



## What's in this Issue?

### Battelle Conference Highlights:

- ⇒ Crude Oil Biodegradation
- ⇒ Biodegradation in the Vadose Zone
- ⇒ Tools for Assessing and Monitoring Biodegradation
- ⇒ Delivery Strategies
- ⇒ Sustainable Remediation

If you have any questions regarding the materials discussed in this issue of INNOSYNC, please contact:  
Paul Ranieri  
([PRanieri@croworld.com](mailto:PRanieri@croworld.com))  
Sophia Dore  
([SDore@croworld.com](mailto:SDore@croworld.com))  
or  
Alan Weston  
([AWeston@croworld.com](mailto:AWeston@croworld.com))

## Battelle International Symposium

### Bioremediation and Sustainable Environmental Technologies

The International Symposium on Bioremediation and Sustainable Environmental Technologies organized by Battelle took place June 27–30, 2011, in Reno, Nevada. The Symposium incorporated topics in addition to those addressed by its predecessor, the In Situ and On-Site Bioremediation Symposium. The Symposium's new name and revised and expanded scope reflect bioremediation's maturity and new directions in environmental research and application. Bioremediation and related technologies continued as core areas, but the program also encompassed green and sustainable remediation, sustainable site management strategies, emerging contaminants, vapor intrusion, and the environmental impacts of biology-based alternative energy production.

The following sections summarize the conference highlights.



### Biodegradation

Biodegradation is the process where contaminants are metabolized into less toxic or non-toxic compounds by microorganisms, contaminants may serve as a source of carbon and energy for the microbe, and some contaminants act as electron acceptors for the microbe. There were several key topics discussed in detail at the symposium, the highlight topics addressed were bioaugmentation, crude oil biodegradation, and biodegradation in the vadose zone.



### Bioaugmentation

Bioaugmentation is the process of adding microbes to the soil to stimulate biodegradation. The most common microbe used is the *Dehalococcoides* bacterium which has the ability to degrade PCE and TCE all the way to ethene. Several strains are commercially available. There are two problems commonly found with bioaugmentation. First, that the introduced microbes are often outcompeted by native microbes which are better adapted to site conditions. Second, many regulatory issues exist that do not allow for the addition of foreign microorganisms to the subsurface in many countries like Canada and Brazil.

### Bioaugmentation Case Study 1: Possible PCB Biodegradation

PCB are extremely recalcitrant molecules that are resistant to most technologies used to degrade or destroy contaminants. A study presented at the Battelle conference described an attempt to achieve biodegradation of these molecules. A laboratory study was performed where granular activated carbon (GAC) was impregnated with microorganisms to stimulate biodegradation of PCB. Mesocosms were constructed and filled with the GAC and microorganisms intended to dechlorinate and degrade PCB. In the mesocosms amended with the biologically active GAC a total decrease in the PCB Aroclor of 75% by mass was observed in 120 days. There was no increase in lower chlorinated congeners, indicating that anaerobic dechlorination and aerobic degradation may have occurred concurrently, although it is possible that the PCB were irreversibly absorbed on the GAC.

## Bioaugmentation Case Study 2: Aerobic Biodegradation of Chlorinated Solvents

Chlorinated solvents are typically biodegraded under anaerobic conditions, however at some sites anaerobic conditions are difficult and expensive to achieve. With the addition of a microbial inoculum chlorinated compounds such as trichloroethene (TCE) and tetrachloroethene (PCE) can be biodegraded aerobically. A full scale bioaugmentation project was conducted to treat 1,1-dichloroethene (1,1-DCE) at a former fire training site in Jackson, Mississippi. The native groundwater displayed aerobic conditions and a low level of indigenous microbes. Based on these findings an aerobic in-situ bioaugmentation approach was chosen using CL-Out®, a microbial product consisting of Pseudomonas bacteria which can degrade chlorinated solvent via a co-metabolic pathway. CL-Out® was added to the aquifer as an aqueous mixture using extracted groundwater from the site. Bimonthly sampling showed high rates of biodegradation of the 1,1 DCE contaminated groundwater for the first six months. Biodegradation slowed after six months which was most likely due to decreased oxygen levels in the subsurface as the oxygen was being consumed. This treatment appeared to be fairly successful, however the use of CL-Out and its metabolic pathway was likely not required for this Site since 1,1-DCE can be degraded via a regular (non-cometabolic) aerobic pathway by microbes that are typically present at all sites. If TCE or PCE had been present CL-Out® and the cometabolic pathway would have been required.

## Crude Oil

Biodegradation of crude oil has received increased interest lately due to the Deep Water Horizon oil spill in the Gulf of Mexico. Topics discussed included the biological and chemical fate of the petroleum hydrocarbons from the released oil, the impact of crude oil on the coastal marshes, new bacteria discovered that were capable of crude oil biodegradation, and the effect of weathering on the crude oil.

### Crude Oil Case Study 1

Dr. Terry Hazen, currently head of the Ecology Department and Center for Environmental Biotechnology at Berkeley Lab, gave a lecture on his research findings for the Deep Water Horizon oil spill. Dr. Hazen had an active research program located in the Gulf before the deep water

horizon spill allowing him to accrue large amounts of data before, during, and after the spill. His data showed that high concentrations of hydrocarbon degrading bacteria were naturally present in the Gulf because it has a large number of natural oil seeps. After the spill the native bacterial population increased dramatically due to the huge increase in their food source. This research showed that some hydrocarbon degrading bacteria populations were attracted by higher concentrations of hydrocarbons and moved toward them in order to degrade them.

Dr. Hazen's research suggested that as of June 2011, the oil was largely gone from the Gulf of Mexico. The research found oil contamination remaining on shore and in the coastal marshes but in the Gulf itself, little evidence remained of the spill.



### Crude Oil Case Study 2

The use of wetlands to treat contaminated water is a cost effective and reliable treatment method that is typically popular with the public. If enough space is available a well designed system can treat water passively in a system that maintains itself. This technology is usually applied to small scale treatment projects. A demonstration of how wetland technology can be used to treat large quantities of contaminated water was presented at the Battelle conference. An engineered wetland at a former refinery in Wellsville, New York was designed and constructed to treat groundwater containing metals and organic compounds. A large scale multistage treatment system was installed with a 3,000 foot collection trench to capture the groundwater, four cascade aerators to oxidize and precipitate metals, a bio-filter to control volatilized

organics, a sedimentation pond for the precipitation of oxidized metals, three horizontal surface flow wetlands for metals polishing and the removal of organics and five pulsed drained vertical flow wetlands for pH buffering. The system had a 15 day hydraulic retention time allowing it to treat 125 gallons per minute via gravity feed. Monitoring has shown that organic concentrations were reduced from 2,700 µg/l to 4.0 µg/l and metal concentrations were reduced from 3mg/l to 0.4 mg/l by the treatment system. This project demonstrated that innovative technologies such as wetland treatment can be successful for large scale treatment.

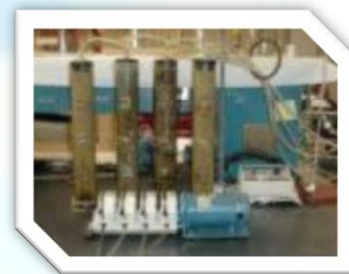


## Biodegradation in the Vadose Zone

Stimulating biodegradation in the vadose zone has several inherent problems. In the saturated zone aqueous injected materials use groundwater to assist their dispersion which is not possible in the vadose zone. Also anaerobic conditions are difficult to achieve since porous soils contain air and infiltration from precipitation is oxygenated.

### Vadose Zone Case Study

Aerosol delivery is an emerging technology for distributing amendments in contaminated vadose zone soils. Amendments to be delivered to the subsurface are made into an aerosol by creating a cloud of tiny liquid droplets suspended in a gas. When injected into porous media, the aerosol particles are transported with the gas until they hit a solid surface and deposit. In a laboratory study performed using sand filled columns as the media, a vegetable oil aerosol amendment was tested by delivery to the columns. The results of the study showed that the aerosol was delivered evenly throughout each column. This test was performed on sandy soils, silty and clay like soils would most likely show less even distribution due to their lower porosity. This technology is still being tested at the laboratory level, however aerosol injection into the vadose could prove to be a promising technology after more testing.



## Tools for Monitoring Biodegradation

Many new tools are now available that provide detailed information about subsurface processes. Tools such as compound specific isotope analysis (CSIA), molecular methods, and modeling were discussed at the conference.

### Compound Specific Isotope Analysis (CSIA) Case Study

Recently a Chevron site where CRA is the consultant used CSIA to determine if contaminants in the groundwater were naturally degrading. The technique is based on the theory that during natural biodegradation lighter isotopes tend to be consumed by bacteria before their heavier counterparts. CSIA of carbon was conducted in December of 2009 to determine whether chlorinated compounds including BCEE (bis(2-chloroethyl) ether), BCIE (bis(2-chloro-isopropyl) ether), 1,2-dichloropropane (1,2-DCP) and 1,2-dichloroethane (1,2-DCA) were being biodegraded under conditions that were naturally anaerobic.

Significant enrichment of the heavier carbon isotope indicated that concentration reductions were likely the result of natural transformation under anaerobic conditions. This is the first reported CSIA data set demonstrating natural anaerobic transformation of BCEE and BCIE in groundwater.

These data will be used in selecting a final remedy for managing the groundwater plume



### Molecular Tools Case Study

Molecular tools can be used to identify the species of bacteria present, determine numbers of particular bacteria, the presence and quantity of bacteria that perform a specific process, prove that a process is occurring, identify a pest organism, and demonstrate changes in a microbial community. Environmental applications are still being developed, however these studies demonstrate how molecular tools can be used to define the processes that are occurring and their use is increasing. Molecular tools made for the perchlorate-reducing bacteria are based on the specificity of the *pcrA* gene. *pcrA* genes are common to all perchlorate-reducing bacteria, and their presence is a direct indicator of perchlorate-degrading capacity. At an example Site, perchlorate contaminated groundwater was potentially discharging into the intertidal zone of an estuary. Organic material in the creek bottom was suitable for natural attenuation of perchlorate, and decreases in concentrations were observed. A correlation between *pcrA* counts and absence of perchlorate was demonstrated across the monitoring well network. The strong correlation between *pcrA* counts and absence of perchlorate was used to confirm monitored natural attenuation. This study showed that molecular tools can be used to prove that biodegradation is occurring.

### Delivery Strategies

Lab treatability study results are sometimes different from field results due to difficulties with effective delivery and distribution of reagents in the subsurface. One of the products discussed at the symposium was zero valent iron (ZVI). In-situ ZVI treatment is an effective way to treat chlorinated solvents. The transition problem from lab to field with ZVI is not related to its ability to remove chlorinated compounds from groundwater, but the delivery of ZVI to the contaminated groundwater. Typical delivery methods for products like ZVI include direct push technology (DPT), hydraulic fracturing (HF), and pneumatic fracturing (PF). A case study was performed to compare these delivery strategies using magnetic susceptibility (MS) to measure the distribution of ZVI into the subsurface. The results of the study are listed below.

- HF - Top-down injection
  - Depth: 12 meter centers
  - Yielded thick discreet fractures
  - ZVI loading at ~7% of the vertical intervals
- DPT - Constant pressure, Bottom-up
  - Depth: 2.5 meter centers
  - Most uniform distribution
  - ZVI loading at ~25% of the vertical intervals
- PF - Bottom-up injection
  - Depth: 12 meter centers
  - Yielded thin discreet fractures
  - ZVI loading at ~6% of the vertical intervals

## Tools for Monitoring Biodegradation continued

This study showed that different delivery techniques for ZVI have associated advantages and disadvantages. Often sacrifices in one area must be made in order to achieve gains in another area. Delivering remedial materials should be addressed with an approach that is tailored to site conditions, budget, and remedial objectives.

## Sustainable Remediation

Sustainable remediation was a topic that is new to the Battelle Bioremediation Conference. Discussion of this topic is increasing because sustainable remediation is a growing business market and regulators are beginning to incorporate it into policy and site management decisions. The practice of sustainable remediation involves the minimization of impacts, re-use of materials, and efficient management practices. Efforts to achieve sustainability can produce cost savings. Manufacture of materials, resources used, transportation of materials/crew/equipment, air emissions, energy consumption, and waste generation are a few of the key categories that were discussed.

### USEPA's 5 Core Elements of Green Remediation

- Water - Significant amounts of water can be consumed for treatment processes. Green remediation strategies focus on reducing water consumption, reusing treated water, and using efficient techniques to manage and protect surface water and groundwater.
- Land & Ecosystems - Remediation sites often involve degraded onsite and offsite ecosystems and may have conditions that make the site unsafe for human or other use. Green remediation strategies focus on remedial actions that minimize further harm to the area, protect land resources and ecosystems at or near the site, and foster the return of sites to ecological, economic, social, or other uses.
- Air & Atmosphere - Onsite and offsite emissions of greenhouse gasses and air pollutants can result from activities such as treatment processes, operation of heavy machinery, and transportation. These emissions may be reduced by applying the most appropriate advanced technologies and sound field practices.
- Energy – Many remedial strategies involve energy intensive technologies. Green remediation strategies focus on opportunities to improve energy efficiency and use renewable energy sources.
- Materials & Waste- Site remediation may use significant amounts of raw materials and sometimes generates its own hazardous and non-hazardous wastes, including materials and debris that often are shipped offsite. Green remediation strategies offer opportunities to reduce materials consumption and waste generation, use recycled and local materials and spent products, and purchase environmentally preferred products.



## Sustainable Remediation Case Study

Renewable energy and non-traditional treatment methods were used for a remediation of chlorinated groundwater with trichloroethylene (TCE) and dichloroethylene (DCE). Multiple remediation strategies were evaluated but the eventual approach was enhanced bioremediation with groundwater circulation using a solar powered extraction system. This treatment system was designed to incorporate the elements of sustainable remediation discussed above by minimizing the use of energy, and water and decreasing output of greenhouse gases and waste. A series of three injection/recirculation well curtains were placed up gradient of the plume, mid-gradient of the plume, and downgradient of the plume. The injected solution consisted of emulsified vegetable oil, microbial inoculum and anaerobic chase water. After six months TCE and DCE treatment zone concentrations were reduced by 93% and 91% respectively. This method allowed for an O&M cost savings of approximately \$100,000 for the first six months. A common concern of sustainable remediation is that the lower cost and high restrictions will come with a compromise on results. In this example no such compromise was observed.



The Battelle Conference covered many topics related to bioremediation, biodegradation and sustainability and provided a venue for discussion of current issues in the remedial field. ITG has the collected abstracts from this conference and will receive a CD containing the proceeding papers from this conference as soon as they have been compiled. Please contact ITG for more information about any of the topics presented at this conference.