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Soil in a day’s work

For those of you whose job has anything to do with soil contamination, this is your magazine, or, as some might say, it is your trade magazine. My job is to put out a magazine about soil contamination, and so, I get a trade magazine about “magazine-making.” And I wonder if my reaction to it is similar to your reaction to Soils. I really enjoy my magazine-making magazine. When it hits my desk, I’m glad to see it, I give it high priority, and actually look forward to cracking it open. I often read it during lunch at my desk, and consider reading it to be something approaching leisure or recreation—even though it is directly related to my job.

I think the reason I enjoy my magazine-making magazine so much, is because in almost every issue, I find some little nugget I can use to make this magazine better. And that is what I try to do with each issue of Soils—sneak in as many nuggets as I can find that you can use to help you in your job. But I have to tell you, this issue is Nugget City!

Bioremediation is our focus topic this month, and there is so much going on in bioremediation technology. Maybe people are particularly intrigued by bioremediation because it is exotic and mysterious and molecular and magical. C. Marjorie Aelion explores some of the mysteries of the biodegradation process in her article on page 38, “Between the before and after,” stressing that we need to know more about what goes on between site assessment and final sampling in a bioremediation project. I learned many things I did not know before in Tom Cason’s article on page 8, “Nitrogen supply key to degradation.” And be sure to read “Oxygen pellets spike bioremediation,” by Steve Vesper, Larry Murdoch and Wendy Davis-Hoover on page 14. You’ll never wrap a sandwich again without thinking of this article.

And Doug Knapp’s article on page 18, “Turn problem sludge into productive bacteria” takes the concept of recycling to dizzying heights.

I could go on and on raving about the wonderful articles in this issue, but I am already in trouble, because my magazine-making magazine says that an editorial that merely recites the table of contents to the readers is a waste of time and space. But, I guarantee, the articles in this issue are lean—jam-packed with nuggets I hope you will enjoy, and be able to use.

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Reactor recipe banishes contaminants

Augmented bioremediation degrades polynuclear aromatic hydrocarbons

By Michael Barnhart and James Hyzy, Ph.D.

Researchers at Waste Stream Technology, Inc., Buffalo, N.Y. set out to determine the remediation potential for polynuclear aromatic hydrocarbon (PAH) contaminated sediments in a slurry phase bioreactor system. They also wanted to learn the operational requirements of a slurry phase system, because costs of dewatering contaminated sediments ranges from $12 to $25 per cubic meter.

Eliminating the dewatering step from a treatment plan can significantly reduce the overall cost for remediation.

Slurry phase bioreactor bioremediation of PAH contaminated soils was investigated via biostimulation and bioaugmentation. Biostimulation is nutrient induced enhancement of the site’s indigenous microbial population of hydrocarbon degraders, while bioaugmentation adds specific contaminant degrading microbial species to the site.

Contaminated sediment samples from Hamilton Harbor in Hamilton, Ontario were examined for their slurry phase bioremediation potential using a 60 liter bench scale slurry phase bioreactor produced by EIMCO of Salt Lake City, Utah, and shown in figure one, above.

The operational parameters of the reactor were fixed for all the microcosms, and sediments were prescreened to -30 mesh sieve. Rake speed was set at four revolutions per minute with aeration rate of one cubic meter per minute and temperature set at 24°C.

The sediment samples were homogenized and split into three separate microcosms for testing: distilled water control, carbon free growth medium for biostimulation and carbon free growth medium plus Bioblend M-3MCA, an
augmentation product of Waste Stream Technology, Inc., Buffalo, N.Y.
The distilled water control microcosm was run to determine if any significant abiotic degradation of the PAH contamination would occur. The biostimulated microcosm was developed with a blend of macro and micro nutrients in a buffered solution. The final microcosm was augmented with bacteria M-3MCA plus the buffered nutrients. Bacteria M-3MCA was isolated on 3-methyl cholangrene, and was found to have the ability to degrade a wide range of target compound contaminants.
Each microcosm was monitored weekly for four weeks for colony forming units, nutrient concentration and total PAH concentration. Chemical analysis of sediments processed through the reactor were sampled and analyzed in triplicate to minimize sampling errors. Results are shown in figure two, left, and reflect considerable differences in results among the three microcosms. The microcosms were evaluated

Continues on page 47 →
Nitrogen supply key to degradation
Bacteria consume nitrogen faster than any other nutrient

Nitrogen is a critical nutrient that commonly becomes a limiting factor in soil bioremediation projects. While phosphorus, potassium and a number of micronutrients are critical as well, nitrogen is consumed by bacteria in the catabolic breakdown of hydrocarbons at a rate several times higher than the next most critical nutrient.

When a contamination event occurs, an alien carbon source is usually introduced into a climax soil community, which, depending on the setting, may consist of a wide diversity of soil dwelling microbial, plant and animal species. With the introduction of a contaminant carbon source, the balance in the natural cycling of nitrogen and carbon is suddenly disrupted, and the soil community begins to adjust to its new conditions. Since the organic carbon is alien and its quantity is excessive, it will eventually be assimilated into the soil community with the production of biomass. During the active conversion of the contaminant hydrocarbon, nitrogen, and other nutrients, along with oxygen, are assimilated with the carbon into biomass which basically is the production of billions of new bacterial cells. Simply stated, this is the basis for bioremediation. In order for this metabolic process to occur, all the critical components, including nutrients and oxygen must be present in appropriate concentrations capable of supplying all the nutritional and respiratory needs of the microbial population.

When one or more of these critical components are absent or of limited availability, the entire conversion process may be considerably slowed or stop altogether. Nitrogen is assimilated in new cells as a critical element in the production of nucleic acids, amino acids and proteins. Without these key building blocks of life, the conversion of contaminant hydrocarbon into biomass is severely inhibited. With the catabolic breakdown of petroleum molecules, a source of organic carbon will be available as long as the hydrocarbon is present. The oxygen component is supplied from the atmosphere by diffusion or by a delivery system, but the naturally occurring usable nitrogen sources must be re-supplied as the small amounts that are typically found in the soil are quickly exhausted.

Gaseous nitrogen accounts for...
approximately 78 percent of atmospheric gases, and a substantial amount of soil gases, but it is not in a form which is usable for most biological processes. In order for nitrogen to be usable by most bacteria and other organisms, it must be “fixed” or converted to a usable form. Nitrogen fixation occurs in the roots of certain green plants, cyanobacteria and certain heterotrophic bacteria. In soil environments where high levels of carbon sources have been observed, such as hydrocarbon contaminated soils, available nitrogen is severely depleted. Under such conditions, nitrogen fixation has been observed at accelerated rates. However, under conditions of high nitrogen demand, such as the production of plant mass, and in the case of hydrocarbon catabolism, nitrogen fixation is usually inadequate to meet the nitrogen demand of the soil ecosystem, and an on-going re-supply from an exogenous source of usable nitrogen may be necessary.

Aerobic bacteria, such as those found in soil, generally require a reduced form of nitrogen such as ammonia. In the reduced state, ammonical nitrogen is easily assimilated into the metabolic pathways which lead to the anabolic synthesis of nucleic acids, amino acids and eventually, enzymes and proteins. Nitrogen is required in relatively large quantities since it can account for as much as 10 percent of the dry weight of bacteria. When the amount of ammonia becomes growth limiting, biomass production slows to the capacity of nitrogen “cycling” within the soil ecosystem, assuming that no additional exogenous nitrogen enters the system.

In practical terms, this means that a successful bioremediation project usually requires periodic monitoring of the nitrogen levels in the soil and timely amendments in order to maintain an available source of usable nitrogen during the hydrocarbon assimilation process.

In general, the most economical and readily available sources of nitrogen are from suppliers of agricultural fertilizers. Some vendors of bioremediation products produce proprietary pre-mixes of balanced nutrients, which not only include the nitrogen source, but potassium, phosphorus, micronutrients and other proprietary components which might include buffers and wetting agents.

Nitrogen sources are available as organic or inorganic, and in either oxidized or reduced forms. The most common source of an organic form of nitrogen is urea, which is available in several forms. Urea is a by-product of protein metabolism, and is represented by the formula:

\[\text{NH}_2\!\text{-C-NH}_2\]

In its unaltered form, urea is generally not usable by green plants or bacteria as a nitrogen source. It must be converted to an inorganic form of nitrogen by a process known as ammonification. The hydrolysis or ammonification or urea is represented by the equation:

\[\text{NH}_2\!\text{-C-NH}_2\!\text{+H}_2\!\text{O} \rightarrow \text{2NH}_3\!\text{+CO}_2\!\text{+O}\]

Many plants, animals and microorganisms can hydrolyze urea through the process of ammonification. The enzyme urease, or urea amidohydrolase drives the conversion to ammonia and carbon dioxide with the consumption of one molecule of water. If the hydrolysis of urea occurs near the soil surface, and the pH rises above 7.0, significant amounts of gaseous ammonia may be lost to the atmosphere. Heavy, clayey soils with a low pH are less likely to result in ammonia loss than are sandy soils with low levels of organic matter and a relatively high pH. Large amounts of urease, soil moisture, and warm temperatures can account for a rapid hydrolysis of urea which results in even more ammonia formation.

Most organic soils have a measurable background level of urease. However, the enzyme may be absent, or at very low levels in the deeper horizons of the subsurface soil.

Other sources of organic nitrogen include natural organic nitrogen carriers, including sewage sludges and plant and animal residues. These types of products include animal manures

Continues on page 10→

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The Tools For Site Investigation

Write in 100

May 1994 Soils 9
and a variety of materials containing by-products of animal and plant processing. Typically, these natural organic nitrogen carriers contain less nitrogen, by analysis, than inorganic sources. The mineralization of nitrogen from natural organic materials is through microbial decomposition of complex nitrogen containing organic compounds. Natural organic nitrogen carriers are sometimes classified as slow release sources because the nitrogen must be converted into a usable form before it can be assimilated by plants or microbes.

In acidic to neutral pH environments where water is available, ammonia exists as ammonium ions. Ammonium ions are easily assimilated by microorganisms and green plants where they are directly shunted into biochemical pathways which lead to the synthesis of amino acids and eventually proteins and enzymes. This availability of a usable form of nitrogen and the continuous supply of a source of carbon provides the basis for the metabolic machinery which eventually leads to the conversion of the contaminant hydrocarbon, simple salts of nitrogen, and other minerals into the production of bacterial biomass in the contaminated environment. It is this conversion of organic carbon and mineral salts to living biomass which forms the basis of bioremediation or the metabolic conversion of one form of carbon to another, and the conversion of inorganic nitrogen to organic forms. Eventually, the living biomass will die as the soil returns to a climax community, and the formation of soil humus will result. During this process, excess carbon and nitrogen is returned to the atmosphere as CO₂ and N₂.

In most cases this process is aerobic, which requires the presence of oxygen to facilitate the production of metabolic energy as a product of the catabolic assimilation of organic carbon. In a typical scenario, the organic carbon source enters a metabolic pathway of the cell as an organic acid or other form. It eventually enters the tricarboxylic acid cycle where some carbon is shunted into pathways for the synthesis of many products, including amino acids and eventually proteins. At the same time, some of the carbon is oxidized to CO₂ and lost as a waste product. Through a series of steps ending with terminal oxidation, energy is stored in the form of high energy phosphate molecules. This stored energy is consumed within the cell in many areas, including the synthesis of amino acids from carbon and ammonium ions. Without oxygen, this stored chemical energy becomes limiting, and the whole metabolic process of the cell is considerably slowed. With many bacterial species, a conversion to inefficient alternate pathways, known as anaerobic metabolism, may result.

Anaerobic metabolism is extremely complicated, and is poorly understood in comparison to aerobic processes. Anaerobic metabolism is much less efficient than aerobic metabolism, however, it is well known that anaerobic processes are, in certain cases, much more effective in the breakdown of certain organic molecules than are aerobic processes. Thus, anaerobic processes occupy a key role in the cycling of nitrogen and organic carbon in nature. While certain bacteria can fix gaseous nitrogen under anaerobic conditions, this process is uncommon, and most species generally require an exogenous nitrogen source. In contrast, denitrification is common and extensive in many soils.

Under aerobic conditions, excess ammonia or ammonium ions can be oxidized to nitrite ions and then to nitrate ions which represent the ultimate form of oxidized nitrogen. This common process is known as nitrification, and it occurs in the organic phase of all soils by microbial action. The conversion to nitrite is:

\[ \text{NH}_4^+ + 1/2 \text{O}_2 \rightarrow \text{NO}_2^- + 2\text{H}^+ + \text{H}_2\text{O} \]

Nitrite is oxidized to nitrate as:

\[ \text{NO}_2^- + 1/2 \text{O}_2 \rightarrow \text{NO}_3^- \]

Nitrate is readily usable by green plants, and is a major component of many forms of plant fertilizers for both agricultural and horticultural purposes. In general, bacteria assimilate nitrogen in its reduced form much more commonly than oxidized forms. Nitrate is an ion which can be highly useful under anaerobic conditions.
because it can function as a surrogate form of chemical oxygen by serving as an alternate electron acceptor to oxygen—and thus facilitates the biochemical assimilation of carbon under anaerobic conditions. In general, aromatic compounds are more readily converted than aliphatic compounds. This phenomenon, along with the role of other reducible ions which function as alternate electron acceptors is getting heightened attention because it may be less costly to deliver reducible ions into a contaminated environment than gaseous oxygen or hydrogen peroxide. For example, the anaerobic conversion of toluene with nitrate has been reported by the EPA as:

\[
C_7H_8 + 7.2H^+ + 7.2NO_3^- \rightarrow 3.6N_2 + 7.6 H_2O + 7CO_2
\]

The stoichiometry of the chemistry assumes the complete mineralization of toluene and the complete reduction of NO₃⁻ to N₂.

Nitrate can also be a troublesome ion since it is not adsorbed to negatively charged clay particles because of its own negative charge. Conversely, ammonium ions with a positive charge are attracted to negatively charged sites on soil particles and are sorbed in the soil matrix. Since nitrate ions are not sorbed, and because of their high solubility, they are readily leachable and thus a threat to groundwater.

Nitrification is essentially a mobilization process whereby fixed forms of inorganic nitrogen are converted to a leachable form with the potential for moving into groundwater. Not only may this process represent an important loss of nitrogen from the biotreatment system, but it poses a potential health threat to humans by contamination of potable groundwater. Nitrate is a blood toxin because it interferes with oxygen exchange in hemoglobin, and both nitrate and nitrite ions can react with amines and amides in the gastrointestinal tract to form carcinogenic nitrosamines. Because of these and other potentially serious environmental and health problems, nitrate is closely regulated, and in bioremediation, it must be carefully used, consistent with regulatory constraints, and in a manner which eliminates or minimizes any threat to groundwater.

Nitrate and ammonium ions represent a source of nitrogen which is immediately available because the conversion from organic nitrogen to the inorganic form is not necessary. Common forms of inorganic nitrogen include: \(\text{NH}_4\text{NO}_3\) (ammonium nitrate), \((\text{NH}_4)_2\text{SO}_4\) (ammonium sulfate), \((\text{NH}_4)\text{H}_2\text{PO}_4\) (monoammonium phosphate), \((\text{NH}_4)_2\text{HPO}_4\) (diammonium phosphate), and \(\text{KNO}_3\) (potassium nitrate). There are many other types of inorganic nitrogen salts, but these are commonly used in fertilizer products. Each material has specific properties which include pH effects, relative

Continues on page 12→
Nitrogen supply, from page 11

solubility and a salt index, all of which have an influence on soils.
Ammonium nitrate contains both ammonium ions and nitrate ions, and is approximately 33 percent nitrogen. It is highly soluble in water, has a moderately strong acidifying effect, and has a high salt index. A high salt index means that the osmotic potential of the soil is positively influenced. Materials with a high salt index should be avoided in soils that are already high in soluble salts.
Ammonium sulfate is moderately soluble in cold water and also has a high salt index. But, it has a very strong acidifying effect. Ammonium sulfate contains approximately 21 percent nitrogen and is very effective in soils with high pH. But it must be used with caution since high pH soils often have high levels of soluble salts.
Monoammonium phosphate contains approximately 11 percent nitrogen and is more commonly used as a source of phosphorus. The salt index is high, but somewhat less than that of either ammonium nitrate or ammonium sulfate, and the acidifying effect is moderate. Water solubility is moderate.
Di ammonium phosphate contains approximately 20 percent nitrogen and, like monoammonium phosphate, is more commonly used as a source of phosphorus. Its salt index, acidifying effect and water solubility are all moderate.
Potassium nitrate contains approximately 13 percent nitrate nitrogen, and is more commonly used as a source of potassium. The salt index is very high but, unlike many other nitrogen sources, the acidifying effect is negative—meaning that the pH is influenced toward the alkaline. Water solubility is moderate to low.
While there are many other ammonium and nitrate salts which may be acceptable nitrogen sources, these are the most common and most likely to be available at low cost.
Ammonium chloride (NH₄Cl) is frequently used as a nitrogen source in treatability studies, but may be difficult to locate in bulk quantities at a low cost for field applications.
Soil tests should include at a minimum, the pH, soluble salts, available nitrate nitrogen, available ammonical nitrogen, available phosphorus and available potassium. Additional tests for one or more micronutrients are also useful. One frequently used test that is of limited utility is known as total Kjeldahl nitrogen test. The Kjeldahl test accounts for all inorganic and organic nitrogen and produces a figure that represents total nitrogen. But, results of this test may be misleading since total nitrogen for both available and unavailable forms are combined, and the ratio of these two forms is not revealed.
Without a treatability study to determine kinetics of the conversion of contaminant to biomass, the demand for oxygen and other essential
elements, it is difficult to predict the amount of exogenously supplied nitrogen that will be required to convert a given amount of contaminant. In general, a C:N:P ratio (carbon: nitrogen: phosphorus) of about 120:10:1 is reasonable, and a ratio of 300:15:1 has been reported as limiting. With these rough guidelines, an approximate amount of exogenously supplied nitrogen that will be required can be calculated if the amount, concentration, biodegradability and type of contaminant is known.

Despite this, even under the most controlled conditions, an undetermined amount of nitrogen may be lost to the atmosphere and to leaching before it is captured in the metabolic conversion process. This loss may be acute if the total nitrogen supply is applied in a single dose. Under optimal conditions, nitrogen should be fed into the system in a continuous supply in amounts roughly in harmony with other limiting factors, such as available oxygen, temperature, other nutrients and microbial populations.

Frequent monitoring of soil nitrogen levels by regular testing provides some insight into nitrogen relations within a bioremediation system. Background tests prior to treatment frequently reveal a nitrogen depleted condition. If nitrogen is available, and the contamination event is not recent, other limiting factors are probably involved. The nitrogen component is typically the first to be reduced to a limiting level. In such situations, it is not unusual to observe total nitrate and ammonical nitrogen in the zero to three ppm range, whereas in agricultural soils, a range of 40 to 50 ppm is common.

Once the frequency, type and amount of supplemental nitrogen has been determined, timely soil testing provides information on the appropriateness of the supplemental nitrogen program. For example, under aerobic conditions, when excess urea has been applied, a conversion of ammonical nitrogen to nitrate, reflected by elevated total nitrate and drop in pH would not be uncommon.

Under reducing conditions of depleted oxygen, an increase in ammonical nitrogen might be observed. In both cases, it is a good idea to review the nitrogen amendment program and reduce either the amount and/or frequency of nitrogen feeding.

Nitrogen is only one of many critical elements in the process of bioconversion of hydrocarbon contaminants. It is no more important than any other element should one or more become limiting. However, nitrogen management in bioremediation is often misunderstood. A clear understanding and management of the nitrogen component in soil bioremediation certainly contributes to the successful completion of a bioremediation project.

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May 1994 Soils 13
Oxygen pellets spike bioremediation

Tests show slow release oxygen pellets can keep microbes supplied

By Steve Vesper, Ph.D., Larry Murdoch, Ph.D., and Wendy Davis-Hoover, Ph.D.

Oxygen is required for aerobic bioremediation. However, oxygen is commonly in short supply in many contaminated environments, especially in low permeability subsurface soils or in saturated sediments. Air is a ready source of oxygen for microbes, but it may not be a convenient source to deliver. Pumps are required, which means a source of power must be nearby. Hydrogen peroxide has been used as a source of oxygen, but this can be difficult to handle, and it is potentially toxic to the degrader population of microbes. Another problem with hydrogen peroxide is the buildup of large microbial populations at the point of introduction that result in clogging of the delivery system. With the delivery of air or hydrogen peroxide, the delivery system must be monitored and maintained to keep it working properly. This usually means sending an expensive crew out to the site.

Research in the Engineering Research Division in the Center for GeoEnvironmental Science and Technology at the University of Cincinnati, Cincinnati, Ohio, and the EPA, has developed a slow-release, solid oxygen source that can be used to support bioremediation.

Working with researchers at the R.T. Dodge Co., a microencapsulation company in Dayton, Ohio, a number of solid sources of oxygen were considered as candidate compounds. The materials had to be relatively inexpensive, easy to handle, and acceptable for introduction into the soil. Finally, sodium percarbonate, Na$_2$CO$_3$·1.5H$_2$O$_2$ was chosen. This material decomposes in water and releases about 13 percent of its weight as oxygen. To extend the oxygen-releasing life of the compound, it is encapsulated in an inert polyvinylidene chloride (PVDC) shell. The PVDC is basically Saran Wrap$^{TM}$. These pellets are easy to manufacture in a standard Wurster coating process. In this process, crystals of sodium percarbonate are fluidized, then sprayed with a PVDC solution to form a uniform wall around the core of sodium percarbonate. Research showed that a wall of about 50 percent by weight was best for reducing the oxygen release rate. The result is a product of sand size grains, on average, about .5 millimeter in diameter.

In lab and field tests, the rates of oxygen release into water from these encapsulated pellets was compared to the rate for unencapsulated sodium percarbonate. Continuous computer monitoring followed oxygen release from the pellets in a completely air tight system. Oxygen release from the PVDC encapsulated sodium percarbonate was extended to nearly double the time of the unencapsulated compound. The PVDC appears to act by restricting the flow of water to the sodium percarbonate core.

Since sodium percarbonate contains hydrogen peroxide, there is the potential for toxicity. Examination of the effects of exposure on two soil bacterial strains revealed that the unencapsulated sodium percarbonate killed the bacteria within 24 hours, but the encapsulated product was non-toxic to these bacteria.

Continues on page 16$^{→}$
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<td>B 15,127 PPB</td>
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**On Site Bioremediation**
Oxygen pellets, from page 14

The next test was to take a local subsurface soil spiked with an organic contaminant and place it in air tight containers. Encapsulated sodium percarbonate was added to some of the containers, while others were held as controls. The containers were purged with nitrogen to eliminate the oxygen, and they were left to sit for 30 days at 12°C—typical subsurface soil temperature. After 30 days, the soils were analyzed. The contaminant was gone from the sodium percarbonate treated soils, but the contaminant concentration in the control containers, without sodium percarbonate, remained at the same concentration as the sterile controls in which the soil had been sterilized and then the encapsulated sodium percarbonate added. Tests on the effect of the microbial population in the samples showed there was about a tenfold increase in the microbial population in the sodium percarbonate treated soil compared to the controls. This indicated that the microbial population was healthy, and that the consumption of the contaminant had stimulated microbial activity.

Another advantage of the addition of the encapsulated sodium percarbonate was that its alkaline nature raised the soil pH. Initial pH of this soil was 4.7, and it was raised to about 8.3 by the end of the experiment. This could be a big advantage in stimulating bioremediation that is generally optimal in more neutral conditions.

The next step was to test the delivery of encapsulated sodium percarbonate to subsurface soils, and whether it would perform as well as in the lab.

University of Cincinnati researchers, in collaboration with a team from the EPA Risk Reduction Engineering Laboratory (RREL) have developed a method of gaining access to subsurface soils via hydraulic fracturing. In this process, sand is introduced into the soil to make horizontal, pancake shaped lenses. This technology is applicable where there is greater vertical stress than horizontal stress in the soil. This can be found in areas subjected to glaciation, for example in the northern U.S., Canada and northern Europe. Another condition where these kinds of soil stresses exist is in swelling clays, for example, along the U.S. Gulf coast. When these sand filled layers are made, they are generally parallel to the ground surface or, in some cases, rise gently toward the surface. The size of the fractures depends on the amount of material pumped into them, but they are typically up to 15 meters in diameter. Fractures can also be stacked, one on top of the other, as little as 50 centimeters apart.

Hydraulic fracturing has been performed around the U.S., including contaminated sites in Ohio, Texas, Michigan and Illinois. These highly permeable layers have been used for the addition of remediation enhancers like steam, or to expedite removal of contaminants with vapor extraction technologies. Scientists realized that not only sand, but materials similar in size and shape to sand could be introduced into these fractures—including inorganic nutrients and the solid oxygen pellets. If a long term source of oxygen could be added to the soil, one might be able to just walk away, and let the bioremediation proceed unattended. This idea was tested at a controlled site.

The University of Cincinnati’s Experimental Field Site has subsurface soils made up of highly impermeable, over-consolidated silts and clays. A surrogate, non toxic contaminant, propylene glycol was introduced into an area of subsurface soil for the experiment. After a four month period of acclimation, the soil was fracture, using a combination of sand and the encapsulated sodium percarbonate. The hydraulic fracturing process worked exactly as if sand alone had been used.

Each fracture contained 180 kilograms of sand, 180 kilograms of encapsulated sodium percarbonate and 18 kilograms of a commercial slow-released fertilizer. A stack of three fractures was made in the contaminated zone, then the center borehole was sealed, and the site was left alone.

The research team periodically sampled the treated site, and a similarly contaminated, unfractured control area over a four month period, and monitored contaminant concentration, microbial populations and pH of the soil.
After four months, some of the sand and pellets were recovered from the fractures to determine the amount of oxygen still available.

The results showed reductions in contaminant concentrations, especially in the vicinity of the fractures, but less reductions in contaminant concentrations in the soil between the fractures. There were increases in the microbial population from 10 to 100 fold in the treated area, mostly near the fractures. The background pH of the soil was acidic, and use of the pellets raised it to more neutral levels, typically between pH 7 and 9. Also, even after four months buried in the subsurface, there was still some oxygen available from the recovered fracture layer material. However, it was less than 10 percent of the original amount.

During this short, four month bioremediation period, the beneficial stimulation of microbial activity was clearly near the fractures. It would take a longer time for the influence to spread throughout the contaminated zone.

While these encapsulated pellets were originally developed to be compatible with the hydraulic fracturing process, they might have other applications as well. The degree of contamination at a site, the location of the contamination and many other factors will determine the utility of this product. The encapsulated pellets are formulated to consist of about 7 percent oxygen available by weight. Since the biodegradation of one kilogram of organic contaminant requires almost three kilograms of oxygen, it would take about 30 kilograms of the encapsulated oxygen source to degrade that one kilogram of contaminant. That is a great deal of material. Use of this product makes sense where aboveground pumps and equipment are unacceptable. It would also be useful where contamination levels are rather low, yet it important to complete remediation and leave the site—as in very remote sizes or in densely populated areas.

One potential user was working in sediments and needed to avoid disturbing the sediment by bubbling gases. Another potential user had nearly completed bioremediation at a site and was interested in adding this material to a series of trenches in soil which contained only low concentrations of contaminants—just to finish off the process. Another had contamination under a building, and the pellets, combined with hydraulic fracturing, made the most sense to access and eliminate the contamination. The utility of these pellets will depend on the balance between their cost and the savings derived from not using other methods of delivering oxygen.

Clearly, use of the pellets will cost more than air or hydrogen peroxide. The price will ultimately be determined by the demand. Recently, Riverside Products of Cartersville, Ga. expressed an interest in manufacturing the pellets. They are a large manufacturer of sodium percarbonate. Let them know if you have an interest in the product or a suggestion for its use by calling Inman Fairchild at 404-386-3115.

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Write in 263

May 1994 Soils 17
Turn problem sludge into productive bacteria

Bioreactor system uses sludges as food source to develop bacterial remedy

By Doug Knapp

A client asked BIO, Inc., Granger, Ind., to design and construct a bioreactor system that could degrade petroleum sludge from underground storage tank closures and produce a large volume of petroleum degrading bacteria to use in bioremediation projects. In theory, the petroleum sludge from the USTs would be similar to petroleum found in contaminated soils, so the bacteria harvested from the reactor should be able to degrade petroleum compounds in soils. In addition, the bioreactor should be able to produce a live, active, more efficient and less expensive bacteria culture than commercially produced bacteria.

For this project, the petroleum sludges would be used as the sole food source to produce bacteria capable of degrading a variety of petroleum products, such as gasoline, diesel, waste oil and other petroleum distillates. The bacteria would be harvested from the bioreactor and distributed by the client to petroleum contaminated soils in landfarming or treatment bed bioremediation projects.

One goal of the client was to reduce off site disposal costs for the petroleum contaminated sludges. The client was spending about $40,000 per year in disposal costs, primarily due to water and solids present in the sludge.

The client would provide the petroleum sludge in bulk—consisting of a mixture of petroleum products, contaminated water and petroleum saturated solids. The petroleum contaminant portion was a mixture of gasolines, diesel fuels and fuel oils. The client also wanted BIO Inc. to monitor the volume of petroleum sludge used during the study period, as well as the approximate concentration of product, water and solids processed. The client wanted to recover as much reusable petroleum product as possible, for resale to a fuels blender for use as a secondary fuel. The bioreactor design would include a fuels recovery system to extract usable product from the sludge. In general, to be acceptable as a secondary fuel, recovered product should contain less than 1 percent solids and water.

The client had bioremediation projects underway using both augmentation and stimulation processes. Their experience was that stimulation processes were slower than augmentation, and more difficult to control, due to soil moisture, nutrients and contaminant concentration factors. However, in the faster augmentation projects, the costs of purchasing commercially produced bacteria made these projects less cost competitive than other disposal alternatives, such as landfill disposal. The client hoped to produce an inexpensive augmentation bacteria to reduce bioremediation cost, and be able to degrade a variety of compounds.

Since the bioreactor was to be set up in a building to maintain efficient operating temperatures, the client was also concerned that the bioreactor design include control of explosive vapors, and minimize off gas emissions and odors from the biological process.

BIO used two 30,400 liter, vertical aboveground tanks, designated as the primary and secondary reactors. The primary reactor would achieve a 50 to 70 percent removal efficiency, while the secondary reactor was designed to be a polishing system for an overall 95 to 99 percent removal of petroleum hydrocarbon.

The primary tank was equipped with a 7,600 liter internal holding and mixing tank to control the amount of hydrocarbon released to the bacteria. This internal tank was designed to separate and extract usable petroleum from the mixture, while allowing for maximum surface area for diffusion of hydrocarbons into the water. During the process, the contaminated water exits the internal tank, passes through the primary reactor to the secondary reactor.

Continues on page 20

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18 May 1994 Soils

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![CleanSoil Model. CSI-200 Priced at $173,000.](image)

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Problem sludge to productive bacteria from page 18

then returns to the internal tank to recontaminate the water, at recirculation rates ranging up to 38 liters per minute to deliver hydrocarbon to the bacteria. The internal holding tank also helped minimize potential explosive vapors in off gas.

The bioreactor was designed to operate aerobically for maximum degradation of hydrocarbons, and to minimize potential odors associated with anaerobic reactions. Compressed air connected to sparge rings delivered oxygen, and a hand held meter was used to measure dissolved oxygen.

Initially, the bioreactor was built with a fixed film plastic medium inside both reactors to provide a growth base for the bacteria. However, after several months, no significant growth was observed on the plastic, so it was removed. At that time, the operating strategy was changed to encourage free swimming, or mobile bacteria within the bioreactor, which may produce more suitable candidates for bioremediation applications in soils. Nutrient and emulsifier additions were made on a batch basis. The emulsifier selected was Simple Green™ which is biodegradable. Nutrient supplements were limited to solid nitrogen (urea) and phosphorous.

The initial bacteria seed introduced into the bioreactor was a mixture of several commercially available bacteria products and activated sludge from the local public works. The mixture concept for the added bacteria seed was based on the assumption that only bacteria which could effectively degrade hydrocarbons as the sole food source would survive in the bioreactor.

Total cost for construction and installation of the bioreactor system was $60,000. Operation and maintenance for a ten month test period averaged $1,500 per month, including:

rent $600
lab fees $500
emulsifier $ 50
labor $200
nutrients $ 10

More than 76,000 liters of petroleum sludge was processed during the ten month study period. It was collected from a variety of USTs, and consisted of 20 percent petroleum products, 60 percent contaminated water and 20 percent petroleum saturated solids—based on the gallons of recovered petroleum product and gallons of bacteria usage. For the ten month test, no waste was shipped to an offsite disposal facility, except for the petroleum recovered for use as a secondary fuel.

Over the ten month study period, the bioreactor system reduced the client’s cost for petroleum sludge disposal from 68 cents per liter to about 20 cents. Excluding rent, labor and lab fees, actual disposal costs were reduced to less than four cents per liter.

Over 30,400 liters of petroleum degrading bacteria were harvested over the test period, and applied to two dedicated bioremediation landfarming projects with a total of 456 cubic meters of soil. Initial total petroleum hydrocarbon levels in each pile exceeded 1,200 ppm. Field screening and laboratory analysis of soils indicates that the harvested bacteria have shown an efficiency for degrading hydrocarbons in soils and have reduced treatment time by an average of 40 percent over stimulation or other augmentation plots. The most recent data indicate that petroleum hydrocarbons in soils have been reduced to less than 100 ppm within 90 days.

The bioreactor was designed to operate in a continuous flow or
batch mode for the delivery of hydrocarbons to the bacteria, to sustain an active biomass for harvesting. During the study period, approximately 4,924,800 liters of water were recirculated at an 11.4 liter per minute flow rate. Analytical results indicate that petroleum saturated water from the internal tank was degraded to drinking water standards within about four days, resulting in a 99 percent removal efficiency for the system.

The bioreactor design can produce a much greater quantity of bacteria than was actually harvested during the study period. The actual bacteria production rate would be the upper limit of the flow rate, in excess of 3,800,000 liters produced, without decanting or clarification for bacteria concentration. Thus, the system produces an almost unlimited supply of bacteria, and costs per unit decrease as the cubic meters of soil increases, or as the total quantity of bacteria harvested approaches the 3,800,000 liter capacity.

Based on operations and maintenance costs divided by cubic meters of soil treated, bacteria costs remain at about $9 per cubic meter for the two study projects. However, based on the $15,000 total operating and maintenance expense, costs for produced bacteria would be less than 76 cents per cubic meter after a total of some 11,400 cubic meters of soil had been accumulated. Treatment costs per meter would also be reduced by a reduction in operating and maintenance expense.

BIO contracted with Microbe Inotech Laboratories, Inc., City, State, to perform bacteria identification analysis and degradation capability analysis. Their report indicates that the bacteria in the bioreactor are indeed capable of hydrocarbon degradation, and the five strains identified showed growth when supplied with gasoline or oil. Total heterotrophic plate counts for the bacteria indicated 40 million colony forming units after 48 hours.

Bacteria strains were identified by gas chromatograph and Biolog methodology. Identified strains include Plesiomonas Shigelloides, Bacillus Macerans, Corynebacterium Variabilis and Alcaligenes Faecalis type II. One strain could not be identified, but most closely resembled Acinetobacter Johnsonii/Genospecies 7. Review of similarity and distance coefficients used for bacteria identification suggest that the strains have undergone significant adaptation, with changes to the cells' amino acid structure to degrade the hydrocarbon food source.

During the study period, over 30,400 liters of petroleum fuels were recovered for secondary fuel use. Analysis of the fuel indicated a high Btu value, with less than 1 percent water or solids. Recovered fuel was collected in a separate 7,600 liter holding tank and sold to secondary fuel marketers. However, the 7,600 liter capacity of the tank did not offset the transportation charges of the fuels blender, so that secondary fuels were basically recycled at no charge.

At normal operating periods, the bioreactor achieved a 99 percent removal efficiency from contaminated water. Lab analysis of effluent or recirculation water was less than drinking water standards for benzene, ethylbenzene, toluene and xylenes. In addition, during standard operating conditions, total petroleum hydrocarbons in effluent water were less than laboratory detection limits.

During the study period, several upsets did occur when free petroleum product escaped the internal tank and flowed across the primary and secondary reactors. The upsets were caused by overfilling the internal tank—human error. Response actions included the removal of usable fuel from the tank to allow for additional capacity within the internal chamber, then pumping recovered free petroleum back into the internal tank. The remaining, non-recoverable free product was degraded by the bacteria over a two week period without interrupting operations. The free product congealed at the top of the bioreactor into 35 to 45 millimeter diameter “tar balls,” consisting of heavy petroleum compounds and biomass.

The compressed air and large ring oxygen delivery system provided adequate dissolved oxygen to degrade the hydrocarbons. Improved dissolved oxygen delivery can be achieved by installation of a fine bubble diffuser system, jet aeration or venturi circulation system.

The addition of the Simple Green™ emulsifier dramatically increased hydrocarbon delivery to the bioreactor from the internal tank. At high recirculation rates or high hydrocarbon concentrations, dissolved oxygen concentration in the reactor may become limiting and could lead to a decrease in removal efficiency. Therefore, emulsifier additions should be limited to about 2 liters per week to ensure that hydrocarbon delivery remains below 100 ppm.

The addition of phosphorous and nitrogen are adequate to maintain biological activity and hydrocarbon degradation. However, that does not rule out the possibility that other nutrient supplements might further enhance the efficiency of the operation.

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May 1994 Soils 21
When officials of BASF Corp. gave their contamination problems a sideways look, remediation plans took a completely different slant.

Along the banks of the Mississippi

R. Mark Conger, CPG, is hydrogeologist for groundwater and remediation programs for BASF Corp., Geismar, La. Keith Trichel is drilling engineer for Eastman Cherrington Environmental, Houston, Texas.

River, about 32 kilometers south of Baton Rouge, La., BASF Corp. owns a 1,040 hectare tract of land, of which about 320 hectares was developed in the late 1950s as a chemical manufacturing complex. Today, the site includes 13 plants which produce a variety of inorganic and organic chemicals sold in the U.S. and international markets. BASF, Geismar, La. operations include various intermediate chemical manufacturing for automotive, textile, pharmaceutical and agricultural markets.

In 1987, during closure of a herbicide manufacturing plant at the site, dissolved concentrations of chlorinated solvents were discovered in the shallow soils and groundwater beneath the plant. Two plumes, each containing dissolved concentrations of ethylene dichloride and monochlorobenzene were found primarily within an interval of silty clays of recent holocene sediments at depths of 2 to 5.5 meters under the former plant structure and loading area.

An extensive assessment was completed, which included over 110 soil borings and installation of 62 monitor wells drilled to depths as great as 35 meters to define the extent of the plumes. The assessment identified approximate land areas of 2 hectares beneath the structure, and .8 hectare beneath the loading area within the shallow zone that were affected.

The structure plume, or south plume, has a principal area of contamination of about 1,440 square meters with monochlorobenzene concentrations ranging from 100 to 200 ppm, and ethylene dichloride from 10 to about 100 ppm in the shallow zone. The loading area plume, or north plume, has a principal area of contamination of about 340 square meters, with monochlorobenzene concentrations of about 100 to 370 ppm, and ethylene dichloride ranging up to 70 ppm in the shallow zone.

Louisiana environmental officials approved a remedial plan in late 1991 which included trenching of a former subsurface wastewater line and installation of a groundwater pumping system. Groundwater pumping was proposed to consist of vertical wells and french drains. Although the plan was feasible in theory, in practice, disadvantages included limited access for heavy equipment to the remediation area, potential damage to steel structures from trenching soils, chemical exposure risks to workers, installation of numerous vertical extraction wells and generation of large volumes of waste soils requiring expensive off site treatment and disposal.

Before this plan could be implemented, BASF learned about groundwater extraction with horizontal wells, which had been applied at only a few sites in the U.S. by late 1991. The potential advantages of a horizontal approach eliminated equipment access and worker risk hazards, reduced likelihood of damage to structures, reduced the volume of wastes requiring off site disposal, and eliminated installation of large numbers of pumping wells.

BASF decided to scrap the traditional vertical approach, and pursue a plan to drill two horizontal wells with 120 meter screen lengths,
Figure one each to be installed on top of a clay layer along the base of the affected shallow zone, parallel and through the axis of each plume. Each well would be sited from a drilling location outside the plant structure's immediate area to allow equipment access. A review of the groundwater data suggested that effective well placement would require less than 4 meters lateral deviation and .6 meter deviation of the horizontal well bores to gain acceptable well performance and contaminant recovery. Continuous directional drilling measurements of the well bore would be necessary to prevent a collision between the drill stem and the foundation piling of the structure.

The horizontal approach would also eliminate installation of as many as 20 vertical extraction wells, and reduce disposal of waste soils for over $3 million in savings over the original plan. State environmental officials approved the new plan in June 1992. Eastman Cherrington Environmental, Houston, Texas, brought in a trailer mounted slant drilling rig, pipe handling trailer equipped with a crane and power generator, and a third trailer to house the drilling fluids pit, mud pump, grouting unit, mud mixing equipment and solids control equipment.

The drilling rig is rated to 600 meters for vertical drilling. Its hydraulic drill stem hoist equipment has a 31.5 metric ton hoist capacity and 13.65 metric ton push-down capacity. One worker is able to operate the hydraulic powered, automated pipe handling system. Drilling operations took place

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Drilling on your side, from page 23

24 hours per day with three to four workers on each 12 hour shift.

The drilling rig is equipped with an adjustable mast that can be inclined from vertical to 75° — or 15° above horizontal. The vertical 90° setting is commonly used for drilling to depths greater than 30 meters, whereas the 75° inclination is used at depths as shallow as 2.7 meters. Due to the geology and location of contaminants at the BASF site, the 75° inclination was used to drill wells with 3.6 and 4.2 meter deep horizontal sections.

The programs required drilling a curved section of borehole from ground surface to the depth desired and installing a surface casing. After grouting the surface casing and allowing a 24-hour curing time, drilling of the horizontal section began with a non-rotating drill string. A downhole mud motor drilling assembly was used, in which the only rotating portion of the drill stem was the drilling bit. The circulation of drilling mud through the drill stem by the mud pump provided hydraulic power to the downhole motor to rotate the drill bit.

Downhole assemblies on each section of the borehole varied, but Eastman chose two types of mud motors. A 30 meter radius motor was used for the curved section and a 90 meter radius motor was used for the horizontal section. The smaller radius motor allows the shortest possible build curve radius, which enables production of a horizontal attitude with minimum displacement. The larger motor allows the horizontal section to be steered, preventing subsurface collisions and allowing corrections to the course and attitude of the borehole.

The curved section drilling assembly consisted of a 17 centimeter diameter positive displacement mud motor with a 31 centimeter diameter expanding bit as in figure one, page 23. The dual string advance method was used to simultaneously drill and install a 25 centimeter poly casing. Upon reaching the 90° of vertical at the desired depth, the inner drill string was retracted, allowing surface casing grouting operations to begin.

The horizontal drilling assembly consisted of a 12 centimeter diameter positive displacement mud motor with a 22 centimeter diameter three blade drag bit as in figure two, above. This assembly was advanced with the open hole drilling method. This motor is designed to drill a 90 meter radius curve, allowing the drill string to be steered up and down or left and right to keep the well bore within the specified depth and attitude.

During drilling, well bore survey systems played a critical role to allow steering adjustments and prevent subsurface collisions and keep the well bore on track. A tool face indicator, a wireless mud pulse telemetry tool which provides hole inclination and tool face location, was used to drill the curved sections. It is mounted about 5 meters behind the bit. A film-based multi-shot was used to survey the remaining 5 meters to confirm the end of the curve inclination and true vertical depth before grouting began.

During drilling of the horizontal section, a magnetic steering tool was used. This tool is a wireline tri-axis probe which allows the determination of the hole azimuth and coordinates. Due to the nearby steel structure, an induced magnetic field was used with the magnetic steering tool. This method, called TruTracker®, is often used to avoid underground obstacles, due to its accuracy of ±2 percent.

The drilling fluids system powered

*Continues on page 26*
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Drilling on your side, from page 24

the mud motor and removed soil cuttings from the borehole. The drilling fluid was a bentonite slurry, extended with an additive called Mixed Metal Hydroxide (MMH), a product of Dow Chemical Co. This additive is an insoluble crystalline, inorganic compound containing two or more metals in a hydroxide lattice. The bentonite/MMH mud enhanced yield properties resulting in a fluid with minimum solids content. The gel structure suspends soil cuttings indefinitely when circulation stops, yet has flow characteristics of a low viscosity fluid when circulation resumes. A degree of inhibition is provided to water sensitive formations, and the mud has proved to have superior cuttings removal in horizontal holes compared to conventional water and bentonite mixtures. The drilling fluid was particularly critical at the BASF site, since the open hole drilling method was used on the horizontal section and undisturbed open hole coring was required at several locations within the horizontal borehole.

Eastman used its patented, hydraulically powered coring system, “Punch Master,” on both wells to collect undisturbed soil core samples as required by state regulations. The coring tool has an inner barrel activated by pump pressure. The inner barrel punches into the formation and the core sample is forced into an enclosed plexiglass cylinder. The cylinder is withdrawn into the outer housing and a valve closes to protect it from contamination while the drill string is withdrawn from the bore hole to retrieve the sample.

The south well was first to be drilled as a 121 meter long horizontal screened section beneath the plant structure at a depth of 3.6 meters. A 60 centimeter deviation was allowed in the depth. The lateral deviation was limited by a narrow corridor between the monitoring wells and the piling supporting the plant structure. The corridor was only about 6 meters wide. The path was also complicated by a subsurface wastewater line running parallel about 1.5 meters above the well path. This wastewater line was suspected as a source of the contamination. High accuracy was important to locate the well bore along the top of the clay layer, just under the contaminated zone, without hitting any of these obstacles.

The north well was also to consist of a 121 meter screened section installed adjacent to an active loading area, and 4.25 meters beneath a concrete roadway, in use as access to the loading area. A 60 centimeter deviation was allowed vertically, and a 2° deviation laterally. A truck and rail loader rack with subsurface pilings was located just 6 meters north of the well path as a potential collision point for the drilling. Just south of the well path, a surface drainage ditch about a meter deep threatened potential borehole washout.

Drilling began in late July 1992, and the south well was completed in 17 days—11 days longer than planned due to a mechanical problem with a bowspring stabilizer on the curved assembly that resulted in two aborted curved section attempts. One aborted attempt to drill the horizontal section was caused by the well bore moving above the depth limit. This happened, because without prior shallow experience drilling in the Mississippi River alluvium, motor steering performance was more difficult than anticipated.
The curved section and first aborted horizontal section drilling were complicated with drilling fluid washouts and lost returns to the surface because of the shallow depths and soil conditions. The south well was completed with 110 meters screened of the 121 meters planned. The well bore was steered within the depth window except for a 12 meter section that was about 30 centimeters too deep. The completed well was installed with a 9 centimeter outer diameter prepacked well screen inside a 16 centimeter slotted poly liner.

Lessons learned on the south bore were applied to the north bore, which was completed on schedule in six days with only minor drilling fluid leakage to the surface. This well was completed with the full 121 meters of screened interval, with a 21 meter section that was again, about 30 centimeters below the depth target.

The pumping system was designed to operate unattended, 24 hours a day and collect necessary data without any spillage. Data collection included accurate flow measurements, continuous water level measurement and pumping controls. First, each well was flushed with potable water to remove the mud filter cake and fine grain sediments. Each well was fitted with an electric submersible 76 liter per minute pump, magnetic flow meter and digital flow totalizer.

In initial pumping tests, the south well, located under the plant structure, showed an average flow rate of about 21 liters per minute, while the north well, located under the concrete roadway, delivered over 64 liters per minute.

Each well was placed into operation for an initial dewatering of the shallow zone to develop areas of pumping influence and establish hydraulic control. Dewatering of the shallow zone was apparent within the first week of continuous pumping, as the pumping rate rapidly decreased and stabilized. After two days of continuous pumping, the south well rate was about 8 liters per minute and the north plume leveled out after four days at about 28 liters per minute.

Before the wells were drilled, the average hydraulic conductivity for the affected zones at the site was calculated to be about 158 meters per year, based on aquifer tests. Using this conductivity, and established porosities of 20 to 39 percent, expected groundwater velocity prior to pumping was estimated to be 1.2 to 2.1 meters per year.

The impact of the pumping to gain hydraulic control is generally assessed by reviewing the observed areas of influence mapped from the 62 monitoring wells under observation at the site. After 18 days of continuous operation, the potentiometric surface indicated an area of influence of about 48.5 meters on each side of the south well, and 21 meters on each side of the north well, as shown in figure one, page 23.

Estimated groundwater velocities within the south plume are 7.5 to 14 meters per year, while in the north plume, 23 to 45 meters per year, which, compared to the pre-pumping potentiometric surface, indicates the horizontal well system has established hydraulic control of the shallow zone at the site.

Significant contaminant removal is occurring, based on groundwater volumes pumped from each well. In the first three months of operation, 722,277 liters of contaminated groundwater were pumped from the south plume, and 3,023,872 liters from the north plume. The principal area of contamination for the south plume has an estimated pore volume of 1,330,000 liters, and the north plume, 570,000. Given the average pumping rate for the first three months, the south well will produce one pore volume every 149 days, and the north well will produce one pore volume every 15 days from the principal areas of contamination. These estimates are calculated using the established average site porosity of 30 percent and established site saturated thicknesses of 3 meters in the south plume and 3.6 meters in the north plume.

Since pumping began, the estimated equivalent of 162.5 kilograms of monochlorobenzene and ethylene dichloride have been recovered in dissolved concentrations.

As it turned out, horizontal well technology was a good choice for this site. Well completions were successful, and installed as designed in reasonable time. Their combined pumping rate of over 26 liters per minute represents the equivalent of about 28 vertical recovery wells that would have had to be installed to cover the site. The areas of pumping influence that have been created, and the pumping data indicate that the chlorinated hydrocarbon plumes will be remediated with minimal site disruption.

Write in S99 for more information
In situ methods for treating contaminated soils can cut costs and limit liabilities associated with excavating and transporting contaminated soils. But, the effectiveness of in situ treatments is challenged in clays and other impermeable soils. Hydraulic fracturing is one method to increase subsurface permeability. Developed by the EPA’s Risk Reduction Engineering Laboratory and the University of Cincinnati Center Hill Research facility, hydraulic fracturing creates tabular lenses of granular material in soils and bedrock.

A hydraulic jet cuts a disk shaped notch at a specified depth in a borehole wall. Water is injected into the notch, building critical pressure until the enveloping soil fractures. Sand mixed with viscous fluid of guar gum and water is pumped into the fracture as it spreads away from the borehole, creating a highly permeable pathway to deliver of recover fluids or air in the subsurface. The sand holds the fracture open while an enzyme additive breaks down the fluid.

The process can repeated at various depths within a single borehole to create a stacking effect of horizontal pathways.

The fractures propagate in a horizontal to sub-horizontal plane, are one to three centimeters thick, and as much as 14 meters in diameter. In general, they are slightly elongated and asymmetric in relation to their parent borehole. Fracture growth is monitored by measuring the deformation of the ground surface in the vicinity of the borehole. A laser and sensor driven system, called the Ground Elevation Measuring System was developed to measure uplift of the ground surface during the fracturing process. Aboveground equipment required for the fracturing process includes a mixer, slurry pump and gel storage tanks. The mixer continuously blends guar gum gel, water, enzyme and sand. The slurry pump transfers this mixture into the fractures. The aboveground system components are transportable and require a small setup area.

Hydraulic fracturing can dramatically improve the effectiveness of most remedial technologies that require fluid flow in the subsurface, including product recovery systems, soil vapor extraction, bioremediation, in situ soil flushing and pump and treat. Hydraulic fractures can be used as reservoirs of granular materials that enhance bioremediation. Time released oxygen and nutrients have been added to the slurry in granular form, and injected into contaminated soil zones to enhance biodegradation of hydrocarbons. Fracturing is particularly effective in over consolidated clayey soils that are difficult to remediate due to their low permeability.

The effectiveness of hydraulic fracturing to enhance bioremediation was demonstrated for EPA’s Superfund Innovative Technology Evaluation program. In situ bioremediation was selected to remediate a former underground fuel storage site where BTEX (benzene, toluene, ethylbenzene and xylenes)
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In soil flushing applications, hydraulic fracturing creates horizontal planes in the subsurface to increase the surface area in direct contact with the surfactant.

Crack the case, from page 28

were the primary contaminants. Hydraulic fractures were created in one of two wells at 1.2, 1.8, 2.4 and 3 meters below ground surface. Sustenance of the microorganisms required a steady delivery of water containing peroxide and nutrients. The flow of water into the fractured well was two orders of magnitude (2,000 percent) greater than in the unfractured well. Delivery through fractured wells was 25 to 40 times greater than through a conventional unfractured well. The rate of degradation near the fractured well was 75 percent higher for BTEX and 77 percent higher for total petroleum hydrocarbons compared to rates near the unfractured well. Soil sampling after one month showed benzene, ethylbenzene and total petroleum hydrocarbon levels were significantly reduced in the vicinity (within 3 to 4.5 meters) of the fractured well, whereas samples within 1.5 meters of the unfractured well showed little or no reduction.

Hydraulic fracturing can also enhance soil flushing operations. The principle behind soil flushing is to contact subsurface sediments with a solution which transfers contaminants from the sediments to a solution, then transports the solution to the surface for final treatment. The effectiveness of this technology is directly proportional to the surface area available to the solution. Typically, this is accomplished by installing multiple injection wells and pumping the solution downhole, where the solution migrates to the surrounding soil area to contact and transfer the contaminants to the solution. Another method is to apply the solution at the surface and allow it to percolate through the soil. Hydraulic fractures installed at a soil flushing site creates horizontal planes in the subsurface into which the solution is pumped at full strength, enabling deeper zones to get the same benefits of near surface sediments. The fractures also serve as a collection and transport pathway to
recover the spent solution. Collection of spent solution is key to the success of this method, since failure to recover the contaminant rich solution leaves it to migrate in the subsurface and result in future liabilities. Ability to recapture the flushing solution is the major factor regulators consider when evaluating this technology.

Hydraulic fracturing was also demonstrated for EPA’s SITE program at a site contaminated with chlorinated organic solvents to a depth of 4.5 meters. A pilot soil vapor extraction project was installed to compare fractured vs. unfractured wells. Well yields average an order of magnitude (1,000 percent) greater at the fractured wells than those at the conventional wells. The zone of influence of the vacuum system was greater than 4.5 meters around the fractured wells, less than one meter for conventional wells.

Hydraulic fracturing can reduce the cost of a typical soil vapor extraction project by eliminating the need for a large number of the wells that would be required in a conventional configuration. Data from the SITE program document how hydraulic fracturing increases the range of influence of wells. Consequently, wells intended to remove contaminants from the soil can be placed farther apart.

For example, hydraulic fractures increased the range of influence of wells at a one site from one meter to 4.5 meters. A remediation plan for vapor extraction with hydraulic fracturing at this site would specify a distance of six meters between wells, allowing significant overlap of influence by wells as a conservative design. In such a case, 165 wells would be needed to cover a .4 hectare site with a hexagonal honeycomb pattern of wells. Without the additional capacity of the fractured wells, 495 wells on a one meter spacing would be needed for the conventional method. The contamination at this site rests at depths of 1.5 to 4 meters, so a depth of 4.5 meters would be sufficient for each well. If installation and surface piping for a 4.5 meter well costs around $2,000, hydraulic fracturing could save as much as $660,000 at a .4 hectare site.

A .4 hectare site with a contaminated zone 2.4 meters thick amounts to approximately 9,880 cubic meters of soil to be treated. The unit cost of treatment with the benefit of hydraulic fracturing would be about $125 per cubic meter vs. $460 per cubic meter using conventional unfractured wells. Hydraulic fracturing can also be concentrated in hot spots to focus the remedial effort and available dollars in the area of greatest concern.

In addition to enhancing the effectiveness of a selected technology that leads to lower costs, by establishing a network of subsurface pathways, technology can be applied in a more controlled and predictable fashion, which raises the confidence level that complete remediation is being achieved.

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May 1994 Soils 31
Bioremediation of heavier hydrocarbons is perceived to be more difficult than degrading the lighter fractions—or, at least, it is known to take a longer time. Pentachlorophenol and creosote are regarded as two persistent and dangerous heavy hydrocarbon products that are typically regarded as tough candidates for bioremediation. EPA is in the process of evaluating one enhancement technology that appears to enable pentachlorophenol and creosote to be biodegraded in situ and ex situ.

The use of pentachlorophenol and its sodium salt is primarily associated with the wood treatment industry. Creosote, the major component of which is polycyclic aromatic hydrocarbons (PAHs), is also widely used by the industry. Both pentachlorophenol and PAHs are hazardous to the environment and human health. In fact, seven PAH isomers are suspected carcinogens, so their presence in soils may be of great concern.

The naturally occurring microbial population in the soil will ultimately degrade contaminants to simple end products—carbon dioxide and water. This microbial activity in soil is not evenly distributed throughout the soil matrix. Instead, it is concentrated at micro-sites where variables such as oxygen tension, water content, nutrient supply, surfaces for adhesion and concentrations of toxins are suitable for microbial growth. In soils that have been rendered hydrophobic by deposition of organic pollutants, these factors can limit the number of micro-sites where microbial growth can occur, thereby limiting the size and activity of the soil's microbial population.

Consequently, natural degradation may transpire too slowly against the immediate risks to the environment and human health. Pentachlorophenol and PAHs are particularly persistent in the environment.

Grace Dearborn, Inc., Environmental Engineering Group (GDI), Mississauga, Ontario, has developed an approach to increase the number of key microbially active micro-sites, enhancing natural contaminant biodegradation. The approach, Daramend bioremediation, was developed with funding from its owner, Environment Canada. GDI has been granted the license to apply the technology.

The key to the technology is a family of soil specific solid-
phase organic amendments that alter soil structure and soil properties. It eliminates much of the soil toxicity, as measured by Microtox™ seed germination and worm studies, and enhances soil biological activity. The first step in its application is to examine each soil on a case-by-case basis, starting with soil characterization, followed by treatment selection and field application. Field application may take place in situ or ex situ to a depth of .6 meters, using standard soil handling equipment.

Figure one

A pilot scale demonstration was performed at an industrial site located adjacent to a river and close to a residential neighborhood. Wood was treated at the site using creosote from the 1900s to the 1960s. Pentachlorophenol and creosote were used from the 1960s to 1992. Industrial activity ceased in 1992, and the site has only been used to store wood treated at other facilities. Past practices in wood treating

Continues on page 34

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May 1994 Soils 33
operations caused chlorinated phenols, creosote and petroleum hydrocarbons to accumulate in the soil. Work began with a bench scale treatability study conducted on soil containing 1,002 mg/kg pentachlorophenol. A series of microcosms were set up in glass jars and maintained at controlled conditions. All microcosms were stirred regularly to homogenize and aerate the soil. The study included an abiotic control and radio-labeled spiking to confirm the major fates, whether volatilization or biodegradation, of the target compounds. Treatments tested, in triplicate, included the abiotic control, an inoculated test, a Daramend D6380 amendment test and the D6380 with inoculum.

The inoculum used in the bench scale study, and later in the field demonstration, was a pure bacterial culture, capable of degrading pentachlorophenol, isolated by enrichment culture, using soil collected from the treatment area. The Biolog™ Inc., Hayward, Calif., biological identification system was used to identify the culture as a strain of Pseudomonas resinirovans.

The results of the treatability study are shown in figure one, page 33. The D6380 amendment and/or inoculation generated significantly improved reduction of pentachlorophenol relative to abiotic loses. The combination of D6380 and inoculation appeared to be the most effective treatment, resulting in a residual concentration of pentachlorophenol of 8 mg/kg, a destruction and removal efficiency of 99 percent in 224 days.

In 1991, an in situ field demonstration was set up, consisting of triplicates of two control and five promising treatment protocols. GDI’s experience is that field scale applications of the Daramend formulas generally outperform bench scale applications relative to control treatments, and that inoculation is not generally necessary to achieve effective bioremediation in the field. In addition, regulatory agencies are generally reluctant to approve inoculation. So, non-inoculated treatments were carried over to the 1991 demonstration, even though they were not the most effective during the bench scale study.

Each 10 square meter plot was tilled every two weeks and irrigated. The treatments tested were an untilled control, tilled control, and a plot each of D6380, inoculated, D6380 plus inoculum, D6390 plus inoculum, and finally a plot of D6380 with inoculum and inorganic nutrients.

Results of the 1991 in situ demonstration are summarized in figure two, page 33. In general, treatments applied outperformed the tilled and untilled controls. The best performers were those with D6380 and/or inoculation. In 112 days, residual pentachlorophenol concentrations of less than 5.6 mg/kg at destruction and removal efficiencies of 78 percent were achieved. The incremental benefit from inoculation was limited, and appeared to be less significant after 112 days, relative to 28 days of treatment.

The 1991 ex situ and 1992 in situ treatments were applied based on these results. The principal contaminants of concern in the ex situ demonstration were 500 mg/kg concentrations of pentachlorophenol and 1,000 mg/kg concentrations of PAHs. The concentration of PAHs for the in situ demonstration was around 25,000 mg/kg. In both

*Continues on page 37*
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Write in 483
Turn up the clock, from page 34

cases, inoculation was not applied. The 1991 ex situ demonstration was constructed with a 10 metric ton sample of soil, spread to a depth of about half a meter over a high density polyethylene liner and covered by a temporary greenhouse-type structure, as in the photo on page 32. The soil was treated with D6380 and inorganic nutrients, tilled weekly, and irrigated with a trickle system to maintain a controlled percentage of the soil’s water holding capacity. A one meter band of soil surrounding the treatment plot was used as an untilled control. Electric heating allowed continuation of the project through the fall and winter to maintain soil temperature at 11 to 28°C. During the summer, soil temperature was not controlled, and ranged from 18-34°C.

Results of the 1991 ex situ treatment are presented in figure three, page 34. Again, the D6380 with inorganic nutrients resulted in better degradation of target compounds than the control. Then in 1992, another in situ and ex situ demonstration took place. The 1992 in situ demonstration consisted of one control and two promising treatment protocols. Again, each 10 meter square plot was tilled every two weeks and irrigated. The treatments tested were a tilled control, a D6380 plot and a D6380 plot with inorganic nutrients.

Results of the 1992 in situ demonstration are shown in figure four, page 34. Note that the in situ treatment was decommissioned prior to completion, and the PAH concentration would likely have been reduced below 1,200 mg/kg, the concentration at the last sampling. PAH degradation was not simply due to a reduction in the light molecular weight isomers, but was reflected in the decrease of carcinogenic PAHs, the higher molecular weight, more recalcitrant isomers.

The 1992 ex situ demonstration consisted of a 100 metric ton sample of soil, again spread to a depth of about half a meter on a liner and covered by a low density polyethylene sheet allowing about a meter of headspace. The soil was treated with D6380 and inorganic nutrients, tilled weekly and irrigated. A one by six meter area at one end of the treatment plot was used as a tilled control. The results for the 1992 ex situ demonstration are summarized in figure five, page 34. As was observed in the previous year ex situ demonstration, the Daramend treatment outperformed the control. After 291 days of treatment, destruction and removal efficiencies of 99 percent for pentachlorophenol and 95 percent for PAHs were achieved. These efficiencies correspond to residual concentrations of 7 mg/kg of pentachlorophenol and 75 mg/kg PAHs. Again, the carcinogenic PAHs were effectively degraded in this case to a residual concentration of 45 mg/kg. In order to verify that reductions in chlorinated phenols were caused by biodegradation, and not by volatilization or adsorption, 14C-CO2 evolution was monitored in the laboratory with treatment area soil that was spiked with 14C-pentachlorophenol. In the first 48 hours, more than 12 percent of the added 14C-pentachlorophenol was recovered as 14C-CO2, verifying ring cleavage and biodegradation.

Organic amendment technology can provide a cost-effective means of remediating industrial soils containing high concentrations of pentachlorophenol and PAHs. Large scale remediation using GDI methods is estimated to cost between $35 and $90 per metric ton, depending on contaminant type, concentration, remediation objective, soil characteristics, volume and geographical location.

Based on the success of this testing, GDI initiated full scale cleanup at the site. A portion of the ex situ treatment is being audited by the U.S. EPA under the Superfund Innovative Technology Evaluation Program.

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May 1994 Soils 37
Between the before and after
Degradation needs more proof than just before and after sampling
By C. Marjorie Aelion, Ph.D.

Most of what we know about bioremediation is the before and the after. Most of what we don’t know is the process that occurs in between. At most sites, the emphasis is on contaminant reduction, with little attention to how this actually takes place. It is very difficult to monitor degradation processes. Fundamentally, we must address assessment of this technology in more depth. How do we judge whether bioremediation is working when field applications do not document the process or investigate the underlying reasons for system success or failure? This is even more difficult to assess in in situ applications than in aboveground bioreactor systems.

For bioremediation to enjoy more widespread regulatory acceptability, it is important to learn how degradation takes place, going beyond before and after sampling that proves that “something apparently happened” out there.

C. Marjorie Aelion, Ph.D., is assistant professor in the Department of Environmental Health Sciences at the University of South Carolina, Columbia, S.C.

Fortunately, many excellent researchers in federal government, consulting companies and academia have helped get bioremediation off the ground. Through large scale demonstration projects, primarily financed by the federal government, data are collected both from laboratory and field applications beyond those simply required to implement the project, and made available to all interested parties. Without access to this information, bioremediation would be difficult to sell to state regulatory agencies, and each site application would have to reinvent the wheel to some degree. The data in these studies includes thorough site assessment, on site monitoring for contaminants and microbial processes, and laboratory analyses which aid in remediation system design and operation.

Research teams of engineers, geologists and biologists are conducting two field projects in South Carolina, both remediating petroleum contaminated shallow groundwater aquifers. The first site is a federal facility with large aboveground fuel tanks, where the underground piping leaked, releasing about 304,000 liters of JP-4 jet fuel. The second site is an abandoned gas station, contaminated by leaking underground storage tanks which have been excavated and removed. The contamination is more limited than at the first site, and is representative of many sites throughout the U.S.

Two approaches to in situ bioremediation are in progress at the sites, and both are combined with physical removal processes. The first site is circulating water from a 76 meter deep uncontaminated well into an infiltration gallery of underground perforated pipe. The addition of nitrate to the water provides both nutrient addition and additional electron acceptors to the bacteria. The system is designed and permitted so that water that is added can either be recirculated to the infiltration gallery or disposed in the local waste water treatment facility. At this time, the water is being sent to the treatment facility, so the site is primarily functioning as a combination of in situ bioremediation and traditional pump and treat.

The second site is a combined system also, incorporating air sparging and soil venting along with in situ bioremediation. Series of ventil and sparging wells are in place at the site, equipped with in situ pressure transducers, temperature probes and multilevel samplers to extract soil gases and measure volatile hydrocarbons and CO2 and O2, which are indicators of microbial activity. Monitoring wells are also installed for groundwater sampling to assess hydrocarbon concentrations, and parameters such as dissolved oxygen, pH and conductivity, and water levels.

Site assessments are critical to bioremediation, yet, because

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Between the before and after, from page 38
of the complexity of subsurface systems, it is difficult to adequately assess parameters of contamination, site hydrology and geology, and microbial activity. Work at the first site, near Charleston, S.C., has shown that spatial heterogeneity can be present even over small distances, making a large area impossible to truly assess. At this site, assessments were carried out by several consulting firms after the initial petroleum leak in 1975.

The site was initially classified as predominantly fine sand with some intermittent clay lenses. Although it was known that several small clay lenses were present, their importance did not become clear until construction of the in situ bioremediation system was completed, and additional multilevel wells were installed to continue research on the microbiology. At this time, free product collected in the newly installed wells and the existence of trapped petroleum was observed in a clay lens near the initial leak site. Because of this clay lens, water circulating through the infiltration gallery which lay above it would not infiltrate into lower sediment horizons. Modifying the pre-approved engineering plans for the system would have entailed a great deal of time and expense, so a second, smaller gallery was constructed in this location. Although not always simple within federal and state government bureaucracies, the flexibility to accommodate new information, yet remain within regulatory and contracting guidelines is critical.

Preliminary microbial investigations of contamination sampled in borings every 150 to 200 millimeters revealed that contamination was present in both sandy and clayey sediments, but that microbial activity at this site was greater in the sandy than clayey sediments.

At the second site, construction was carried out with the state regulatory agency’s help and consent of the private owner. Because of cooperation among all parties, the smaller level of bureaucracy and the smaller scale of contamination, the project has progressed much more quickly, easily and inexpensively than at the first site.

In our laboratory, we run several experiments on samples from these sites to assess microbial activity that would not normally be used in a conventional remediation project. Contaminated sediment cores are taken at different depths and incubated in microcosms. First, 14C-amino acids or glucose are used to examine the overall activity of the general bacterial community in comparison to the specific hydrocarbon degraders. The sediment microcosms are spiked with 14C-radiolabeled substrates that are representative of the contamination. For example, with the jet fuel and gasoline contamination, benzene, toluene and hexadecane were used to represent the aliphatic and aromatic fractions of petroleum hydrocarbons. Under aerobic conditions, these contaminants are oxidized to CO2 and H2O, and the CO2 can be trapped in a KOH-base trap after the microcosms are acidified, and the radioactivity is counted with a liquid scintillation counter. The percent of the label that was initially added that has been oxidized to
CO₂ can be calculated to give a relative and direct indication of the degradative capabilities of the sediment organisms to degrade the contaminants of interest. The ¹⁴C/CO₂ can only be derived from the contaminants that were supplied to the microcosm. This method requires purchase of radiolabeled isotopes, which have become increasingly expensive under the hazardous and radioactive waste disposal regulations, and a liquid scintillation counter, another investment that is not normally warranted in a routine field remediation.

A second method uses a gas chromatograph to investigate the production of CO₂ and consumption of O₂ from sediment microcosms and the subsequent decrease in specific components of the complex hydrocarbon mixture. At the first site, where nitrate is being added to the aquifer, we compared aerobic and denitritication degradation rates to assess the potential impact of nitrate addition on contaminant degradation. From laboratory studies, it appeared that CO₂ production from denitritication was approximately one third that of aerobic metabolism. In this case, it is not possible to determine from which compounds the CO₂ is produced, therefore, the decrease in specific contaminants is an indirect indication of degradation. However, a comparison to a dead control gives some assurance that biological processes were responsible for compound disappearance.

Although several chemicals can be monitored at once, not all compounds are separated on the gas chromatographic column. A selection is made by the operator for a suite of compounds, and constraints on the length of the analyses can create selection for specific types of compounds. The gas chromatograph is helpful for in-house monitoring for information not required by the state regulatory agency. To satisfy state requirements, groundwater sampling must be done by a certified laboratory, yet, for selecting which wells to sample, or monitoring additional wells, in-house analyses can limit analytical costs. None of these data could be used in the regulatory sense, or in a court of law, and the gas chromatograph does require an initial equipment expense.

The last method, and perhaps the most common because of the limited equipment necessary, is standard plate counts of bacteria or hydrocarbon degrading bacteria. Often, sediment samples are examined with a standard nutrient agar before and after the system is operated, and an increase in bacterial numbers suggests evidence that microorganisms were important in contaminant removal. Again, this is indirect evidence, and may be unrelated to compound disappearance if there is no evidence that the organisms being selected were the only ones actively involved in compound disappearance, or were involved at all. Often these samples are sent out to a laboratory for analysis, yet the outlay for equipment is minimal and standard analytical methods are in place, easily allowing in-house analyses.

In addition to laboratory analyses, field monitoring is important to assess the biological component involved in
Between the before and after, from page 41

site cleanup, although not carried out often. At our two field sites, groundwater was sampled for several components, both inorganic and organic chemicals. At the jet fuel spill site, we sampled for benzene, toluene, ethylbenzene and xylenes, for total petroleum hydrocarbons, total organic carbon, naphthalene, inorganic chemicals, including ammonium, nitrate, phosphate, dissolved inorganic carbon—and for environmental parameters, such as dissolved oxygen, pH, conductivity and temperature. At the gas station site, we monitored for some, but not all these components in groundwater because of a more limited budget.

Data of field derived gases is an additional tool to investigate biological components not normally required by regulations. In addition to monitoring groundwater for benzene, toluene, ethylbenzene and xylenes and for total petroleum hydrocarbons by certified analytical labs, we monitored the vadose zone for O₂, CO₂ and hydrocarbon concentrations. We use both laboratory and portable gas chromatographs, and hand held gas meters. Each offers a different level of sophistication, range of costs and ease of operation. The laboratory gas chromatograph is quantitative and requires user experience, while the portable model is qualitative, but still requires user experience. Gas meters are qualitative, but require little user experience and cost much less. A hydrocarbon and CO₂ meter costs about half as much as a portable gas chromatograph, which is approximately a third the cost of a laboratory model. One complication in the use of the meters is the need to serially dilute gas samples in Tedlar sampling bags to bring the hydrocarbons in range on the 10,000 ppm hydrocarbon meter, as well as the 5 percent CO₂ meter. Gas samples are brought back to the lab for gas chromatograph analyses to corroborate the meter data. This has helped assess environmental parameters of soil vapor hydrocarbons, oxygen and CO₂ concentrations at the air sparging site in particular. The impact of intermittent operation of the air sparging system on biological activity can be monitored relatively easily in real time with the meters.

Obviously, most in situ bioremediation projects are not inclined or equipped to do this level of lab and field monitoring. Neither of these two experimental projects has been completed, so the impact and benefits of these elaborate monitoring programs has yet to be quantified. It is apparent, from the scientific and state regulatory perspective, however, that more information on field processes is necessary to get a handle on these issues for the acceptance of in situ bioremediation as a proven technology.

The difficulty of implementing in situ bioremediation depends on the structure of the projects, the willingness of the regulatory agency to work with the project, the complexity of the geologic situation, the degradative capabilities of the biological component and the chemical characteristics of the contaminants. It is still difficult to know how much site assessment work is enough. There is a need to examine the benefit vs. cost of collecting information, because, in many cases, owners and state regulatory agencies are unwilling to pay for analyses unless they are required. Yet, even the extra effort of collecting site information is not always enough—as we discovered at the jet fuel site. Because of local concern about the contamination and a large budget, more information was collected than would normally be required. Yet, at this very site, in spite of several assessments that were completed, and where clay represented only a small fraction of the total contaminated subsurface sediment, inconvenient, expensive delays were encountered in construction and operation because of one particular small clay lens, uniquely placed in relation to the contamination, coupled with an inflexible and bureaucratic contracting system. The practical problems of redesigning or modifying plans can be daunting, depending on the agency involved. Constant negotiation and discussion are necessary to modify the approach as unexpected conditions are encountered.

There is often a chasm between the lack of specific field application information, where only laboratory results are presented, and the focus on only the before and after pictures, with none of the process information of what happened in between. A giant step forward for in situ bioremediation implementation and technology will occur when practical information, versus the theoretical or assumed microbial metabolic processes are evaluated.
Piping technology offers security

By Andy Youngs

The piping networks for underground storage tanks have come under scrutiny as a frequent culprit in releasing hydrocarbon contaminants to the subsurface. While tanks and piping are manufactured in controlled environments, to conform to national codes, the piping network is typically assembled in the field, leaving joint integrity up to the skill level and mood of the contractor.

On top of that, the piping system is buried out of sight, in a hostile subsurface environment of freeze/thaw, changing water tables and other forces. Then, the system is pressurized, typically to about 30 psi, so that even a small opening can let out a lot of product in a short time.

The weakest link in a piping system is, of course, the links—or joints where pipe pieces connect. One company, Advanced Polymer Technology, Inc., Elkhart, Ind., has developed a flexible piping system fabricated in continuous runs to eliminate the need for in line joints. Installers can make necessary connections inside accessible containment chambers with brass swivel fittings to eliminate the problems that arise with buried joints. The heart of the Poly-Tech™ system is the primary product piping which has an integral secondary containment jacket and eliminates buried, non-accessible, non-contained joints. The only connections are within the accessible containment chambers. The system also includes vent and vapor recovery piping, tank and pump chambers, flexible entry boots, fittings for piping and composite manholes.

The primary piping is composed of a fuel line grade nylon inner liner, a nylon braided fiber reinforcement and a polyethylene cover. In addition, a proprietary coating is applied to enhance permeation resistance to standard petroleum fuels as well as alcohols and alcohol blends. The nylon used as the inner liner material is the same material which has been specified by automakers for automotive fuel lines since 1980. It was developed to resist fuels and chemicals while maintaining flexibility and resistance to kinking.

The braided nylon layer gives the pipe a tested burst pressure of over 800 psi, and continuous pressure capability over 50 years of 375 psi. In other tests, the pipe sustained full kinking over 50 times without loss of hydrostatic strength or burst pressure.

A secondary jacket fits loosely around the primary piping, with 24 ribs protruding inward toward the primary. Under the weight of backfill, the secondary jacket conforms to the primary, providing a permanent installation with 24 channels through which fuel leaks can flow to a sump with installed leak detection.

The concept of controlled flexibility means that the pipe is made flexible enough to provide for custom installation, but rigid enough to tolerate minor grade fluctuations without allowing blockages to occur. Controlled flexibility piping generally has a working bend radius of about one meter. The brass swivel fittings are fitted with redundant sealing.

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May 1994 Soils 43
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Eastman Cherrington Environmental, Houston, Texas, offers a wide range of drilling services, with horizontal rigs small enough to work on congested sites without interrupting customer traffic, yet large enough to drill long horizontal distances under runways and landfills. Horizontal wellbores can be extended beneath obstacles such as storage tanks, buildings and natural obstructions to access contaminant plumes, says the company. Call 713-722-7777 for more information.

New hydraulic drill offers more power

Ingersoll-Rand introduces the A-400 hydraulic monitoring drill for large diameter auger drilling for air/mud rotary, DHD and core drilling. The A-400 provides 9,072 kilograms of pulldown and pullback with precise regulation, says the company. This model joins the A-200 which offers 6,802 kilograms of pulldown and pullback; and the A-300, which offers 8,172 kilograms of pulldown and pullback. Call 201-573-3157 for more information.

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44 May 1994 Soils
Keep a low profile

Southern Iowa Manufacturing, Inc. Osceola, Iowa, designed their trailer mounted drill rig with an adjustable height mast extension to allow it to operate in a tight overhead situation—as low as 4 meters, says the company. Call 800-338-9925 for more information.

Versatile unit sets up fast

Concord® Inc., Fargo, N.D., designed their new 9200 series soil sampler and drilling unit to be either pickup or trailer mounted. The Concord chuck allows use of soil probes up to 9 meters without use of a Kelly bar. The unit can auger down to 23 meter depths and can be equipped with a 63 kilogram drop hammer. Hydraulic outriggers are standard. Call 701-280-1260 for more information.
Panels shore up leaky levees
Gundle Lining Systems, Inc., Houston, Texas, installed Gundwall panels to a depth of 7.5 meters to cut off a seepage path through a sand and peat levee on Twitchell Island in the Sacramento Delta outside Stockton, Calif., preventing the need for excavation into an already weakened levee. Panels were vibrated into place in about two days, says the company.

Screen, cut, mix, reclaim and wash
Recycling Attachments, Inc., Solon, Ohio, says their rotary screening bucket attaches to your skid steer, loader or excavator and not only screens, but cuts like a pugmill to prepare soils for bioremediation and thermal treatments. The trommel design reduces volume while the tumbling action aerates and blends materials to enhance natural treatment processes.

Sump recovers fluids from the shallows
Keck Instruments, Inc., Williamston, Mich., designed their new total fluids product recovery system for shallow pump applications in sumps with less than 7.5 meters of suction lift. The unit operates from zero to 53 liters per minute using less than half a cubic meter of air. With automatic controls, the pump is available in a variety of sizes and seal configurations to pump nearly any viscous fluid.

There's no air in this deal
Convergent Biomass Technologies, Round Lake, Ill., is licensed to develop a staged anaerobic digestion process to convert organic waste to a methane-rich fuel gas and salable residual solids. The Institute of Gas Technology, Chicago, Ill., is licensing several of its patents to CBT to commercialize the process. Acid and methane forming microbes carry out the conversion in two separate digesters. Product gas is enriched to near pipeline quality, containing up to 90 percent methane, by selectively removing carbon dioxide from the methane phase digester. The Institute is an independent, non-profit center for technology development and education.

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Reactor recipe, from page 7

after the results of the last day of testing were completed to see if there was any significant change in the concentration of PAH. The test results were evaluated by analysis of variance (ANOVA), which indicates the similarity of statistical means for two data groups. The results of the ANOVA are shown in figure three, page 7.

Results of the ANOVA indicate that in the distilled water microcosm, the computed F-ratio of 1.5 is less than the F-test value at the 95 percent confidence interval of 7.71. Since the F-ratio value falls within the confidence range of the F-distribution, the data for initial and final PAH concentration are not significantly different—which indicates that there was no significant reduction in PAH concentration during the test.

In the biostimulated microcosm, the computed F-ratio of .0764 is less than the test value at the 95 percent confidence interval of 18.5 Since the F-ratio value falls within the confidence range of the F-distribution, the data for initial and final PAH concentration are not significantly different again, no significant reduction in PAH concentrations.

In the augmented microcosm, the computed F-ratio of 95.6 is greater than the F-test value at the 95 percent confidence interval of 7.71. Since the F-ratio value falls outside the confidence range of the F-distribution, the data for initial and final PAH concentration is significantly different—a significant reduction in PAH concentration.

Testing for the augmented microcosm was extended to determine if additional PAH degradation would take place, but after 14 additional days, PAH concentrations remained relatively unchanged from day 28 levels. Additional testing was able to duplicate the results for the augmented microcosm, however the residual concentration of PAH materials in the reactor did not decrease below approximately 200 ppm (dry weight basis) during the 42 day test period.

Results indicated that the high residual total PAH concentration may have been due to binding of the PAH compounds to soil particles and biological detritus of the sediments which prevented further bacterial action. This observation was confirmed by analytical testing of the water fraction of the M-3MCA soil slurry which contained a minimal amount of PAH compounds after day 20.

Further investigation is underway with use of lower percentage solids slurries, as this may lead to more complete degradation of PAH compounds in sediment materials. Initial results are promising, and may indicate that a direct dredge to slurry reactor system is possible and may offer a cost effective treatment for harbor sediment remediation.

Efforts to stimulate the indigenous microbial population in the sediments were unsuccessful. No PAH degrading bacteria were found to exist in the sediments, in spite of the fact that they had been continuously exposed to PAH contamination for the last 40 years.

It may also be possible to further enhance the performance of a slurry reactor system by using specialized organisms for PAH degradation which may outperform the M-3MCA microcosm. Another way to increase slurry reactor performance may be to add surfactants which could increase the bioavailability of the PAH compounds which are bound to clay and detritus particles in harbor sediments. Such testing is underway, using various types of surfactants and target specific microorganisms.

The EIMCO reactor operated continuously for approximately one year without down time at a cost of about $15 to $30 per cubic meter for 10 to 30 percent solids materials, excluding capital cost for the equipment. The reactor can also be staged to function as a continuous flow process to minimize material handling costs.

The bottom line is that bioaugmentation in a slurry reactor system is emerging as a promising method to provide the most consistent results at the lowest cost to remediate PAH and other recalcitrant xenobiotic compounds in harbor sediments. Write in 595 for more information
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Paragon Environmental Systems, Escondido, Calif., introduces its operational brochure for the ExtraTherm, a vapor extraction and treatment system. The brochure features step by step explanation of how the Extra-therm system works. Also included is a specification chart for the 150, 250, 500, 1000 scfm systems and a process and instrumentation diagram. For a brochure, call 800-985-0055.

Sive Services, Alamo, Calif., now offers the design, installation and operation services, as well as the equipment, for the application of steam injection and vapor extraction. The patented SIVE process uses underground steam injection and vapor extraction. The patented SIVE process uses underground steam injection applied in conjunction with conventional in-situ soil and groundwater remedial methods. For their brochure, call 510-820-5449.

Enviro Products, Lansing, Mich., releases their general brochure that highlights sampling and instrumentation equipment, remediation and drilling equipment and well supplies. EPI caters to the environmental soil and ground water industry. For a brochure, call 800-ENVIRO 4.

Dexsil Corp., Hamden, Conn., introduces their 1994 catalog that features field kits and instruments and covers PCB testing, waste oil, waste water analysis, lubricating oil analysis and magnetic field meters. For a catalog, call 203-288-3509.
Three phase motors are often incorporated into portable thermal treatment units, soil vapor extraction units, drilling equipment and other soil treatment machinery. Getting 3-phase power service to many soil remediation sites can be an expensive problem, especially if the utility company has to bring it in to a remote area. The Phasemaster® rotary converter, from Kay Industries Inc., South Bend, Ind., converts 230 or 460 volt 1-phase service to 230 or 460 volt 3-phase power. The unit also solves the problems of 1- to 3-phase conversion for solid state power supply loads in transmitters, computers and other electronic equipment. A phase converter uses transformer action to split off and phase shift only a portion of the 1-phase supply, with very little additional energy use. The rotary converter is a single armature device with a stator frame with a symmetrical 3-phase winding and modified squirrel-cage rotor. A large capacitor bank is placed across a coil group between one input line and the manufactured phase. When the converter is energized, 1-phase voltage is applied to one winding group. This produces an internal magnetic field proportional to that of the applied 1-phase line. The capacitor bank provides a phase-shifted voltage to an adjacent coil group which creates another internal field which produces rotor torque. As the rotor spins, it picks up a replica of the utility supply through induction. The rotor current, in turn, creates its own field, and as the rotor passes each stator coil group, the 1-phase rotor field is replicated in the other two coil groups. The result is true 3-phase output. The Phasemaster® converter provides 3-phase power to any combination of motors varying in horsepower, speed, duty cycle, etc., running individually, simultaneously, intermittently or continuously. The unit can be placed any distance from the equipment it operates, as long as sufficient size wire is used as connection, says the company.

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