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Revision Memo

12/02	This revision provides editorial changes to land farming and and maintains all previous technologies Composting has been augmented with additional information on “non-engineered piles” while slurry biotreatment has been virtually eliminated.
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SCOPE

This section covers several types of biological treatment available to remediate contaminated soil and sludges. Technologies included are land treatment or land farming, biopiles or ex situ treatment, in situ bioremediation of soil, composting, and slurry biotreatment. Slurry biotreatment is not covered in detail because it is costly and not recommended at this time.

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DEFINITIONS

Acclimation is the process by which microorganisms adapt to environmental changes such as modified temperature, moisture, oxygen, nutrient, or hydrocarbon levels.

Aerobes are organisms that require air or free oxygen for growth.

Anaerobes are organisms that grow in the absence of air or oxygen and do not use molecular oxygen in respiration.

Aquifer is water-bearing bed or stratum of permeable rock, sand or gravel.

Bacteria are the microorganisms which are responsible for the largest portion of microbial degradation.

Bacteria Seeding is the addition of microorganisms to a biological treatment system.

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Bacteria Sludge is a mixture of liquids and solids where liquid is predominantly water. The solids are predominantly composed of microorganisms with some inorganic solids present.

Bioaugmentation is the addition of microorganisms (predominantly bacteria) to increase the biodegradation rate of target pollutants.

Biodegradation is the chemical alteration and breakdown of a substance, usually to smaller products caused by microorganisms or their enzymes.

Biomass is a term used to represent the total weight of microorganisms in a given system, particularly a bio-slurry reactor.

Biopile is an above ground biological treatment facility.

Bio-Refractory Hydrocarbons are hydrocarbon compounds which resist biological breakdown.

Bioremediation is the enhancement of biodegradation by controlling the microbial environment to stimulate the rapid growth and activity of microorganisms.

Biostimulation is the addition of microbial nutrients, oxygen, heat, or water, or some combination thereof, they enhance the rate of biodegradation of target pollutants by indigenous species (predominantly bacteria and fungi).

Bulking Agent is a material such as sawdust, sand, wood chips, or manure that is added to a soil or sludge to increase porosity and moisture holding capacity.

Co-metabolism is the fortuitous biological transformation of a non-biodegradable chemical by a microorganism that is using a different compound as a primary food source.

Cultured bacteria are those that are grown in a controlled artificial environment for a specific purpose, such as to degrade a certain type of chemical substrate.

Curing is the process of allowing composted material to further react and stabilize in a storage tank or static pile after initial treatment in a reactor.

Decrepitation is the crumbling of soil resulting in the inability of the soil to hold moisture and air.

Dry Solids is the amount of material remaining after drying a sample at 103°C to constant weight.

Emulsifiers are agents which promote the formation and stabilization of an intimate mixture of two immiscible liquids (e.g., oil, water) in which one of the liquids is dispersed in the other in the form of fine droplets.

Enzyme is any group of catalytic proteins that are produced by living cells and that mediate and promote the chemical processes of life without themselves being altered or destroyed.

Exogenous bacteria are those added to the system or environment from an external source.

Ex Situ refers to those remediation processes that take place after the soil has been dug up and placed in an above ground "biopile" or treatment facility.

Fertilizer is a material which supplies nutrients essential for plant growth and biological activity.

Humus is a brown or black complex of various organic materials formed by the partial decomposition of vegetable or animal matter.

Indigenous bacteria are those that exist or originated naturally in a particular region or environment.

Inoculum is a small amount of substance containing bacteria from a pure culture which is used to start a new culture or "seed" a commercial system.

In Situ means literally, "in the natural or original location."

Leachate is water or other liquid which has percolated through the soil or sludge and which may have removed material from the soil or sludge.

Leaching is the removal of material from a soil or a sludge by percolation (i.e., slow downward movement of water in the soil or sludge).

Matrix is the solid phase, fine-grained material in which soil microorganisms live.

Mesophilic microorganisms are those that grow at moderate temperatures (20-40°C or 68-104°F).

Microbial Degradation is the breakdown of organic compounds into compounds of lower carbon number by the action of microorganisms.

Microorganisms are minute plants or animals that cannot be seen without a microscope.

Most Probable Number (MPN) is a statistical method of determining bacterial counts by analyzing a series of small cultures of successively diluted samples.

Nutrients are chemical elements such as nitrogen, potassium, phosphorous, sulfur, calcium, etc., essential for plant or animal growth.

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Oily Sludge is a mixture of liquids and solids in which the liquid is predominantly hydrocarbons with lesser amounts of water. The solids are generally sand or soil particles, scale, or solid hydrocarbons.

Osmotic Shock is the destruction of cells that occurs because of a rapid change in the salt concentration of the surrounding fluid.

Permeability is the volumetric rate at which a fluid passes through a unit cross section of porous material under a unit pressure gradient.

Respiration is the process by which microorganisms oxidize organic chemicals to CO₂ and water.

Septic refers to a condition where oxygen is depleted to the point where anaerobic bacterial degradation takes place, often accompanied by the evolution of H₂S, SO₂, or methane.

Subsoil is the stratum of soil directly under the surface soil.

Substrate is the substance with which an enzyme reacts during biological degradation.

Synthesis is the process by which living cells produce the biochemicals and genetic materials that allow them to reproduce and grow.

Thermophilic microorganisms are those that grow in the 40-60°C (104-140°F) temperature range.

Topsoil is the surface soil. The depth of topsoil usually includes the average plow depth.

Vadose Zone is the unsaturated portion of the soil near the surface that contains water below atmospheric pressure and air or other gases at atmospheric pressure.

BACKGROUND

Biodegradation is the natural process by which hydrocarbons and other organic materials are consumed by microorganisms (such as fungi and bacteria) that utilize these materials as a food source. Biological Treatment or Bioremediation is the process of stimulating the growth and activity of microorganisms to hasten the decomposition and removal of contaminants from the environment. This can be accomplished by controlling the environment in which these microorganisms live, typically by providing oxygen and/or nutrients that are normally limited in supply (biostimulation). Most often, these nutrients are comprised of the nitrogen and phosphorus found in common fertilizers. Adding specialized microbes to enhance biodegradation (bioaugmentation) has also been proposed by some vendors, but scientific studies have failed to show a benefit for this technique.

Biological treatment has been practiced in a number of ways through the years. The most well-known type of biological process involves the treatment of wastewater with activated sludge. This process has been practiced for decades, most commonly in large aerated reactors containing tons of biomass that consumes the waste materials in the water. The same biological organisms that treat wastewater can be harnessed to treat soils and sludges, although different systems are required to bring the microbes in contact with the contaminant. The principle technologies covered in this section are listed below.

LAND FARMING

In land treatment or land farming, sludge is spread on the surface of the soil and tilled into the top few inches. The soil soaks up excess moisture and provides a matrix for biological degradation of the residual oil. Fertilizer is added to provide nutrients for the oil degrading bacteria. If necessary, pH-adjusting chemicals may be added to bring the soil into the neutral pH range. Land farming is applicable to both oily wastes and biological sludges. This technology has been practiced at several ExxonMobil locations for many years, but has been essentially banned for hazardous wastes (including API bottoms and DAF sludges) in the United States since about 1990.

SOIL BIOREMEDIATION

Soil bioremediation is similar to land farming, except that the intent is to remediate contamination that is already present in the soil. Bioremediation may be conducted "in situ" (i.e., in place), or "ex situ," after the soil has been dug up and placed in an above ground "biopile" or treatment facility.

COMPOSTING

Composting is similar to above ground ex situ biotreatment, except that it involves the addition of bulking agents such as wood chips, straw, and manure, and is normally carried out at higher than ambient temperatures. The higher operating temperature increases the rate of degradation relative to conventional bioremediation, although the addition of bulking agents also increases the total volume of material to be dealt with.

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SLURRY BIOTREATMENT

Slurry biotreatment, as the name suggests, is similar to conventional waste water treatment, except that the solid phase to be remediated is slurried in water and kept in suspension by vigorous mixing. This intensive treatment often increases the rate of biodegradation, but is generally more costly than solid-phase bioremediation.

BASIC CONCEPTS

Because bioremediation is a biological process operating at essentially ambient conditions, it takes much longer than most chemical processes. While it is common for chemical reactions to proceed to completion in seconds or minutes, bioremediation may take months or years. In addition, not all chemical contaminants are biodegradable, and those that are degrade at widely varying rates. Often, this means that the extent of cleanup achievable with bioremediation may be less than that achievable with other processes. In many cases, this is not an issue, since the levels achievable with bioremediation are acceptable. However, it is a factor that needs to be considered on a site-to-site basis, and may be subject to regulatory controls.

Natural biodegradation occurs primarily in the unsaturated or "vadose" zone of the soil, which is the soil between the surface and the groundwater table. Assuming a source of hydrocarbons is readily available (for example after a spill) this process is still limited by several factors, including lack of sufficient oxygen, water, or nutrients for bacterial growth. Thus, the promotion of biodegradation typically involves supplying all the necessary components that may be lacking in the natural system.

All of the technologies discussed in this section are comprised of the same basic elements, with minor process differences that depend on the circumstances of the remediation. These basic elements are listed below and discussed in more detail in the following sections.

CONTAMINANT	Hydrocarbon material to be removed by biological treatment. Used as a carbon source for microbial synthesis and respiration, hydrocarbons vary widely in their biodegradability.
SOLID PHASE	Soil or sludge containing the hydrocarbon contaminant to be remediated. This material provides the environment in which the microbes must live.
MICROBES	Naturally occurring microorganisms that are able to utilize the contaminant as a food source.
OXYGEN	Required for microbial respiration, by which hydrocarbon is oxidized to CO ₂ and water.
NUTRIENTS	Required for synthesis of microbes. Usually only nitrogen and phosphorus are needed.
WATER	The medium in which microorganisms live. Also a product of hydrocarbon degradation.

OPTIMUM CONDITIONS

The optimum conditions for bioremediation are similar to those promoting the growth and vitality of any living organism. Temperatures in the range of 50-100°F (10-38°C) are preferred, although bio-activity slows considerably at the low end of the range. An exception to this rule is composting, where temperatures are purposely allowed to increase into the thermophilic range 100-140°F (40-60°C). Moisture is essential to support the microbial population, which congregates at the interface between the water and oil phases. Within the soil matrix, hydrocarbon degrading bacteria need enough water to provide an adequate habitat, but not so much that it chokes off aeration. Generally, maintaining the water content in the range of 30-70% of the holding capacity¹ of the soil is sufficient.

HYDROCARBON BIODEGRADABILITY

A summary of "dietary preferences" of microbes is given in [Figure 1](#). The most readily biodegraded compounds are straight chain hydrocarbons. However, even in this preferred group, there are notable exceptions. Lighter alkanes (C₅ - C₁₀) are solvents, and tend to inhibit microbial activity. Alkanes above C₂₀ are solid at ambient conditions and highly insoluble, and thus less amenable to biodegradation.

Isoparaffins are degradable, but at a slower rate than straight-chain molecules because the branching inhibits biological oxidation. Ringed compounds are even more slowly degraded, generally exhibiting lower biodegradability with increased condensation (ring overlap) and complexity.

The least biodegradable compounds are the 5+ ring aromatics, asphaltenes, and resins; all of which have very low water solubilities and biodegrade extremely slowly. Some of these materials, such as hopane and oleanane, are so resistant to biodegradation that they are used as conserved "markers" against which to measure the biodegradation of other compounds.

¹ Holding capacity or "field capacity" of the soil is the amount of water retained after saturated soil is allowed to drain.



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How biodegradable petroleum compounds are and how rapidly they degrade is also strongly related to boiling point. A first-pass estimate of the biodegradable fraction of a given oil is the amount that boils below 842°F (450°C). Other factors that are indicative of higher biodegradability are a high level of saturated compounds (> 40%) and low levels of aromatics and polars (< 20% each). The ratio of saturates to polars has also been used as an indicator of biodegradability (should be > 2).

The approximate field biodegradation rates of three types of petroleum products are compared on [Figure 2](#). Because the reaction is usually represented as first order², [Figure 2](#) is a semi-log plot of percent hydrocarbon remaining, which plots as a straight line versus time. Note that for diesel and gasoline, biodegradation is rapid, and reductions of 90% or greater can be achieved in a year or less. For heavy, weathered hydrocarbons, however, the rate is much slower, often requiring multiple years to reach desired levels of contaminant removal.

SOIL PROPERTIES

Soil is one of the most rich and variable substances on earth, and biological processes that occur in soil strongly depend on the type and condition of the soil. Fundamentally, soil is composed of solid particles and void space, which is partially or completely filled with water. Near the surface, air is a significant component of soils as well. [Figure 3](#) considers some of the most basic physical properties of soil, and the typical weight-volume relationships usually measured. The figure plots volume on the abscissa (x-axis) against weight on the ordinate (y-axis). Most of the weight of soil comes from the solid particles, which have a density that is typically 2 - 3 times that of water. For the hypothetical soil described on [Figure 3](#), the dry bulk density is 100 lb/cu ft. Given the typical particle density of 2.67 g/cc or 167 lb/cu ft, this soil would be about 40% void space and only 60% solid. As indicated on the figure, one hundred pounds of dry soil would only occupy 0.6 cu ft of volume. The rest would be taken up by air and water in proportions that depend on the location, geologic conditions, time of year, etc. A typical soil in the unsaturated zone would be about 60% saturated, which means that the void volume would be 60% filled with water, with the remainder filled with air. Soil scientists often express this moisture content on the basis of weight percent of dry soil, which in this case would be 15% dry soil. On a total weight basis, this is equivalent to 13 wt.% moisture. It is important to distinguish these different measurement conventions, especially for high moisture soils.

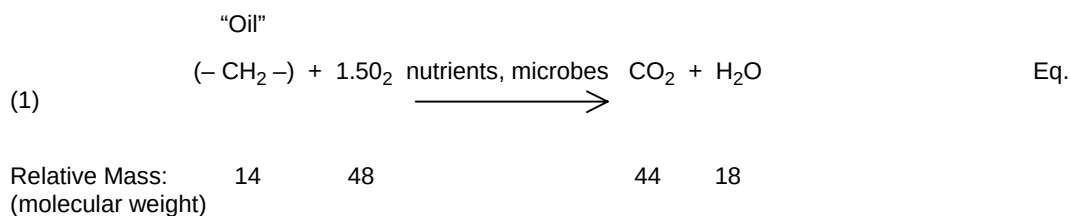
Soil is further characterized by particle size and shape, and more importantly, by the amount of organic matter it contains. The U.S. Department of Agriculture classifies soils by the amount of clay, silt, and sand they contain, as depicted in the "textural triangle" shown in [Figure 4](#). To a large extent, clay, silt, and sand are determined by particle size, as broken down in [Table 3](#).

Soil type is important for bioremediation. Clay is less suitable because its small particle size and tight structure does not allow for adequate aeration or mass transfer of nutrients into its pore structure. Coarse sand or gravel can also be a problem since it often doesn't contain sufficient organic carbon material for adequate wettability. Sandy loam material is best, because it holds moisture yet has a high enough permeability to allow for easy flow of air and nutrients into the biologically active zone.

MICROBES

In most natural environments, hydrocarbon (HC) degrading microorganisms are present, although not always in large numbers. Following a hydrocarbon spill, natural selection enriches the number of HC degraders at the expense of other organisms. Under favorable conditions, this enrichment occurs rapidly, and HC degradation rate increases. The conversion of hydrocarbons to CO₂ and water is a complex process, often requiring many steps, and even multiple communities of microorganisms. However, biodegradation is fundamentally an oxidation process, catalyzed by enzymes, that can be represented by the following idealized chemical equation.

Oxidation:



During solid phase biodegradation, some of the HC metabolized is converted to biomass while the rest is utilized as an energy source for the microbes. The biomass grows to a maximum level as determined by the environment, and

² $C = C_0 e^{-kt}$ or $\ln(C / C_0) = -kt$.

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then stabilizes until the HC concentration drops to the point where the carbon source becomes limiting. Most often, the rate of HC degradation is limited by the availability of oxygen or nutrients to the microbes.

WHAT ABOUT "DESIGNER BUGS"?

Many vendors sell bioremediation products that contain "specialized bugs" that they claim will enhance the rate of biodegradation. ExxonMobil studies as well as those conducted by the U.S. Environmental Protection Agency for the express purpose of measuring the effects of bioaugmentation on petroleum hydrocarbons have never detected any enhancement attributable to these preparations. The most likely reason that externally prepared (exogenous) microbial treatments have not proven effective is the need for microbes to be "acclimated" to their environment and to compete with other similar organisms for limited resources. In the time it takes exogenous microbes become acclimated, naturally occurring microbes can grow in response to improved conditions. For this reason, the use of agents containing microbes is generally not recommended.

OXYGEN

As indicated by [Eq. \(1\)](#), oxygen supply is a critical factor in aerobic biodegradation. On a weight basis, 48/14 or about 3.4 pounds of oxygen is needed to fully oxidize a pound of HC. In solid-phase bioremediation, this oxygen must either be supplied passively, through diffusion into the air-filled pores, or actively, through a piping network connected to an air blower. In slurry-phase bio-treatment, oxygen is supplied either by sparging air into the reactor or through the action of large mixer/aerators.

NUTRIENTS

The rate at which a hydrocarbon contaminant is biodegraded is a function of many factors, but depends fundamentally on the number of oil-degrading bacteria present and the metabolic activity of these bacteria. The growth rate and ultimate number of bacteria depend on the availability of water, oxygen, and nutrients.

How much nutrient to supply and in what ratios has been the subject of extensive investigation. Much of this work has been devoted to the optimization of wastewater treatment units³, and is not directly applicable to soil remediation systems. However, the reactions are fundamentally the same, whether the process is taking place in a wastewater treatment unit or in a soil treatment facility.

Material balance considerations can be helpful in simplifying the concepts behind what are really complex biochemical reactions. For example, as indicated by [Eq. \(1\)](#), the overall oxidation of hydrocarbons requires nothing but oxygen, and is a net producer of water. Nutrients, such as nitrogen, are required for synthesis of the biomass, but do not participate directly in the hydrocarbon degradation reaction. Thus, nutrient requirements for microorganisms are related to their chemical composition. Porges, et al proposed in 1956 the formula $C_5H_7NO_2$ for the chemical composition of a heterogeneous microbial population. Other studies have shown that bacterial cells also contain phosphorus at a molar concentration about one tenth that of nitrogen.

In the production of microbial "biomass," any of these elements (as well as other trace chemicals not listed here) can be limiting. In soil or sludge remediation, carbon occurs in temporary excess as a primary constituent of the contaminant being treated. Trace elements (K, Na, S, Ca, Fe, etc.) are typically available in adequate amounts in the soil. Thus, assuming a sufficient supply of water is available, aerobic biomass is most often limited by the availability of oxygen, nitrogen, or phosphorus. However, while a large amount of oxygen is ultimately consumed as a reactant in the overall oxidation process, nitrogen and phosphorus are only required for bacterial cells, and are recycled to the environment when the cells die.

Because fertilizer is relatively inexpensive (fertilizer costs are typically in the range of 1-5 \$/ton of soil treated), the amount of fertilizer used is usually not a significant factor in overall project cost. Thus, using maximum amounts of fertilizer (minimum C:N or C:P ratios) would appear to provide the fastest biodegradation rates. Studies have shown, however, that adding too much nitrogen fertilizer can have an inhibitory effect on biodegradation. The mechanism for this inhibition is not completely understood, but some studies suggest that it may be the result of osmotic shock to the microorganisms due to increased salt concentration in the soil water. This in turn depends on the type of soil, the moisture content, and the level of hydrocarbon contaminant present. [Figure 5](#) indicates the minimum carbon to nitrogen ratios (i.e., maximum nitrogen levels) to avoid this inhibition effect as a function of soil hydrocarbon concentration and moisture content. This figure is based on the assumption that inhibition will result when the weight ratio of nitrogen to water in the soil is greater than 0.005 (a water to nitrogen ratio of 200:1). Thus, for a soil containing 1% hydrocarbon and 17% moisture on a dry soil basis, the C:N ratio could be as low as 10:1. However, for a soil with 6% hydrocarbon and 10% moisture, the minimum recommended C:N would be 100:1. Laboratory and

³ A good discussion of the factors that go into determining nutrient requirements is contained in the ExxonMobil Environmental Design Practices Section XIX-A5, *Biological Treatment of Wastewater*.

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field studies have indicated that the optimum ratios of C:N:P are in the range of 100:2:1 by weight. The ratio of carbon to phosphorus is typically maintained at about 100:1.

WATER

Water is an important component in bioremediation because it is the medium in which the bacteria live. Too little water will cause the microbes to dry up just as living plants do. This is termed the "wilting point." On the other hand, too much water in a solid-phase system will close off the pore spaces and severely limit oxygen transfer. This happens at or near the saturation point. How these parameters change with different soil types is shown on [Figure 6](#). As mentioned above, a useful parameter to help gauge the amount of water needed is water holding capacity or "field capacity." This is the amount of water remaining after saturated soil is allowed to drain by gravity. Note that both the holding capacity and the wilting point for clay are much higher than they are for sand. The target range of moisture level for soil bioremediation (between the wilting point and 70% of water holding capacity) is shown on the figure. As long as the moisture level is in this range, sufficient air voids will be maintained to allow adequate aeration for biodegradation.

PROJECT STEPS

Regardless of the technology ultimately used, all biological treatment projects will involve the following steps.

1. **Characterize Site and Analyze Material to be Treated** - At this point the primary goal is to determine how much contaminant there is, its chemical characteristics, and what the clean up target(s) will be. The analyses recommended for this purpose are listed in [Table 2, Tier 1 Analytical Soil Characterization](#). Clean up targets are generally set in cooperation with local regulatory agencies. During this phase, laboratory treatability studies are also recommended to determine the rate and extent of biodegradation achievable.
2. **Decide on Technology** - Is contaminant in a soil or sludge? Near surface or deep? Do regulations or circumstances require excavation? Is there a time constraint? These and other factors must be considered along with cost in determining the feasibility of biological treatment and the best type of treatment to use. In most cases where biological treatment can meet clean up goals, in situ or ex situ treatment will be the favored technologies.

COMPARISON OF BIOLOGICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	USED FOR	DESCRIPTION	ISSUES	COST, \$/TON ⁴
Land Farming	Sludges, oily wastes	Waste is spread on soil and tilled in with fertilizer to promote biodegradation and incorporation into soil.	Practice currently banned in U.S. for hazardous wastes. Old land farms have become waste facilities requiring clean up in the U.S.	< 40
Land Treatment	Contaminated soil	Soil is mixed with fertilizer, spread to a depth of 1-2 ft, and tilled until clean up standards are met.	Requires large land area and may take more than one season to remediate.	40 - 80
In Situ Bioremediation	Contaminated soil	Fertilizer is added and soil is tilled in place to promote biodegradation.	Process is limited to top 2 ft of soil. May take longer than ex situ or slurry systems. Leachate from project could enter ground water.	< 40
Ex Situ Bioremediation	Contaminated soil	Soil is dug up, mixed with fertilizer (and potentially with bulking agent), and placed in an above ground treatment facility.	More costly than in situ system. May require aeration blower and air emissions control facilities.	40 - 80
Composting	Contaminated soil and sludge	Material is mixed with bulking agent and fertilizer and placed in enclosed vessel or static pile for treatment at elevated temperature.	Bulking agent increases volume of contaminated material. Static piles can create odor problems.	80 - 120
Slurry Bioremediation	Soils, sludges, and oily wastes	Solid is mixed with water and nutrients in large aerated slurry-phase reactor.	High cost severely limits applicability.	100 - 200

⁴ Costs vary widely and there may be significant overlap between technologies, depending on the site conditions. Approximate ranges given are typical for 1995, Eastern U.S.

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3. **Treatment Preparation** - For materials with high (> 10%) hydrocarbon content, or soils with high clay content, addition of a bulking agent should be considered. No firm rule can be established for the amount of bulking agent to add, but ratios in the range of 1:1 by volume are common. Evaluation of several ratios in laboratory treatability studies is recommended where prior experience on similar materials is not available.
4. **Add Fertilizer** - Ensure that adequate amounts of nitrogen and phosphorus are added to maximize biodegradation. Avoid nitrate inhibition using guidelines in [Figure 5](#).
5. **Moisture Control as Needed** - Sprinkling and/or drip irrigation systems are installed to provide the capability to maintain moisture level in the desired range. For in situ or land farming projects, depending on natural rainfall may be a viable option. In this regard, bioremediation is not unlike crop farming, and may work well in temperate climates without artificial watering.
6. **Air Supply** - The oxygen requirement will be satisfied in different ways depending on the technology. An air blower may be utilized for an above ground biopile. For in situ or land treatment systems, oxygen is provided through natural diffusion, and may be enhanced by frequent tilling to increase porosity.
7. **Monitor Progress** - A monitoring program must be established for the purpose of measuring progress and determining when the project is complete. For parameters such as moisture content and pH, soil probes are available to simplify measurements. For other parameters, particularly contaminant levels, an analytical sampling program will be required. Guidelines on the number and frequency of samples to take are given in the individual technology sections.
8. **Close Out Project** - After target contaminant levels are reached, a final sampling program may be required to prove to regulators that clean up criteria have been met. Depending on the circumstances, a statistically designed grid of samples may be necessary to determine that criteria have been met with a satisfactory level of accuracy.

The following sections provide additional design details for individual technologies.

LAND FARMING

Land farming has been used extensively within ExxonMobil to treat petroleum wastes using natural microorganisms. Land farming is effective in removing biodegradable portions of crude oil and petroleum products, but does not remove heavy asphaltenes and resins, nor appreciable amounts of inorganic compounds. However, these materials are effectively immobilized in the land farm. The general procedure is to:

- Spread oily or biological sludge on the soil.
- Allow excess liquid to evaporate or soak into soil.
- Add nutrients in the form of fertilizer (may include emulsifiers).
- Mix the sludge and nutrients into the top 6-12 in. (15-30 cm) of soil.
- Repeat mixing (aeration) and fertilization as needed.
- In arid locations water may be added to keep soil moist.
- Reapply sludge when degradation has taken place to the degree required.

WASTE SUITABLE FOR LAND FARMING

For a waste to be amenable to land farming, it should contain organic compounds that are both biodegradable and not subject to significant leaching (that is, not water soluble). The waste can be liquid, semi-solid, or solid, but must not contain materials that are toxic to microorganisms in the concentrations applied. Wastes most commonly land farmed within ExxonMobil are derived from process wastewater treatment. These and other wastes that have been successfully land farmed are listed below.

- API separator sludges.
- Float from dissolved air flotation (DAF) units.
- Sludge from backwashing granular-media filters.
- Waste biological solids.
- Slop emulsions.

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- Slop-tank and other tank bottoms.
- MEA sludge.
- Cooling tower sludge.
- Oily soil/gravel recovered from oil spills.
- Desalter bottoms.

Wastes not suitable for land farming include those with large quantities of acids, alkalis, soluble toxic substances, salts, heavy metals, or component not readily biodegradable. Specific materials that should be avoided are:

- Sludges containing organic lead compounds, or high copper levels.
- Clay from lube-oil treatment (high phenols or naphthenic acids).
- Sludge from sulfuric acid treatment.
- Trash (paper, wood, rags, etc.).
- Alkylation wastes.
- Phenolic caustic/sludges.
- Sulfidic caustic.
- Spent acid.
- Catalysts from conversion processes.
- Asphalt wastes.
- Stretford sludge.
- Boiler soot/slag.
- Untreated sanitary wastes.

Wastes should be analyzed for oil/water content and oil characteristics (see [Table 2](#)) prior to land farming. If the waste contains a material not previously land farmed, a treatability test should be done with soil from the proposed land farm site.

TYPE OF SOIL

It is desirable to have a loamy (high organic or humic matter) surface which will retain air and moisture. If the surface soil is clay or silt, (that is, of low porosity), then sand or organic residues such as bagasse (sugar cane residue) or bark may be mixed into the soil to increase porosity.

Test borings should be used to determine the soil formation and the presence and initial quality of any subsurface aquifer. To prevent sludge contaminants from reaching the aquifer, the following minimum distance should be observed between the soil surface and the aquifer.

SOIL TYPE	MINIMUM DISTANCE	
	ft	m
Sand	8	2.4
Loamy Sand	6	1.8
Sandy Loam	5	1.5
Loam or Silty Loam	4	1.2
Clay Loam or Clay	4	1.2

It is desirable to have subsoil with a permeability of 10^{-6} cm/sec or less to prevent leachate contamination of ground water. This may be achieved by removing the top soil and installing a compacted clay or other liner before replacing the top soil.

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DRAINAGE

The site should be level to minimize oily water run off and erosion. For clay or silt soils, the maximum slope should be less than 1%. A greater slope is acceptable with loamy soils because these soils tend to absorb liquids as soon as they are applied. Land with standing water should be avoided since this inhibits oxygen transfer into the soil. Water that collects in the periphery and any low areas should be drained to a surge basin and then fed at a reasonable rate to an API separator from which water can be treated as required to meet local regulations. As an alternative, the water may be recycled to the land farm during dry spells.

AESTHETICS

The site should not be prominently visible to public areas surrounding the site. Planting of border shrubbery or trees can assist in screening the disposal area.

Appearance can be improved by strip farming the sludge. Sludge is spread in strips about 12 ft wide with alternating 12 ft strips of grass. Use of these strips is rotated between seeding with grass and spreading of sludge. Initially, the grass may be plowed under to improve the porosity and the nutrient content of the soil. During later rotations, the grass may be removed and disposed of to reduce the organic and the metal content of the soil. Continually increasing the organic (humus) content of the soil may eventually reduce oily-waste degradation since bacteria will then have a preferred source of food.

SITE PREPARATION

High permeability soil (e.g., sand) should be avoided since leaching from the land farm could affect the quality of ground water. In some cases a liner may be employed. In this case, the soil should be removed to a depth of 3-4 ft, the liner installed, and the soil replaced. This is only practical if the level of subsurface water is below the intended liner. The following table lists possible liner materials.

MATERIAL	THICKNESS	ESTIMATED LIFE (YEARS)	RESISTANT TO	DAMAGED BY
Concrete	—	50+	H ₂ O, many liquids and solids	H ⁺ and OH ⁻ , acid & alkaline
Asphalt	2 - 3 in.	10 - 14	H ₂ O, H ⁺ , OH ⁻ , freeze/thaw	Organics vegetation, sunlight
Clay	—	20 - 60	H ⁺ , OH ⁻ , solids	Permeating water
Butyl	30 - 40 mils	20 - 25	H ⁺ , OH ⁻ , O ₃ , H ₂ O, organisms, cracking, aging	Certain organics
Neoprene	47 mils	10+	H ⁺ , OH ⁻ , chemicals	Sunlight
Polyethylene (HDPE)	20 mils	~10	Solvents, H ⁺ , OH ⁻	Sunlight, weathering, punctures

If liner is used, a leachate collection system should be installed to allow water that might collect above the liner to be withdrawn. Water from the leachate collection system should be analyzed for heavy metals and soluble organics. Results of these tests will indicate the type and degree of treatment required.

It is good practice to install wells to monitor the quality of subsurface water near a sludge farm. A number of wells in different locations should be made by drilling and installing a ~ 16 in. I.D. slotted pipe to a depth of ~ 4-7 ft below the water table. A smaller 3-4 in. slotted pipe should be installed in the center of the larger pipe, and the annulus filled with coarse, uniform-grain sand. For more information on design of monitoring wells, see [Design Practice XX-B3](#).