NRT SCIENCE AND TECHNOLOGY COMMITTEE

Fact Sheet: Bioremediation in Oil Spill Response

An information update on the use of bioremediation.

May, 2000

The purpose of this fact sheet is to provide on scene coordinators and other decision-makers with the latest information on evolving technologies that may be applicable for use in responding to an oil spill. Bioremediation is one technique that may be useful to remove spilled oil under certain geographic and climatic conditions. For the purpose of this effort, bioremediation is defined to include the use of nutrients to enhance the activity of indigenous organisms and/or the addition of naturally-occurring non-indigenous microorganisms. This fact sheet is an update of the NRT Science and Technology's 1991 Bioremediation fact sheet.

Bioremediation is a technology that offers great promise in converting the toxigenic compounds of oil to nontoxic products without further disruption to the local environment. Bioremediation is typically used as a polishing step, after conventional cleanup methods have been used. Bioremediation products considered for use during spill cleanup operations must be listed in accordance with the requirements of Subpart J of the National Contingency Plan (for further information on product listing, please consult EPA's Oil Program website at www.epa.gov/oilspill). Genetically engineered organisms are not being considered for use at this time by EPA for oil spill and are therefore not discussed in this fact sheet.

REQUIREMENTS FOR SUCCESS

Several factors influence the success of bioremediation, the most important being the type of bacteria present at the site, the physical and chemical characteristics of the oil, and the oil surface area. The two main approaches to oil-spill bioremediation are: (1) *bioaugmentation,* in which oil-degrading bacteria are added to supplement the existing microbial population, and (2) *biostimulation*, in which nutrients, or other growth limiting substances, are added to stimulate the growth of indigenous oil degraders.

Addition of oil-degrading bacteria has not been shown to have any long-term beneficial effects in shoreline cleanup operations because:

- The size of the hydrocarbon-degrading bacterial population usually increases rapidly in response to oil contamination, and it is very difficult, if not impossible, to increase the microbial population over that which can be achieved by biostimulation alone[1-4];
- The carrying capacity of most environments is probably determined by factors such as predation by protozoans, the oil surface area, or scouring of attached biomass by wave activity that are not affected by bioaugmentation; and
- Added bacteria seem to compete poorly with the indigenous population.[5,6]

Under the appropriate conditions, biostimulation has been shown to have beneficial effects in shoreline cleanup operations. The main challenge associated with biostimulation in oil-contaminated coastal areas or tidally influenced freshwater rivers and streams is maintaining optimal nutrient concentrations in contact with the oil.

NUTRIENT APPLICATION

Effective bioremediation requires that (1) nutrients remain in contact with the oiled material, and (2) nutrient concentrations are sufficient to support the maximal growth rate of the oil-degrading bacteria throughout the cleanup operation.

Open Water Environments. Bioremediation of open water spills is not considered to be appropriate or achievable because of the above two requirements. When nutrients are added to a floating slick, they immediately disperse into the water column, essentially diluting to background levels. At such levels rapid conversion of the hydrocarbons to biomass, CO_2, and other innocuous end products would not be readily supported.

Marine Environments. Contamination of coastal areas by oil from offshore spills usually occurs in the intertidal zone where the washout of dissolved nutrients can be extremely rapid. In 1994 and 1995, studies were conducted on the shorelines of Delaware[7] and Maine[8] to study the rate of nutrient transport in low and high energy sandy beaches. These studies found that surface application of nutrients (including slow-release or oleophilic formulations) is ineffective on high-energy beaches because most of the nutrients are lost to dilution at high tide. However, on low energy beaches surface application of nutrients was found to be an effective and economical bioremediation strategy. Subsurface application of nutrients might be more effective on high-energy beaches but because crude oil does not penetrate deeply into most beach matrices, it is difficult to insure that the nutrients reach the oil-contaminated area near the surface.

Freshwater Environments. An oil spill is most likely to have the greatest impact on wetlands or marshes. Less research has been conducted in these types of environments, so it is not yet known how well bioremediation would enhance oil removal. However, the same principles apply to this type of environment as in the marine environment: nutrients must remain in contact with the oiled material, and nutrient concentrations must be sufficient to support the maximal growth rate of the oil-degrading bacteria. There is an added complication in a wetland; oil penetration is expected to be much lower than on a porous, sandy marine beach. Below only a few centimeters of depth, the environment becomes anaerobic, and petroleum biodegradation is likely to be much slower even in the presence of an adequate supply of nitrogen and phosphorus. Technology for increasing the oxygen concentration in such an environment is still undeveloped, other than reliance on the wetland plants themselves to pump oxygen down through the root system. By the year 2000, however, data will be available from an intentional oil spill study being conducted jointly by the U.S. EPA and Fisheries and Oceans-Canada on a freshwater shoreline of the St. Lawrence River in Quebec. This study is examining bioremediation with nitrate and ammonium in the presence and absence of wetland plant species (*Scirpis americanus)*.

Soil Environments. Land-farming techniques have been used extensively by petroleum companies and researchers for treating oil spills on soil. Again, the same principles apply: nutrients must remain in contact with the oiled material, and nutrient concentrations must be sufficient to support the maximal growth rate of the oil-degrading bacteria. For surface contamination, maintenance of an adequate supply of oxygen is accomplished by tilling. The maximum tilling depth is limited to about 15 to 20 inches. If the contamination zone is deeper, other types of technologies are used, such as bioventing, composting, or use of biopiles, all of which require addition of an external supply of forced air aeration.

FIELD EVIDENCE FOR BIOREMEDIATION

Demonstrating the effectiveness of oil spill bioremediation technologies in the field is difficult because the experimental conditions cannot be controlled as well as is in the lab. Nevertheless, well-designed field studies can provide strong evidence for the success of a particular technology if one can convincingly show that (1) oil disappears faster in treated areas than in untreated areas and (2) biodegradation is the main reason for the increased rate of disappearance. Convincing demonstration of an increased rate of oil degradation was provided from a field study conducted during the summer of 1994 on the shoreline of Delaware Bay[9]. Although substantial hydrocarbon biodegradation occurred in the untreated plots, statistically significant differences between treated and untreated plots were observed in the biodegradation rates of certain hydrocarbon compounds.

To distinguish between oil lost by physical means and oil that has been biodegraded, biodegradable constituents are normalized to a resistant biomarker compound. Hopanes often serve as this biomarker compound because they are highly resistant to biodegradation and exist in all crude oils. Normalizing to hopane automatically accounts for disappearance of oil by physical washout mechanisms. In refined oils that have no hopanes biodegradation can be confirmed by normalizing to a highly substituted 4-ring PAH or by examining the relative rates of disappearance of alkanes and PAH homologs.

It is important to note that some bioremediation products contain surfactants and emulsifiers that change the appearance and mobility of the oil. These processes should be distinguished from true biodegradation.

OTHER RESEARCH

Research is ongoing to evaluate bioremediation and phytoremediation (plant-assisted enhancement of oil biodegradation) for their applicability to clean up oil spills contaminating salt marshes and freshwater wetlands. By December of 2000, EPA is planning to produce a draft guidance document detailing the use of bioremediation for sandy marine beaches and freshwater wetlands. EPA is also studying the biodegradability of non-petroleum oils (vegetable oils and animal fats) and their impacts on the environment during biodegradation. Reports will be available some time in 2000 and 2001.

CONCLUSION

In conclusion, bioremediation is a proven alternative treatment tool that can be used in certain oil-contaminated environments. Typically, it is used as a polishing step after conventional mechanical cleanup options have been applied. It is a relatively slow process, requiring weeks to months to effect cleanup. If done properly, it can be very cost-effective, although an in-depth economic analysis has not been conducted to date.

One of the advantages to using bioremediation products is that the toxic hydrocarbon compounds are destroyed rather than simply moved to another environment. The biggest challenge facing the responder is maintaining the proper conditions for maximal biodegradation to take place, i.e., maintaining sufficient nitrogen and phosphorus concentrations in the pore water at all times. Based on field experiments and solid evidence from the literature it has been shown that addition of exogenous cultures of microorganisms will not enhance the process more than simple nutrient addition and that bioremediation is less effective on high energy shorelines.

The NRT S&T Committee technical contact for bioremediation issues is Dr. Albert D. Venosa of the Environmental Protection Agency. He can be reached at venosa.albert@epa.gov.

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