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Bioremediation: A Growing Trend in Pollution Treatment and Control

What people usually think of as pollution, bacteria think of as lunch. The scientific community is finding that this quality has made bacteria the perfect agents for the efficient and cost-effective remediation of water and soil.

by Michael Kukuk[1]

I. INTRODUCTION

On the list of things that people feel warm and fuzzy about, bacteria are somewhere between traffic jams and taxes. Bacteria are responsible for botulism poisoning and infections on skinned knees. In 1976, they killed 29 people at a Legionnaire's convention in Philadelphia. Just recently, because of them, one person died and more than 600 became violently ill on the cruise ship *Viking Serenade*.

But if they have never been thought of as man's best friend, bacteria are making inroads in that direction by providing safe, natural, cost-effective cleanups of water polluted with everything from fuels to heavy metals.

Because of their adaptability, bacteria have survived on the planet for two-and-a-half billion years to become one of the most beneficial—and deadly—organisms on Earth. They have evolved an ability to degrade most naturally-occurring organic compounds and have proven equally responsive to manufactured compounds.

The ability to exploit their adaptability is the basis for bioremediation, a growing trend in pollution treatment and control. Using surface or in-situ treatment methods, bioremediation usually involves stimulation of indigenous microbes to reduce or eliminate contamination.

At a time when more traditional remediation technologies are proving to be slow, expensive and sometimes unpalatable to the local community, bioremediation is becoming a popular alternative for many contaminated sites.

Symptoms and Sources

A 1986 survey by the Environmental Protection Agency showed that conventional groundwater extraction followed by in-vessel physical/chemical treatment—also known as pump-and-treat technology—is completely effective in only about 15 percent of aquifer cleanups, mainly because of the absorbancy of the soil above the groundwater table.

To a large extent, contaminants remain in the subsurface soil and serve as an ongoing source of pollution, slowly desorbing or dissolving into the groundwater. (For example, in a typical gasoline spill, less than 5 percent of the mass is dissolved into the groundwater.) Pump-and-treat systems, which extract and clean the contaminated water, chew up the largest part of remedial budgets just treating the symptoms of pollution and largely ignoring the source.

With bioremediation, however, simultaneous treatment of symptoms and sources is possible using one or a combination of the following methods:

<u>Surface bioreactors.</u> These are aboveground aeration vessels used to treat groundwater, surface water, wastewater, etc. before discharging it back into the hydrologic cycle (usually into a stream or a groundwater aquifier).

<u>Soil/solids land treatment units.</u> These are land farms that treat organic contamination in an aerated soil bed, relying on the dynamic physical, chemical and biological processes occurring in the soil.

<u>In-situ groundwater and soil bioremediation.</u> This normally involves the injection of inorganic nutrients and oxygen, nitrates, etc., into the soil and aquifer materials to encourage growth of indigenous microbes for the degradation of contaminants. This method is becoming increasingly popular among municipalities seeking to clean contaminated groundwater aquifers, many of which serve as sources of drinking water.

In-situ bioremediation has become a particularly attractive treatment method because, theoretically, it results in complete degradation of the contaminants. Petroleum compounds, for example, are reduced to carbon dioxide and water. Other remedial technologies, like carbon adsorption and air stripping, simply transfer the contaminant to a different medium.

In-situ programs are not without problems, however. Bacterial growth and its effect on contaminants are typically limited by unfavorable environmental conditions—lack of oxygen or essential nutrients such as nitrogen and phosphorous, for example—and successful bioremediation will likely require environmental enhancement to produce a setting in which microbes can thrive.

Factors affecting the bacteria's ability to degrade waste may include contaminant concentration, pH, temperature, solubility and osmotic and hydrostatic pressure. Also, adequate mixing—ensuring that the microbes receive nutrients and oxygen and have sufficient contact with the contaminant—may be difficult to achieve at many sites.

Estimating Cost and Success

Like all efforts to control pollution, cost is a driving force in the choice to use bioremediation. In most cases, bioremediation involves little site disruption, and the potential liability associated with transporting and disposing contaminated material and/or water eliminated. Furthermore, while microbes may work more slowly than other treatment methods, they may save 30 to 70 percent of project costs.

One midwestern city is still calculating savings from its use of bioremediation to clean contaminated

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soil that threatened its groundwater supply. Petroleum hydrocarbon from the city's electric utility had polluted soil at several generating plants and substations, and officials suspected that it was also contributing to shallow groundwater contamination. In other areas throughout the city, there were similar concerns surrounding transformer oil.

Using a land farm and in-situ methods, the city had attacked both problems, ultimately treating groundwater, surface water and the contaminated soils. The utility calculated that the land farm alone would provide long-term savings over other remedial methods (dig and haul, for example), due in part to the fact that utility employees would be trained for project construction, operation, maintenance and monitoring.

In weighing the appropriateness of microbial treatment, cities should conduct a thorough site assessment to determine if conditions necessary for success are present. Results of the assessment should include: a description of the facility; identification of the contaminants; determination of the extent of contamination; determination of physical/chemical properties of the contaminants; a description of the chemical and biochemical processes in the groundwater in the immediate vicinity of the site; and a thorough description of the site hydrogeology.

The latter is a major factor in determining the odds for in-situ success. Hydraulic conductivity, porosity and permeability all affect the subsurface distribution of contaminants, as well as the mixing of agents such as nutrient solutions and dissolved oxygen. Profusion of these agents is generally dependent on the flow of groundwater.

Once the physical and chemical natures of the contaminant are determined, its biodegradability should be investigated. General conditions for successful degradation must be identified, and the suitability of the site to bio-stimulation should be evaluated.

Laboratory and literature studies can be used to determine many of these factors, but, with a soil gas survey during the initial assessment, engineers may set their own baseline to measure bioactivity. A passive respiration test analyzing soil gas O_2 and CO_2 composition will indicate whether the indigenous microbes are naturally degrading the contaminants.

Choosing Weapons

Determining whether a specific contaminant will respond well to biodegradation will be followed by a similar decision as to which type of bacteria to use. The microbes can include: (a) indigenous bacteria that have been in contact with the pollutant; and (b) bacteria that have been genetically engineered in the laboratory.

Most bioremediation experts do not recommend the widespread use of genetically-engineered bacteria, noting strict federal rules on their use and the fact that natural bacteria do just as well on most contaminants.

Subsequent concerns will include project design, including several critical factors. First, the design should provide adequate contact between the treatment agents and the contaminated soil and groundwater. Second, hydrologic control of treatment agents and contaminants must be achieved to prevent their migration beyond the treatment area; and, finally, there should be means for recovery of spent treatment solutions and/or contaminants where necessary.

A number of design alternatives exist for the delivery of nutrients and oxygen to the subsurface and for containing and recovering groundwater. The most common involve the use of surface flooding and subsurface drains (gravity systems) or a system of injection and recovery wells or trenches (forced systems).

Most of today's biological in-situ techniques are variations of methods developed by researchers at Suntech, a former Texas-based oil company, to remediate gasoline-contaminated aquifers. Oxygen and nutrients, including nitrogen, phosphorous and other inorganic salts, are circulated through the aquifer using injection and production wells. The wells are usually no more than 100 feet apart, depending upon the area of contamination and the permeability of the formation. Oxygen, for use as an electron acceptor in microbial metabolism, is supplied by sparging air into the groundwater.

The Suntech remediation process is most efficient for groundwater contaminated with less than 40 ppm of dissolved organics (i.e., gasoline); at higher levels, floating product, which can be toxic to the microbes, is usually present. As the cleanup is completed, the number of microbial cells will return to background levels.

For remediation of residual petroleum hydrocarbons in surrounding soil, engineers may rely on bioventing or the transfer of oxygen in the subsurface, where indigenous organisms can use it to metabolize contaminants. Unlike soil venting or soil vacuum extraction technologies, the bioventing system uses low airflow rates to stimulate microbial activity, and environmental conditions such as soil moisture and soil nutrient levels must be managed to avoid inhibition of microbial activity, and environmental conditions such as soil moisture and soil nutrient levels must be managed to avoid inhibition of microbial respiration.

A project of the Public Service Company of Colorado (PSC), in Denver, illustrates the combined use of in-situ and bioventing methods and their effectiveness in cleaning groundwater and surrounding soil. Plans for cleanup began in 1987, when the company discovered that used oil had leaked from a temporary catch basin in the facility's garage.

Oil and grease concentrations at the site ranged up to 9,600 mg/kg, and soil samples showed the presence of benzene, toluene, ethylbenzene and xylene (BTEX) compounds. Although groundwater sampling showed low levels of BTEX compounds, xylene levels exceeded EPA's proposed drinking water standards.

In July 1989, an in-situ bioremediation system was installed to clean the contaminated groundwater and promote biodegradation of contaminants in the soil above and below the water table and in the aquifer.

The treatment took place in several

stages. First, groundwater was pumped at the rate of 11 gallons per minute from a recovery well downgradient of the leaking tank to ensure contaminant capture and identification. The recovered water was treated by carbon adsorption to remove dissolved hydrocarbons before being pumped to a nutrient gallery.

In the nutrient gallery, the groundwater was amended twice—first with ammonium and phosphate compounds to provide inorganic nutrients, then with hydrogen peroxide to increase the water's level of dissolved oxygen. The amended groundwater was then reinjected upgradient of the leaking tank, thereby delivering the nutrients and oxygen needed to sustain aerobic biodegradation in the saturated zone.

To speed remediation of the contaminated soil, PSC also added batches of nutrients directly to the soil and installed a bioventing system to induce a dynamic flow of ambient air above the water table to highly-contaminated areas in the subsurface. By 1991, concentrations of BTEX in the monitoring wells were approaching the cleanup goals.

In March 1992, PSC submitted an application for closure to the state of Colorado. The total cost of the project was $500,000.

Planning for the Long Term

Operation and maintenance of a bioremediation system may commonly extend for several years and prove to be the most expensive items in the project. By addressing equipment access and operational logistics during the design phase, engineers should be able to create a system that minimizes the need for manpower and thereby cuts their costs.

In addition to monitoring the concentration of the contaminants, it will be necessary to monitor a number of other variables to determine the process performance and to assess site conditions. When designed, operated and maintained properly, bioremediation systems can effectively cut the costs associated with the cleanup of polluted water sources while, at the same time, reducing future liability.