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A Comparison of Popular Remedial Technologies for Petroleum Contaminated Soils from Leaking Underground Storage Tanks

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Today's remediation of contaminated soils is as diverse as the types of contaminants and the site conditions. Some of the most widely implemented types of remediation for petroleum products include: Land farming, Excavation, Bioremediation, and Volatilization. This paper will focus on the various aspects of these clean up technologies. Issues discussed will be a process description of each technology, the environmental effectiveness, and total cost of the technology, generally, as each applies to petroleum product impacted soils. Keep in mind there are many factors that come into play when choosing the appropriate remedial technology. Things to consider are as follows:

- Site conditions such as types of soils, topography, depth to groundwater, impacted versus non-impacted ground water, and population.

- Federal, State and Local Regulatory requirements.
- Economic limitations.
- Cleanup technologies available.
- In situ treatment of petroleum product impacted soils vs. ex-situ removal.

VOLATILIZATION

In-situ volatilization (ISV) is the process by which volatile compounds are removed from the in-place soil through the utilization of forced or drawn air currents. Depending upon the types of compounds that are present and site conditions, in-situ volatilization can be a very effective, cost efficient remedial action.

Process Description

ISV, or in-situ air stripping, involves the removal of volatile organic compounds (VOCs) from contaminated soils by mechanically drawing or venting air through the soil matrix. The unit operations represented are common to most in-situ volatilization systems, although such systems vary considerably in size and design because of the specific requirements. The basic operations can be characterized as follows:

- A pre-injection air heater warms the influent air to raise temperatures and increase the volatilization rate. Often the soil acts as a vast heat sink and subsurface temperature rises are not appreciable. In cold climates, however, air heaters are valuable for system freeze protection.
- Injection and / or induced draft fans establish the airflow through the unsaturated zone.
- Slotted or screened pipe is often used to allow airflow through the system but restrict entrainment of soil particles.
- A treatment unit, often activated carbon, is used to recover volatized hydrocarbons thereby minimizing air emissions. The effluent from this unit must comply with air pollution standards discussed later in this section.
- Miscellaneous air flow meters, bypass and flow control valves, and sampling ports are generally incorporated into the design to facilitate airflow balancing and access system efficiency.

Environmental Effectiveness

The effectiveness of in-situ volatilization techniques is highly dependent upon site-specific conditions, soil porosity, clay content, ambient temperatures and a variety of other factors. Full scale, bench scale, and pilot-case studies generally confirm the following effects:

- In-situ volatilization has been successful for remediation in an unsaturated zone containing highly permeable sandy soils with little or no clay. In soils with low porosity or clayey soils, additional time is needed to establish the pressure gradient required to enhance volatilization.
- Recovery periods have been as short as a few weeks or typically on the order of 6 to 12 months.
- Light, more volatile, components of petroleum products such as those found in gasoline show the greatest recovery rates.
- In-situ volatilization can be used in conjunction with various contaminant removal systems, such as bioremediation.
- Ultimate cleanup levels are site dependent and cannot be predicted. These levels may be set by various regulatory agencies.

Economic Feasibility

Capital Costs

Capital costs can be relatively low for the basic ISV system incorporating vertically installed vent piping, conventional fans or blowers, and basic monitoring and control devices. Costs will be a function of design flow rate, size of piping, degree of automated monitoring, and, if necessary, effluent treatment required. Cost for the effluent treatment (carbon absorption, incineration) could raise the cost of this technology an order of magnitude or more. Blower costs range from $300 to $3,000 or more depending upon the design flow rate and pressure drop. Slotted PVC piping for schedule 40, 0.15-meter (6-in.) diameter will cost less than $82 per linear meter ($25 per linear foot). Unslotted PVC of similar size will cost less than $65.6 per linear meter ($20 per linear foot). PVC fittings (elbows, tees, etc.) with diameters greater than 0.15 meter (6 in.) may exceed $100 each. The cost of a monitoring device or data logger will be $4,000 or more depending on the degree of sophistication desired.

Installation Costs

A system utilizing PVC piping is relatively easy to install due to the ease of pipe joining and low weight. Installation costs for vertically installed pipe vent are similar to that of groundwater monitoring wells since the same construction materials and techniques can be used. Installed costs range from $48 to $65.6 for a 0.15 meter ($15 to $20 for a 6 in.) pipe per meter (foot) of depth. The installation cost for gas exhaust treatment depends on the option chosen. Incineration options will raise the overall installation cost significantly.

Operation and Maintenance Costs

Operation and maintenance costs are generally modest for these simple systems. The operation and maintenance costs will vary, largely due to the amount of automation that has been incorporated into the system. Operating costs are derived from the power requirements for fan operation and vary with the cost of electricity. Annual cost for full time operation can be estimated using the following formula:

Annual fan operating cost = Fan brake hp x 0.746 kW/hp x 8,760 hrs. /yr. x electrical cost, $kW-hr.

Operations and maintenance costs for exhaust gas treatment may be high. Replacement of carbon periodically will be far less expensive than operation of even the simplest incineration unit.

In addition, cost for periodic inspection and data collection should be considered. Maintenance costs can be conservatively estimated to be 4 percent of the total installed costs.

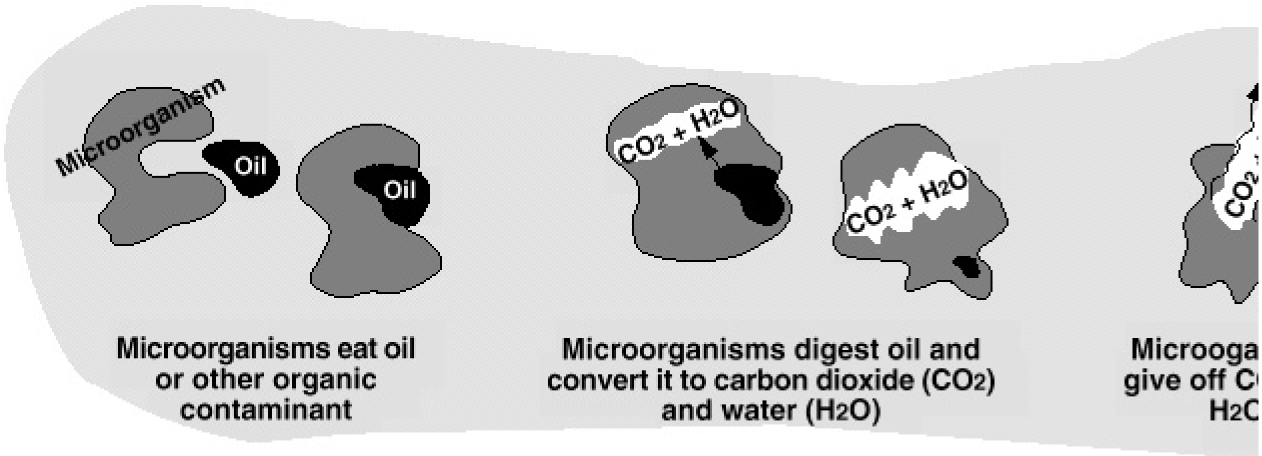
Qualitative Ranking of Cost

ISV systems, in their most basic forms, rank low in terms of cost. Exhaust treatment systems, however, can raise the cost of the entire system dramatically. Depending on flow rate, carbon usage and other factors detailed earlier, the cost for a carbon absorption system may still be modest. Incineration options can prove very costly, particularly when the presence of chlorinated hydrocarbons require more expensive construction materials. (EPRI and EEI 1990, 17-18, 35-37)

BIOREMEDIATION

Bioremediation is a treatment process that uses naturally occurring microorganisms (yeast, fungi, or bacteria) to break down, or degrade, hazardous substances into less toxic or nontoxic substances. Microorganisms, just like humans, eat and digest organic substances for nutrients and energy. In chemical terms, "organic" compounds are those that contain carbon and hydrogen atoms. Certain microorganisms can digest organic substances such as fuels or solvents (e.g., petroleum products) that are hazardous to humans. The microorganisms break down the organic contaminants into harmless products -- mainly carbon dioxide and water (Figure 1 Schematic Diagram of Aerobic Biodegradation in Soil). Once the contaminants are degraded, the microorganism population is reduced because they have used their entire food source. Biomass (dead microorganisms) or small populations in the absence of food pose no contamination risk. (EPA 1996)

Figure 1 Schematic Diagram of Aerobic Biodegradation in Soil



Stimulation of microbial growth and activity for hydrocarbon removal is accomplished primarily through the addition of oxygen and nutrients. Several factors influence this rate of growth, including temperature and pH. Biodegradation has been found to be an efficient method for the reduction of hydrocarbons in soil. The technology is based upon that which has been successfully used for land treatment of refinery waste. (EPRI and EEI 1990, 37-38)

It is by far the most elegant and pure cleanup solution – resulting in the transformation of toxic compounds to carbon dioxide and water – but the overall process can be unpredictable and unreliable due the variety of physical, chemical and biological factors. Selection of a bioremediation technology requires an understanding of the biological process involved and the physical application methods available. Microbes will live as long as optimal conditions exist. Once these conditions no longer exist they die off and leave behind fatty acids and metabolic processes that marine living organisms can consume or can be used to enrich the soil to enhance and stimulate plant growth. (Clark 1998, 30)

According to Jennifer A. Ehlert, Ph.D. Central Michigan University, "Bioremediation offers the opportunity to completely destroy the contaminant by converting it to carbon dioxide and water. The drawback to this technology is the lengthy cleanup time and the commitment to monitoring. Time is a luxury that is usually not afforded when dealing with a cleanup."

<u>Process Description</u>

The basic operations are (Heyse et. al. 1986):

- A submersible pump transports groundwater from a recovery well to a mixing tank.

- Nutrients such as nitrogen, phosphorus and trace metals are added to the water in the mixing tank. These nutrients are then transported by the water to the soil to support microbial activity.
- Hydrogen peroxide is added to the conditioned water from the mixing tank just prior to reintroduction to the soil. As hydrogen peroxide decomposes it provides the needed oxygen for microbial activity. Hydrogen peroxide is also added directly to wells and infiltration galleries. Air spargers, or the physical injection of ambient air into subsurface areas, are sometimes operated in lieu of peroxide injection.
- Groundwater is pumped to an infiltration gallery and/or injection well, which reintroduces the conditioned water to the aquifer or soils.
- Groundwater flows from the infiltration galleries or injection wells through the affected area and then backs to the recovery wells. The flow of the water should contact all soils containing degradable petroleum hydrocarbons.
- The water is drawn to a recovery well and pumped back into the mixing tank to complete the treatment loop.
- Groundwater, in which hydrocarbon concentrations have been reduced to very low levels, is often sent through carbon absorption for removal of residual hydrocarbons. Biodegradation is less efficient at low substrate concentrations and requires longer treatment times. (EPRI and EEI 1990, 59)

A simple example of the degradation process for hydrocarbons is outlined below:

1.The microbes consume and convert the petroleum products

2.The converted petroleum products becomes a fatty acid

3.Microbes perish after all the petroleum products is consumed

4.The end products are: carbon, food for indigenous organisms, carbon dioxide and water

<u>Environmental Effectiveness</u>

The effectiveness of biodegradation is dependent upon a number of site-specific factors such as nutrient availability, the size and type of microbial populations, aeration, pH of the soil, temperature, and ease of biodegradation in the substrate. Ex-situ bioremediation, while being more costly than in-situ processes, allows better or total control of your environmental parameters, and thus faster and more complete contaminant degradation. Because the soil is mixed and monitored over time, you know when contaminant levels have decreased sufficiently, says Dr. Ehlert.

There are times when the microbes in the soil must be augmented or infused with different microbial strains and nutrients to accomplish contaminant removal. Bioaugmentation is a tool that allows bioremediation processes to be used in situations that might otherwise be considered marginal or unacceptable for bioremediation. Proponents of this technique argue that given the proper amount of time, populations will develop to remove the petroleum - laden soil. However, time is usually not a luxury that can be afforded. According to Forsyth, Tsao & Bleam (1995), there are four major conditions under which bioagumentation should be considered:

- Low Microbe Count – when indigenous microorganisms capable of degrading the target contaminant number less than 105 per gram of soil or per millimeter of groundwater, remediation will not occur at significant rates until the population increases (Providenti et al., 1993). This condition may occur in low biomass soils (often nutrient limited subsoils), recently contaminated soils (exposure to the contaminant for an insufficient time to allow adaptation and growth), or as a result of toxic or inhibitory compounds in the spill. Depending on the growth rate of the indigenous microbes, a significant lag period may be observed before any biodegradation is apparent.
- Complex wastes – When the site contains high levels of nonbiodegradable waste types (e.g., heavy metals), physical or chemical removal of toxic materials may be required before bioremediation can begin.
- When Time is Money – When speed of decontamination is a prime factor, adding a microbial population with known biodegradative capabilities can be used to start the remediation process with little or no lag period.
- Assurances – When little other than the original source of contamination is known about the site and little time or money is available for testing, bioaugmentation provides a measure of assurance that proper microbes are present in sufficient numbers to do the work. Bioaugmentation may be less expensive than testing required to evaluate indigenous microbes or determine their growth requirements. Because the needs of bioaugmentation strains are well characterized and generally minimal, the soils can readily be adjusted to conditions acceptable for growth (Molnaa and Grubbs 1989). When inhibitory materials or compounds requiring long adaptation times are present on site, bioaugmentation can often reduce bioremediation

> times by one half or more. (Hinchee, Fredrickson, and Alleman 1995, 7)

According to Robert Lambdin, Environmental Coordinator, Atwell – Hicks, "A way to enhance bioremediation is to use a combination of bioremediation and soil vapor extraction. Soil Vapor Extraction (SVE) is a remediation technique, to enhance bioremediation, which is used to reduce hydrocarbons found in the vadose zone. The underlying process in SVE is to capture the volatilized hydrocarbons in the vapor phase with a capture (vacuum) well. Once the contaminated vapor is captured, the air can be treated and released to the atmosphere. It is useful because it brings air into the treatment zone, which creates an enhanced oxygen concentration, which gives the local microbes a better environment to survive, they already have the food (in the form of the contamination) and now they have increased oxygen. It is a two-phase project with a single capital expenditure. Most people do not view soil vapor extraction as an enhancement to bioremediation, they view it as cleaning the vapors, but you are still bringing air into the outside of the plume and it does increase bioremediation. "

Economic Feasibility

Capital Costs

Capital costs for biological treatment are greatly affected by the method of aeration. For hydrogen peroxide injection, costs can range from $3,500 to $5,000 for groundwater pumping rates of 37.8 to 151.2 liters (10 to 40 gallons) per minute. If air spargers are used, costs can range from $11,000 to $15,000 for pumping rates of 37.8 to 151.2 liters (10 to 40 gallons) per minute. (American Petroleum Institute, 1986)

Capital costs for a groundwater monitoring well with PVC casing (6-inch diameter) are approximately $32.8 to $ 65.6 per linear meter ($10 to $20 per linear foot).

In general, capital costs for biological treatment depends on the size, conditions and remediation level required. Total cost may range from $20,000 to $200,000, but are generally dependent upon the nature and magnitude of the soil impact.

Installation Costs

Installation for wells may have costs that range from $49.2 to $65.6 per meter ($15 to $20 per foot). PVC casings are the least expensive and stainless steel casings (necessary for certain types of contaminants) are the most expensive.

Operation and Maintenance Costs

Annual operation and maintenance costs for biodegradation systems with air sparging aeration can range from $5,000 to $10,000 for groundwater pumping flow rates of 37.8 to 151.2 liters (10 to 40 gallons) per minute. For the same flow rate, hydrogen peroxide injection systems may range from $3,500 to $15,000 per year. As pumping rates increase, operation and maintenance costs will also increase proportionally for hydrogen peroxide injection.

Annual sampling and analytical costs for groundwater monitoring based on four sampling events per year and three monitoring wells may cost approximately $5,000.

Qualitative Ranking of Cost

Depending on the magnitude of the contamination, the cost of biodegradation can be relatively low. Other than well installation, no major construction is needed and equipment requirements are minimal. Therefore, costs for this process are kept low, compared to other remedial technologies. (EPRI and EEI 1990, 51-52)

LAND FARMING

Land treatment is the process by which affected soils are removed and spread over an area to enhance naturally occurring processes. These natural processes include volatilization, aeration, biodegradation and photolysis.

Experience has proven that land farming, if properly performed, is an effective method for the removal of hydrocarbons from affected soils. However, a great deal of available land and time can be required to accomplish hydrocarbon destruction.

Process Description

The land treatment or land farming process involves the tilling and cultivation of soils to enhance the biological degradation of hydrocarbon compounds. The basic land farm operations are as follows:

- The area, which will be used for land farming, is prepared by removing surface debris, large rocks, and brush.

- The area is graded to provide drainage and surrounded by a soil berm to contain run-off within the land farm area.
- Agricultural fertilizer is added if the site is deficient in nutrients such as nitrogen, phosphorus, potassium or trace elements. Fertilizer is added as needed during the biodegradation process.
- The soils containing petroleum products are spread uniformly over the surface of the prepared area. It is important to distribute the hydrocarbons over the land farm area as uniformly as practical to minimize localized loading. Generally, petroleum products can be applied in quantities up to 5 percent by weight of the soil.
- The land farming material is incorporated into the top 15.24 to 20.32 cm (6 to 8 in.) of the soil with a tiller, disc harrow or other ploughing device. The soils must be well mixed to increase contact between the organics and microorganisms and to supply air for aerobic biological degradation.
- Depending on the rate of degradation, soils, which contain petroleum products, can be applied to the site at regular intervals. Reapplication at proper intervals replenishes the hydrocarbon supply and maintains biological activity.
- Monitoring of soils and surface runoff is typically conducted to measure hydrocarbon and nutrient levels and soil pH and to assure that the hydrocarbons are properly contained and treated in the land farm operations, and is required in many states.

Three general categories of land farming are used: windrow, static pile, and in-vessel. In windrow method, the mixture to be composted is piled in long rows (windrows) that are turned periodically by mechanical means to increase exposure of organic matter to oxygen. The static pile (forced-aeration) approach uses a blower to aerate the mixture to be composted. This mixture is placed upon a base of wood chips or other suitable material in which a network of aeration pipe has been constructed. Blowing or drawing air through the pile then introduces oxygen. In-vessel composting (mechanical or enclosed reactor composting) occurs in enclosed containers where environmental conditions can be controlled.

<u>Environmental Effectiveness</u>

The effectiveness of land farming is highly dependent on site-specific conditions. As mentioned previously, physical and chemical soil properties, site hydrogeology, ambient temperature, and a variety of other factors influence the effectiveness of land farming. Years of experience with the land farming of petroleum compounds confirm the following:

- Land farming is an effective means of degrading hydrocarbon compounds. Lighter compounds, including constituents of gasoline, will be preferentially degraded and volatilized. Heavier compounds will degrade at a slower rate and become bound to the soil particles.
- Ultimate degradation rates are site-dependant and cannot be predicted. As a result, waste application rates may be set by regulatory agencies without the aid of data from bench or pilot studies.

Economic Feasibility

Capital Costs

Capital costs for land farming operations can be relatively inexpensive. If the proposed site and large equipment are already owned by the operator, then capital costs are significantly reduced and the initial expense is minimal. Items and costs are shown in Table 1 - Capital Costs for land treatment operations. Rental of major equipment may be considered as another alternative.

Table 1 Capital Costs for land treatment operations.

Item	**Cost**
Land	$0.55 - $1.1/ metric ton treated material
Dump Truck	$80,000 - $100-000
Tractor	$23,000
Rototiller	$17,000
Disc harrow	$33,000
Sprinkler	$1,000

Installation costs

These costs are relatively low because the land is the treatment medium. Site preparation such as removal of trees, shrubs, rocks, and other debris may cost on the order of $0.55 - $1.10/metric ton ($0.5-$1/ton) of treatment material. The addition of lime and fertilizer may cost $0.55/metric ton (0.5/ton) of treated material.

Operation and Maintenance Costs

Operations and maintenance costs are shown in Table 2 Operations and Maintenance Costs for Land Treatment Operations. Soil and waste analysis are considered part of operations because results from these analyses often dictate further treatment operations.

Table 2 Operations and Maintenance Costs for Land Treatment Operations

Item	Cost (per metric ton treated material)
Cultivation And Site Operations	$1.65 - $2.20
Material transportation and Application	$9.35
Soil Analysis	$5.50

Qualitative Ranking of Cost

Land farming is a relatively inexpensive remedial technology when compared with other options described in this report. (EPRI and EEI 1990, 101, 116-118)

EXCAVATION

Excavation, as referred to in this document, is the process by which contaminated soils are removed from the site for disposal. Although excavation and disposal were widely used in the past for removing soils contaminated with hydrocarbon compounds, today it is generally considered a storage, not a treatment, process and raises issues of future liability for the responsible parties regarding the ultimate disposal of the soils. However, according to Larry Swihart, P.E., of STS Consultants in Lansing, Michigan, "landfills will give you certificates of indemnification for anything you put in there and you are essentially protected from liability." However, Mr. Swihart cautions that before sending materials to a landfill, "you should review the construction of the landfill and look for the authorization of the regulatory agency which gave the final approval for the landfill to operate. I won’t send anything to a landfill that is not double lined (two liners)" he adds.

Process Description

The process is conducted with the use of excavating equipment such as a backhoe or excavator. Contaminated soil is removed from the point of origin and deposited in a dump truck. The soil is then hauled to a landfill where the soil is dumped. The process is repeated until all of the contaminated soil has been removed from its original location and deposited in the landfill. As stated previously, the contamination is still present. However, it is now placed in a controlled atmosphere where impacts to the environment are minimized.

Environmental Effectiveness

Excavation is often the first step in many of the options available for treatment of soils containing petroleum products. Excavation of the materials can be extremely effective in terms of site cleanup because it can be confirmed by field sampling and laboratory analysis that all the petroleum-laden soils have been removed. In the anaerobic environment of the landfill, no significant degradation of the petroleum constituents in the soil occurs, although the soil has been removed and disposed, it has not been effectively treated.

The positive considerations are that a relatively short time period is required to complete the operation and that complete cleanup is possible. "Most clients, if you're in the industrial field, need the site quickly and by the cheapest means possible. Landfilling is not my first choice however, my primary concern is of economic and timing factors which satisfy my clientele." says Mr. Swihart. The more negative aspects are the worker / operator safety considerations that are necessary, and the short-term impacts of the operations (mainly dust and odor generated and increased runoff).

Economic Feasibility

Capital Costs

The cost of the actual excavation will depend on excavation depth, site surface characteristics, properties of the petroleum constituents present (such as explosivity) and quantity costs associated with the purchase of excavation equipment (such as backhoes, dozers, and dump trucks), and can range from $25,000 to $100,000 (Environmental Law Institute, 1984). All the above costs are also subject to other factors such as community and interstate relations and inflation and regulatory effects. Such factors are often difficult to quantify.

Costs

The excavation and landfill option for disposal of petroleum-bearing soils is a short-term operation, and, as such, does not require any installation costs. However, in Michigan, landfilling of petroleum – laden soils including excavation, tipping fees and haulage costs on the order of \$13 yd^3, according to Mr. Swihart.

Operations and Maintenance Costs

Estimates for leased equipment are \$3.93 per cubic meter (\$3/yd^3) for scarpers, \$2.61 per cubic meter (\$2/yd^3) for backhoes and \$1.31 per cubic meter (\$1/yd^3) for front-end loaders.

Qualitative Ranking of Cost

When comparing excavation technologies to bioremediation and incineration, excavation is less expensive. Mr. Swihart recommends excavation based on the economic standpoint and quick land re-use, you can't compare. When comparing the various technologies, landfill disposal of petroleum product contaminated soil (\$11 yd^3) is more cost effective than other alternatives such as bioremediation (\$42 yd^3) and in-situ volatilization (\$40 yd^3).

Summary

A summary of remediation technologies discussed in this paper is summarized in the table below.

Technology	Applicable Petroleum Products	Advantages	Limitations	Relative Cost
In Situ				
Volatilization	Gasoline Fuel oils	Can remove some compounds	VOCs only	Low

		resistant to biodegradation		
Biodegradation	Gasoline Fuel oils	Effective on some non-volatile compounds	Lengthy Cleanup Time	Moderate
Non In Situ				
Land farming	Gasoline Fuel oils Coal Tar Residues	Uses natural degradation process	Some residuals remain	Moderate
Excavation	Gasoline Fuel oils Coal Tar Residues	Removal of soils from site	Potential long term liability	Low

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