Bioremediation
What is it and how does it work?

Bioremediation and Waste Management

Biological treatment and our reliance on bacteria is not new or novel, it has played a central role in conventional waste treatment throughout the history of mankind. What is new however, is our growing understanding of the natural process and how we can utilize bacteria for industrial, municipal, agricultural and residential applications in breaking down and enhancing the removal process of agricultural wastewater, fertilizers, pesticides and controlling resulting odors, as well as industrial by-products and toxic chemicals, mining and oil production slug and other hazardous wastes, and are fundamental to sanitation clean-ups.

How it Works

Bioremediation consists mainly of bio stimulation, where nutrients and/or oxygen are added to soil or water to stimulate native bacteria populations, and bioaugmentation, where external microorganisms, naturally occurring or engineered strains, are introduced to enhance the degradation process.

The primary use of biological agents has been in enhanced natural remediation and wastewater treatment of sanitation system for residential and municipalities, lakes and ponds, once-through lagoons for agricultural and industrial active wastewater systems. More recently bioremediation has expanded into the removal of toxic chemicals where contaminants treated have been primarily petroleum and other hydrocarbons, followed by wood preservatives, industrial solvents, pesticides, heavy metals and other hazardous wastes.

Bioremediation can usually be done on site, where contaminants are broken down to harmless by-products. The biological systems used are often less expensive, and disruptive to the environment. In many cases, bioremediation may be combined with other remediation methods in order to design a comprehensive treatment system that reduces overall costs and environmental impact.

Bioremediation is increasingly used as part of a treatment plan at sites where other unrelated conventional or alternative remediation methods are also at work. For this reason, it is sometimes difficult to define and identify a project and its associated costs as pertaining solely, or to what degree, to bioremediation.

Derivative and next-generation bioremediation technologies continue to move from research to commercial applications. More and more previously resistant compounds are proving to be susceptible to biodegradation under the proper conditions. The trends in research and development will remain an important force in bioremediation's continuing growth.

System Approaches

The choice of a bioremediation approach, whether it be in situ, on-site, or off-site, depends a great deal on the specifics of the site and the media being decontaminated:

In Situ Bioremediation

Bioremediation is frequently applied in situ, without resorting to excavation. The desirability of this approach is often dictated by the site itself, such as contamination that may stretch under a road or building. Frequently, the appeal of bioremediation is directly related to the viability of in situ treatment, contrasted with traditional "dig and haul" remediation, such as incineration and landfilling. Groundwater and soil treatment are the leading applications for in situ bioremediation. The issue is of major concern, with groundwater and soil contamination at an estimated 300,000 to 400,000 sites in the United States alone. Some cost estimates for a general clean-up of these sites are as high as $1 trillion over the next 30 years.

On-Site Bioremediation

Some sites cannot be effectively or economically treated in situ. Fortunately, there are numerous bioremediation systems for on-site remediation, including:

- Engineered treatment cells reduce very high contaminant levels in soils and sludges with a method similar to composting. The media is aerated with piping, and nutrients, water, and oxygen are administered. Volatile vapors are automatically displaced by the air. This approach is distinctly more economical than alternatives such as disposal through landfilling.

- Composting is another bioremediation alternative that may be done on site, usually for pre-treatment of very highly contaminated soil. Aerated piles using leachate circulating systems accelerate natural degradation.

- Land farming employs cultivation methods, such as frequent turning, to mix liquid or solid residues with soil, providing a uniform zone for natural bioremediation. The equipment used is often modified agricultural machinery. Land farming is most frequently applied to soils contaminated by petroleum hydrocarbons.

- Bioreactors are contained environments that enhance the biodegradative capabilities of microorganisms coming in contact with contaminated soil, sludge, sediment, water, or air. In a bioreactor, variables such as pH, temperature, and nutrient and oxygen delivery can be precisely controlled, optimizing the environment for bioremediation. Bioreactors can use naturally occurring, cultured or genetically engineered microorganisms to treat such contaminants as PCBs, TCE, hydrocarbons, and industrial process wastewater streams. Bioreactors, along with biofilters, represent the chief area of application for genetically modified bacteria in the bioremediation industry.

Off-Site Bioremediation

The effectiveness and popularity of in situ and on-site bioremediation leaves relatively little to cover in the offsite treatment category. When a site does not provide ample space for remediation work, or when site conditions are too severe for bioremediation to work, the contaminated soils may be excavated and transported to central processing facilities, where technologies such as engineered treatment cells, composting, land farming, and bioreaction/biofiltration can be performed on a large scale under controlled conditions.

True Measure of Performance…Sludge Reduction

The basic process of biological treatment of wastewater involves the conversion of soluble organics to carbon dioxide, water and bacterial cells. These bacterial cells produced are the main component of sludge that must be collected and removed (wasted) for the plant to fully recycle the biological treatment process.

The amount of biomass produced in the form of sludge, which must be disposed of, is dependent on the Food/Mass (F/M) Ratio since this determines the amount of energy that is available, above what is required for the bacteria cell maintenance and cell synthesis. Studies have shown that certain bacteria species that are more efficient (i.e. have a higher metabolic rate) can be used to augment the populations in the mixed liquor resulting in an Improved (lower)biomass conversion efficiency, which we express as a yield coefficient, Y.

The yield coefficient is calculated by dividing the kilograms of solids removed from the system by the kilograms of BOD removed in the process. The calculation of solids generation must take into account the solids coming into the system in the influent, the solids being wasted (removed) from the system and the solids going out in the effluent.

The BOD removal calculation must take into account soluble and particulate BOD coming into the system as well as soluble and particulate BOD exiting the system.

The formula for this reaction is:

Yield Coefficient = **<u>BOD inf (mg) – BOD eff (mg) x F or Q inf (MG) x 8.34 lbs/mg-MG</u>**

(TSS was (mg) x F or Q was (MG)) – (TSS eff x F or Q eff (MG))x 8.34 lbs/mg-MG

Microbe Lift and Sludge Reduction in Biological Treatment Systems

The basic function of a biological treatment system is to convert soluble organics to carbon dioxide, water and bacterial cells. The cells can then be separated from the purified water and disposed of in a concentrated form called "sludge". The advantage of biological treatment is that it can reduce soluble organics in large volumes of water far more economically than any other type of chemical or physical / chemical process. This bulletin will deal with aspect of sludge reduction. As mentioned earlier, the basic process of biological treatment is the conversion of soluble organics to carbon dioxide, water and bacterial cells. This reaction is defined by following equation:

$\mathrm{BOD} + \mathrm{N} + \mathrm{P} + \mathrm{O_2}\ \mathrm{CO_2} + \mathrm{H_2O} + \mathrm{Cells}$

The soluble organics are represented by BOD. The N is nitrogen, required for protein synthesis and P is for phosphorous which is required for energy transfer. Depending on the F/M or food / mass ratio in the system there is another process that goes on simultaneously. This process, digestion, occurs when there is not enough food for the bacteria to continue growing and is represented as follows:

$\mathrm{Cells} + \mathrm{O_2CO_2} + \mathrm{H_2O} + \mathrm{N} + \mathrm{P}$

In a batch system where cells are grown and allowed to go into endogenous respiration, eventually all of the carbon would go off as CO2 and the only thing left in the water would be minerals. Hence, the process is called "mineralization".
The amount of sludge produced per kg of organics removed across the system is defined by the yield coefficient, Y_c. The yield coefficient is dictated by the equilibrium F/M ratio in the system. Normally the F/M ratio is defined as the total kg of BOD per day / total. kg of biological solids in the system (not including inventory in the clarifier). However, in this case, the equilibrium (F/M) is defined as the concentration of Mixed Liquor Suspended Solids MLSS/concentration of BOD in the mixed liquor.

In a completely mixed activated sludge system, it is assumed that the concentration F organic is uniform throughout the aeration basin and equal to the effluent concentration of organics. (Effluent is just mixed liquor with the solids settled out.) The equilibrium concentration of organics is the amount of organics the bacteria have to work within their immediate environment. As the effluent organic concentration approaches 1 ppm, the cells have less and less energy to work with in maintaining all vital cell functions. The minimum level of energy required to keep a cell intact is called the cell maintenance energy. The cell maintenance energy is the energy the cell needs to overcome entropy, the tendency of things to precede to a state of maximum randomness. With no energy the cell could not stay intact and would lyse, as in the digestion process. When there is more energy available that what is required for cell maintenance, the cell can synthesize new building blocks and multiply, producing sludge.

In waste water treatment plants (sewage works), there is a direct relationship between the equilibrium concentration of organics and the yield coefficient. The lower the equilibrium F/M, the less sludge production. This concept is applied to extended aeration systems that tout lower production as an advantage.

Two inherent drawbacks to biological treatment that Microbe Lift can alleviate through improved biological performance.

1. The fact that a living system and treatment efficiency can be affected by temperature and the presence of toxic or inhibitory compounds which can kill the system.

2. The fact that a biological sludge is produced which must be removed for disposal. In areas where space is at a premium, sludge disposal costs can be significant.

In many Microbe Lift programs conducted to improve BOD removal efficiency of the system a secondary benefit has been a reduction of the amount of waste activated sludge generation from 15 to 40%. What occurs when the Microbe Lift IND is added is the establishment of a more dynamic microbial population. This population not only responds faster to changes in loading on the system, but also reduces the effluent concentration of BOD. This then lowers the equilibrium F/M, reducing the amount of available energy closer to cell maintenance energy of the cell. While Microbe Lift IND is an important tool in sludge reduction, to optimize this benefit requires careful control of the critical operating parameters to optimize the sludge reduction.