viscosity of HRC in centipoise (cP).

To be pumpable for push-point injection, HRC has to be about 20,000 cP (like honey). This is achieved by cutting raw GPL, which is about 200,000 cP (gel-like), with glycerol - by a factor of about 2, noting that the relationship between dilution and viscosity is non-linear. Therefore, we produce a form of HRC at 200,000 cP, as a function of the specific chemical structure, such that when it is cut about 50:50 with glycerol we achieve a pumpable 20,000 cP material.

Longevity as a Function of Aquifer Characteristics

The viscosity of the HRC is still only one side of the equation. The other important feature concerns the environment the HRC is placed into. An experimental model for the dynamics of HRC utilization in the bioremediation of TCE is published in Farone, Koenigsberg and Hughes (1999). Copies of this and other papers cited herein are available on request from Regenesis and it is convenient to use our web site at www.regenesis.com.

The model, which was calibrated with laboratory microcosm tests, clearly demonstrates that the nature and extent of microbial populations has a significant effect on the longevity of HRC. Simply put, most microbes - not just the kinds that ferment lactic acid into hydrogen or those that promote reductive dechlorination - will produce esterases and lipases that degrade HRC and release lactic acid.

Therefore, if an aquifer has a high microbial population it will metabolize a given mass of HRC at a faster rate than if the microbial counts are moderate to low. An example of this is presented in Figure 3 that shows a difference in lactic acid release rates at three different microbial concentrations. Note that this lab test represents a highly accelerated condition relative to field results, because everything is optimized and reacted in close proximity in the test tube environment.

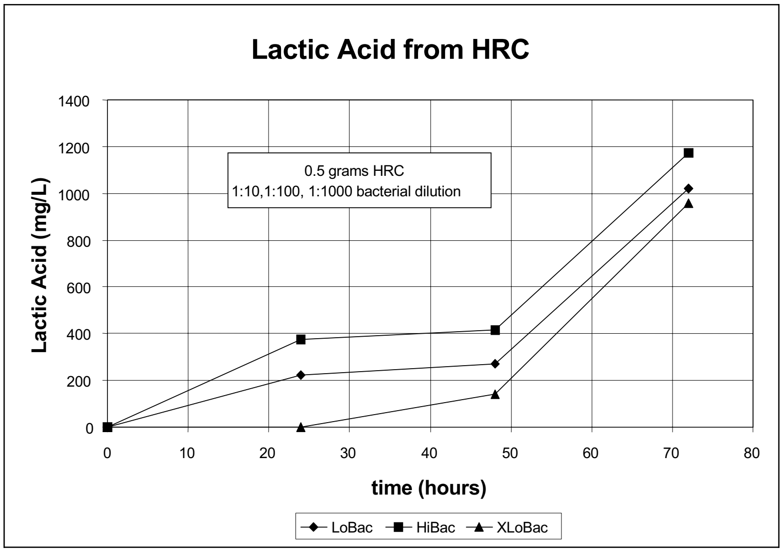


Figure 3. Lactic Acid Release Rates as a Function of Microbial Population.

Early Laboratory Work

Table 1 presents data that reflect a set of minimum times that standard HRC has lasted in the laboratory. Again, note that laboratory tests generally have high rates of activity relative to the field. The tests summarized below, were conducted to test the efficacy of HRC in remediating TCE and were not longevity tests per se. For economic reasons they were only run for about three months to collect the remediation rate data. Still, the tests supply some useful minimums for longevity. The tests were macrocosm studies conducted in Aquifer Simulation Vessels (ASVs) with a flow rate of about 1 ft/day. For a further discussion of the ASV type studies, please refer to TB 2.4.3.

Table 1. Macrocosm (ASV) Tests.

Product	Duration of Test	Presence of Product at Conclusion
GPL 52%/Glycerol 48%	84 days	Yes
GPL 52%/Glycerol 48%	80 days	Yes
GPL 52%/Glycerol 48%	80 days	Yes
GPL 52%/Glycerol 48%	94 days	Yes

Recent Laboratory Work

Recently an ASV study was established to specifically look at both longevity and diffusion issues regarding 20,000 cP HRC and 200,000 cP GPL. 15 g of each formulation was placed in the influent end of the ASV; there was no flow so that diffusion alone would be measured. While the main purpose of the test is covered in TB 2.4.3, it can be noted that, after 66 days, there is still considerable material left in the system of both products. The experiment will be continued until the product is exhausted. This is expected to be about one year for the 20,000 cP HRC and several years for the 200,000 GPL.

Field Results

Data from the Oldest Trials

The most powerful evidence for product longevity is of course the observations made in the field. As presented in Table 2 and graphically in Figure 4, the 20,000 cP HRC will last from 119 days to 580 days. It is important to note that this is a "living table" such that some of the applications are still in progress and the average longevity figures is getting larger. However, based on the range of this field experience and the fact that some tests are still in progress, we claim that 20,000 cP HRC degrades slowly, on average, for nine months (as modulated by certain features in the contaminated aquifer). However, just because the organic acids are gone does not mean the effects are over. Residual hydrogen will still be present and biomass accumulates which will later be available as fermentable carbon. The stimulated biomass is also more able to utilize native carbon as well. Therefore, ~20,000 cP HRC now sold is estimated to stimulate reductive dechlorination within the aquifer for at least 12 months.

Also, some work during the early phase of product development (not cited here) looked at the properties of a 1,000,000 cP sorbitol polylactate hard gel. In one test, the material physically lasted for at least two years at the point of application. In this experiment, which is presented in Dooley, Murray and Koenigsberg (1999), the SPL hard gel was placed in a canister with sufficient holes to allow it to ooze out slowly. It was placed in an injection well and the exposed surface was in contact with a fairly vigorous flow (relative to an aquifer velocity) of 0.25 gal/min. The active recirculation period ended at about 330 days, however, and the canister was retrieved after two years significant HRC was still present.

Regenesis is working on ways of delivering higher viscosity materials directly as "implants" using warmed GPL to lower the viscosity during application and special push-point injection and hollow stem auger techniques. These implants can be used as barriers or source treatments and can be expected to last for several years for very long-term plume management.

Table 2. Longevity Profile of GPL-HRC at 20,000 cP.

Site	**Last Field Observation of Organic Acids-** Lactic, Butyric, Propionic **(in days)**	**Duration of Data Collection (in days)**	**Status**
Site 1	150	364	Product exhausted before monitoring completed
Site 2	173	173	Product still present at conclusion of monitoring
Site 3	181	181	Product still present at conclusion of monitoring
Site 4	197	197	Product still present at conclusion of monitoring
Site 5	321	321	Product still present at conclusion of monitoring
Site 6	119	119	Product still present; monitoring on-going
Site 7	240	240	Product still present; monitoring on-going
Site 8	243	243	Product still present; monitoring on-going
Site 9	399	399	Product still present; monitoring on-going
Site 10	580	580	Product still present; monitoring on-going

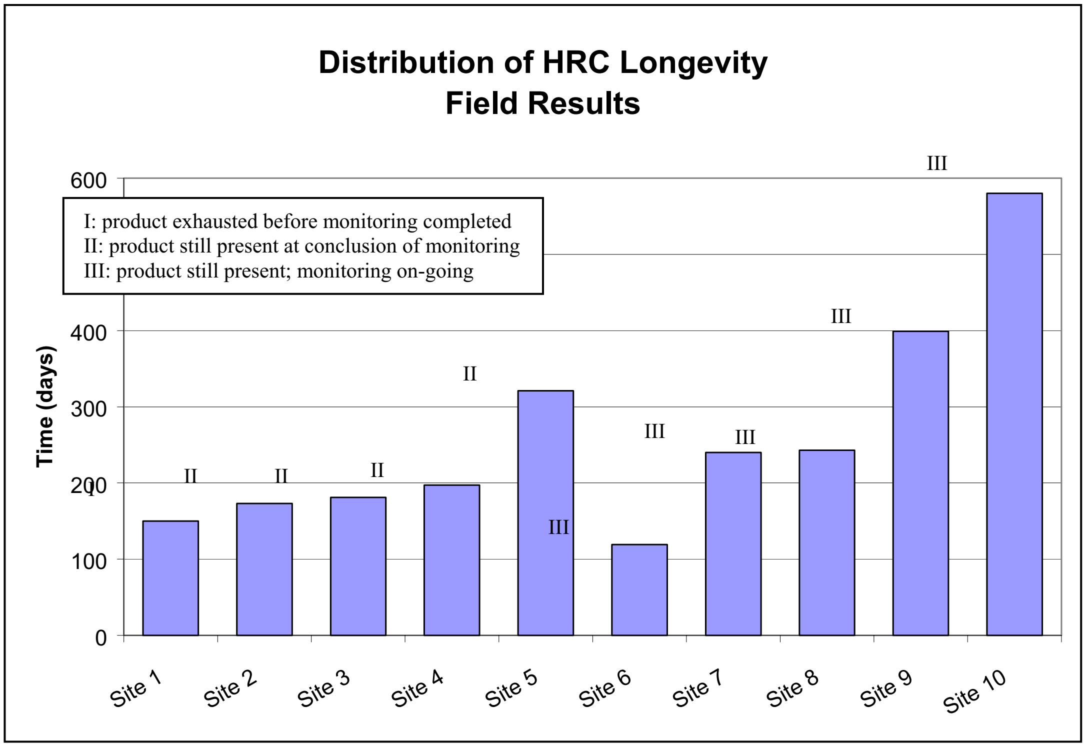


Figure 4.

Secondary Effects

Often we see remediation continuing after HRC breakdown products are no longer in the system. This observation led us to postulate that there may be more than one phase in the effect of adding HRC to the aquifer. Generally, we use the presence of elevated levels of organic acids as the metric, although we can also look at TOC data as well. However, sometimes after the footprint of the HRC is gone we can still see elevated rates of remediation. On further consideration we believe that the organic load to the aquifer that is provided by HRC is not a uni-directional event and that the biomass of microorganisms constructed from HRC can be recycled. This can cause an after effect as could native carbon in the system that might be more responsive to the elevated microbial population levels. While this is clearly not a dominant driver for reductive dechlorination relative to HRC, it apparently can have an impact. Lastly, at the formal exhaustion of the organic acids there is still hydrogen available.

To support this hypothesis we can look at an HRC injection as described in Sheldon, (1999). This experiment was a pilot test with a monitoring well (MW-8) that was clearly in the center of the HRC injection zone. Another well (MW-1) was in the experimental grid but was outside the migration zone for the HRC and its breakdown products during the course of the experiment. Figure 5 shows the nature of the organic acid profile over time and it should be noted that propionic acid is formed from lactic acid and then breaks down to release hydrogen. Acetic acid is generally considered to be a non-hydrogen evolving end point.

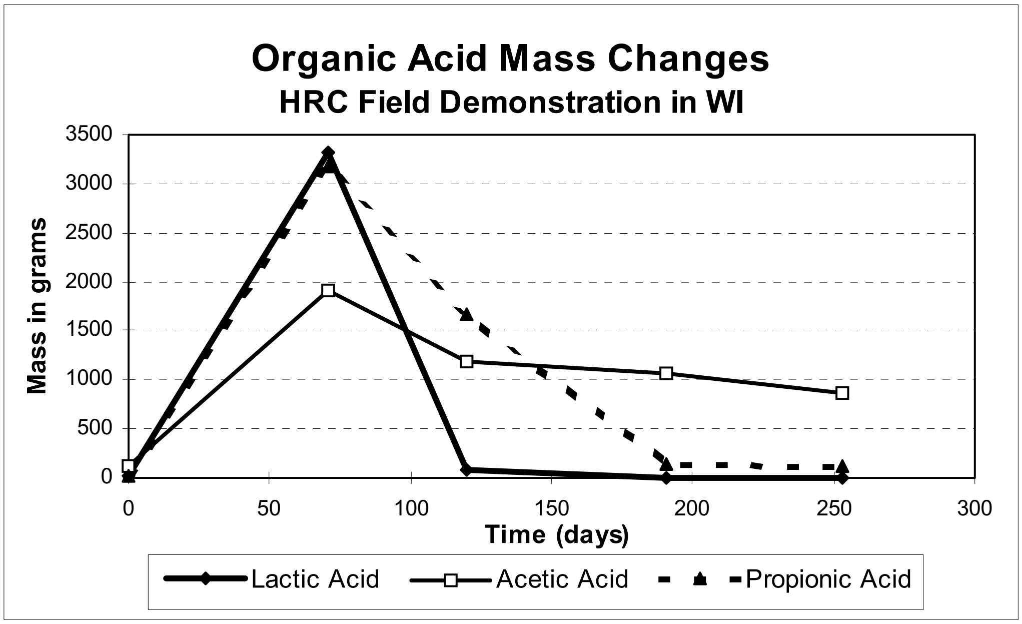


Figure 5.

The total mass of organic acids is calculated from a contouring exercise and the last appearance of lactic acid per se is between 70 and 120 days (the formulation was only about 10,000 cP in this early work). The disappearance of propionic acid between 120 and 190 days is further noted. With this background information we can now examine Table 3 and evaluate the remediation rate differences between the impacted and non-impacted wells (MW8 vs. MW1). It is clear that even after the organic acids are "gone" that there are still rate differences to be accounted for. At least two hypotheses can be presented.

- The HRC is still releasing slowly and is being consumed as fast as it is produced which would still allow remediation to proceed and cause a rate difference.

- The HRC is exhausted, but the organic material is being recycled and or native organic material is being mobilized by growing microbial populations - such that remediation continues.

Flow rates at this site are on the order of 0.5 ft/day and that is not sufficient to flush the system of HRC in the period involved in the study.

Table 3. TCE Degradation Rate Differentials at WI Site

Day	Half Life (d) Well TW01	Half Life (d) Well TW08	Ratio TW01/TW08
0-70	338	29	11.50
70-120	211	43	4.94
120-149	256	53	4.84
149-191	309	45	6.80
191-253	205	38	5.41

Summary

The main active ingredient in Hydrogen Release Compound is a polylactate ester called Glycerol (tri)Polylactate or GPL. Abiotic and microbially mediated hydrolysis of the ester linkage, between glycerol and the polylactate complex, releases the polylactate complex. The polylactate complex is a tetramer of lactic acid (4 lactic acid molecules esterified to themselves) and its degradation results in the release of individual lactic acid molecules which undergo fermentation to release hydrogen. These chemical features and the resultant viscosities, are an important component of longevity.

GPL is manufactured as a highly esterified thick gel and can be subsequently cut to a syrup-like consistency for injection. All other conditions being equal, product viscosity combined with the nature of microbial activity in the aquifer are the key determinants of product longevity. This is essentially a surface area argument. The thinner the material the more it will spread out and be exposed to chemical and biological degradation.

Based on the evidence presented in the laboratory and field, we can claim that ~20,000 cP HRC is estimated to stimulate reductive dechlorination within the aquifer for about 12 months. The longevity of this effect is a function of certain biological and geochemical features of the aquifer. HRC has been shown to promote reductive dechlorination resulting from the lactic acid release and possibly other indirect effects related in part to the formation of a nominal amount of recycling organic material that has a more prolonged effect on aquifer conditions. An “after effect” in the aquifer involving the recycling of carbon may extend the positive remediation effects beyond the formal longevity based on lactic acid release.

References

Dooley, M., W. Murray and S. Koenigsberg. 1999. “Passively Enhanced In Situ Biodegradation of Chlorinated Solvents”. In: A. Leeson and B.C. Alleman (Eds.), *Engineered Approaches for In Situ Bioremediation of Chlorinated Solvent Contamination*, pp. 121-127. Battelle Press, Columbus, OH.

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Case History HA-05

3-D MicroEmulsion™
HRC ADVANCED®

REGENESIS
Advanced Technologies for Groundwater Resources

3-D Microemulsion® Enhances Reductive Dechlorination and Reduces PCE and TCE Concentrations to Non-Detect

CASE SUMMARY

Dry Cleaning Operations, Belleville, IL

Operations at a dry cleaning facility in Illinois resulted in elevated levels of chlorinated ethenes in the subsurface. Downgradient of the contaminant source (in Well MW-4), the total chlorinated compound concentration was greater than 6,400 parts per billion (ppb), the main contaminant being tetrachloroethene (PCE). A pilot test using Hydrogen Release Compound (HRC®) was initially designed and deployed to produce conditions favorable for the reduction of contaminants. Well MW-4 was the designated sampling point to observe the contaminant reduction. The HRC pilot application was mis-applied over a 20 foot vertical interval instead of the recommended and planned 10 foot interval, resulting in under-dosing of HRC and only moderate treatment performance. A second application was performed 18 months later using the correct dosing and a form of HRC Advanced® known as 3-D Microemulsion (3DMe)™.

REMEDIATION APPROACH

3DMe is a completely new molecule with staged hydrogen release capabilities and is applied as a microemulsion for enhanced distribution. The 3DMe microemulsion was directly injected at 6 locations surrounding the targeted monitoring well MW-4 (Figure 1). It was injected at a rate of 120 pounds per injection point and at 10 to 20 feet below ground surface (at the correct 10 foot interval). The injection points were spaced approximately 7 feet from one another.

Figure 1. Pilot Injection Layout

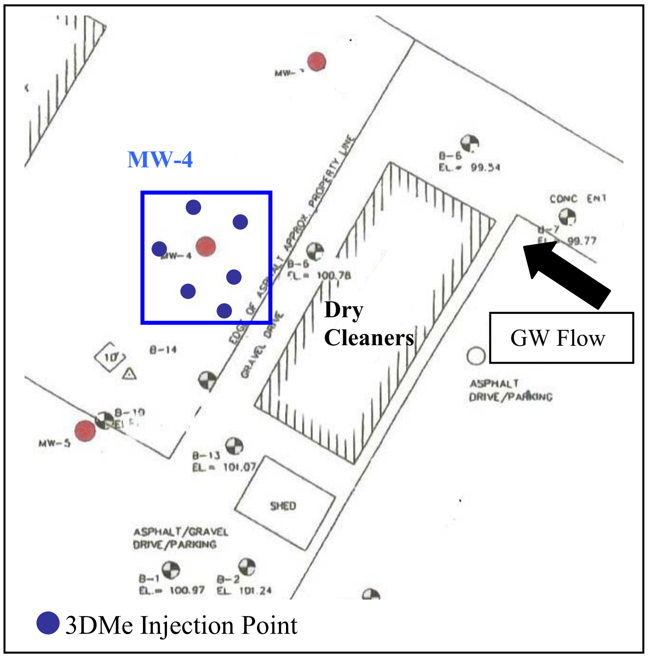

Table 1. MW-4 Concentrations Prior to 3DMe Injection (ppb)

Contaminant	Concentration
PCE	5,680
TCE	301
cis-DCE	474
VC	ND

- **Application Type:** Pilot Test
- **Quantity Applied:** 720 lbs
- **Application Rate:** 15 gal/ft
- **Injection Spacing:** 7 feet
- **Soil Type:** Clay
- **Groundwater Velocity:** <0.1 ft/day
- **Treatment Thickness:** 10 feet
- **Depth to Groundwater:** 10 feet

RESULTS

Although HRC was applied and under-dosed in September 2004, moderate increases in the reductive dechlorination process were observed near Well MW-4. The moderate effect resulted in a 50 percent decrease in PCE concentrations. As expected some daughter products were also produced.

Within 30 days of the 3DMe application, PCE was reduced from 5,680 ppb to non-detect followed by a similar reduction in TCE. A reduction of 77 percent was observed in cis-DCE between August 2006 and April 2007. Slight increases in vinyl chloride (VC) and ethene indicated that complete dechlorination was occurring with no stalling effect (Table 2).

Concentrations vs. Time

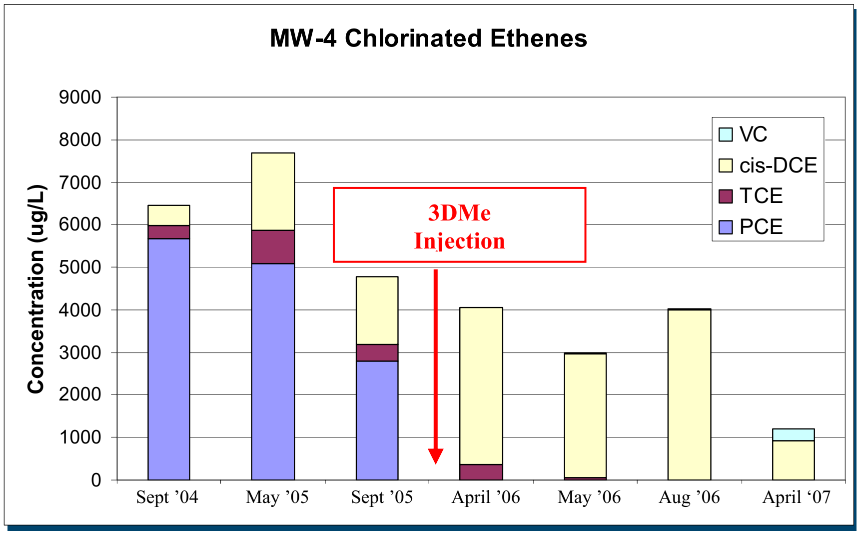

Table 2. Vinyl Chloride and Ethene detection in Well MW-4 (ppb)				
	April 2006	May 2006	August 2006	April 2007
VC	ND	17	25	270
Ethene	3	3	NA	13

CONCLUSION

Biostimulation using 3DMe was successful in treating the target contaminants as a result of the proper dosing/emplacement of the material and overall product performance. In MW-4, PCE and TCE were reduced to non-detect while total chlorinated compounds were reduced by more than 70 percent.

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3-D Microemulsion™ Treats PCE, TCE and cis-DCE

SITE SUMMARY

A limited subsurface investigation revealed elevated concentrations of chlorinated compounds in groundwater at a manufacturing facility in Massachusetts. Further assessment indicated past releases of tetrachloroethene (PCE) had occurred relating to a former above ground storage tank housed on-site. PCE levels of approximately 12,000 micrograms per liter (ug/L) and daughter products trichloroethene (TCE) and cis-1,2-dichloroethene (cis-DCE) were measured in the subsurface. Enhanced anaerobic bioremediation using 3-D Microemulsion (3DMe)™, a form of HRC Advanced®, was implemented via direct-push application to accelerate reductive dechlorination.

TECHNOLOGY SUMMARY

3DMe is composed of free lactic acid, controlled-release lactic acid (polylactate) and certain fatty acid components which are esterified to a carbon backbone molecule of glycerin. When injected into contaminated soil and groundwater, 3DMe produces a sequential, staged release of its electron donor components. The immediately available free lactic acid is fermented rapidly while the controlled-release lactic acid is metabolized at a more controlled, gradual rate. The fatty acids are converted to hydrogen over a mid-to long-range timeline giving 3DMe an exceptionally long electron donor release profile. This staged fermentation provides an immediate, mid-range and very long-term, controlled-release supply of hydrogen (electron donor) to fuel the reductive dechlorination process.

REMEDIATION APPROACH

- **Remediation Objective**: Degrade PCE, TCE and cis-DCE
- **Application Type:** Barrier
- **Product:** 3-D Microemulsion
- **Quantity Applied:** 960 lbs
- **Application Rate:** 6 lbs/ft
- **Injection Spacing:** 5-7.5 ft

SITE CHARACTERISTICS

General

- **Name:** Confidential
- **Location:** Massachusetts
- **Industry:** Manufacturing
- **Contaminants of Concern:**

Table 1. MW-16 Concentrations

Contaminant	Concentration
PCE	12,000 ug/L
TCE	2,300 ug/L
Cis-DCE	1,300 ug/L

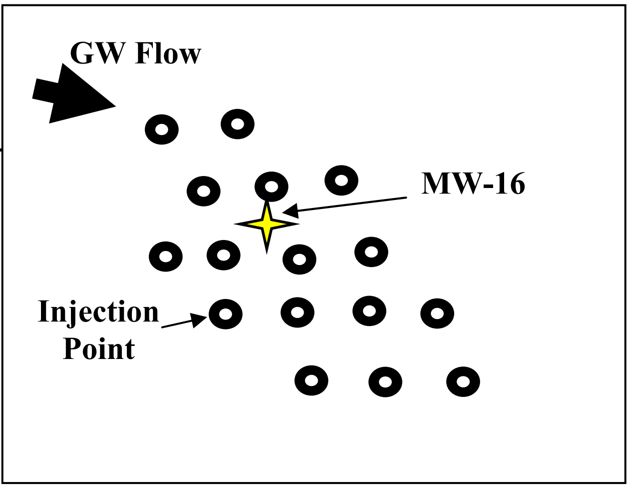

Figure 1. 3DMe Injection Design

Hydrogeology

- **Treatment Area:** MW-16 – Downgradient of incoming source of contaminants
- **Soil Type:** Fine to Coarse Sand with Interbedded Layers of Silt and Clay
- **Groundwater Velocity:** unknown
- **Groundwater Flow Direction:** Southeast
- **Depth to Groundwater:** 4-10 ft

RESULTS

Figure 2: Chlorinated ethene concentrations in MW-16

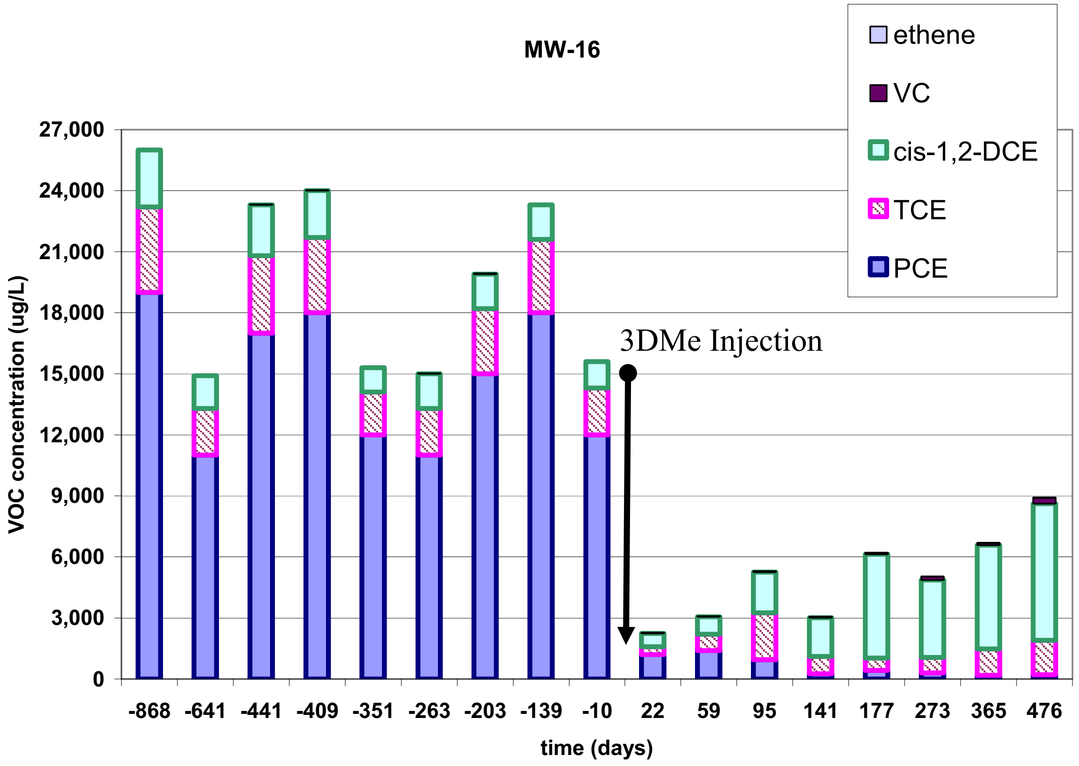

Table 2: Metabolic acid data from MW-16

Day	Lactic acid	Pyruvic acid	Propionic acid	Butyric acid	Acetic acid
-10	0	0	0	0	0
22	1410	3.5	3.5	3.5	35
59	576	0.35	105	0.3	83
95	130	1.7	370	13	130
141	372	3.5	354	116	129
176	222	3.5	357	210	135

Table 3: MW-16 Contaminant and Breakdown Product Table

Note: all units are ug/L						
Date	**Day**	**PCE**	**TCE**	**cis-1,2-DCE**	**VC**	**ethene**
11/25/2002	-868	19000	4200	2800	0	
7/10/2003	-641	11000	2300	1600	0	
1/26/2004	-441	17000	3800	2500	0	26.7
2/27/2004	-409	18000	3700	2300	0	27.4
4/25/2004	-351	12000	2100	1200	0	
7/22/2004	-263	11000	2300	1700	0	21.7
9/20/2004	-203	15000	3200	1700	0	30.9
11/23/2004	-139	18000	3600	1700	0	
4/1/2005	-10	12000	2300	1300	0	
3DMe INJECTION						
5/3/2005	22	1200	390	650	37	6.8
6/9/2005	59	1400	800	860	17	6.2
7/15/2005	95	950	2300	2000	48	9.3
8/30/2006	141	250	850	1900	52	8.4
10/04/2006	176	430	600	5100	70	9.8
1/9/2006	273	300	760	3800	170	11
4/11/2006	365	180	1300	5100	96	9
7/31/2006	476	210	1700	6700	290	16

CONCLUSION

Immediately following the 3DMe application, a rapid and simultaneous decrease in all chlorinated ethenes (both parent and daughter products) was observed. This can be attributed to the partitioning of contaminants into the 3DMe material. Over time, both the 3DMe and the contaminants will be biodegraded resulting in metabolic acid production (from 3DMe) and reductive dechlorination of the contaminants. Three months following the 3DMe application a 98% reduction in PCE (from 12,000 ug/L to 250 ug/L) was observed. This positive trend was sustained over a 14 month period even with a continuing influx of contamination. As a result of the longer-term PCE degradation, TCE appears to be fluctuating with some increase. Also an expected increase in the daughter product cis-DCE was observed (Table 3). As Figure 2 shows, no significant increases in aqueous phase chlorinated ethenes have occurred following the 3DMe application and sequential reductive dechlorination is commencing as indicated by increases in the daughter products TCE, cis-DCE and VC. Ethene concentrations appear to be increasing ever so slowly indicating successful, complete dechlorination.

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