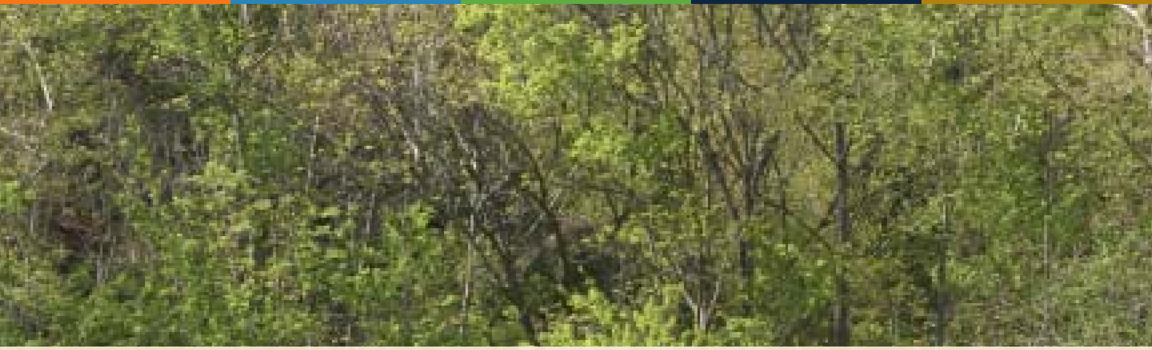
Technology Overview

Above Ground Treatment Technologies

Third in a Series of Remediation Process Optimization Advanced Topics



March 2006

Prepared by
The Interstate Technology & Regulatory Council
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ITRC (Interstate Technology & Regulatory Council). 2006. *Above Ground Treatment Technologies*. RPO-4. Washington, D.C.: Interstate Technology & Regulatory Council, Remediation Process Optimization Team. www.itrcweb.org.

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Acknowledgments

The members of the Interstate Technology and Regulatory Council (ITRC) Remediation Process Optimization (RPO) Team wish to acknowledge the individuals, organizations, and agencies that contributed to the 5-part series on advanced RPO topics. The following individuals from state and federal agencies, and the private sector are active members of the RPO Team and supported the preparation of these documents:

- New Jersey Department of Environmental Protection–Tom O'Neill–Co-team Leader
- South Carolina Department of Health & Environmental Control–Sriram Madabhushi–Co-team Leader
- California Department of Toxic Substances Control–Ning-Wu Chang
- Florida Department of Environmental Protection–Bheem Kothur
- Georgia Department of Natural Resources–Christopher Hurst
- South Dakota Petroleum Release Compensation Fund–John McVey
- Virginia Department of Environmental Quality–Tom Modena

- U.S. Air Force–Don Gronstal, Rod Whitten, Javier Santillan
- U.S. Army Corps of Engineers–Dave Becker
- U.S. Navy–Karla Harre
- U.S. Department of Energy–Beth Moore
- U.S. Environmental Protection Agency–Kathy Yager, Richard Hammond, Pamela Baxter, Ellen Rubin
- Lawrence Livermore National Lab–Maureen Ridley

- Battelle Corporation–Russell Sirabian
- Booz Allen & Hamilton–Joann Socash
- Dajak, LLC–Mark Kluger
- Intergraph Corporation–Tanwir Chaudhry
- Mitretek Systems–John Horin, Patricia Reyes
- Northeastern University–Mary J. Ondrechen
- Remedial Operation Group, Inc.–Bud Johnson
- S.S. Papadopoulos and Associates, Inc–Michael T. Rafferty, P.E.
- SRS/Westinghouse–Kevin Brewer

Special thanks goes to the primary authors of this document on Above Ground Treatment Technologies: Chris Hurst, GA DNR, and Dave Becker, USACOE.

Above Ground Treatment Technologies

Introduction

This overview introduces the reader to the basic concepts of optimization of above ground technologies. In 2004, the Interstate Technology and Regulatory Council (ITRC) Remediation Process Optimization (RPO) Team developed a technical regulatory guidance document titled, *Remediation Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation*. Based on feedback to the RPO training and continued research into the topic, the RPO team identified the need for detailed information on optimization of above ground treatment systems. This overview provides a general overview of some common optimization opportunities found for above ground treatment systems for (1) extracted ground water, (2) air sparging/soil vapor extraction (AS/SVE), and (3) multi-phase extraction (MPE). Although there are many areas in which optimization can be applied, this overview will focus only on these three. Figure 1. shows a layout of components of a typical remediation system. It should also be noted that the discussion of extracted ground water is not intended to advocate pump and treat systems, but rather is an acknowledgment that these systems are in existence and are likely candidates for optimization.

This overview is organized according to an identification of the following information: (1) operational information needed to evaluate remedial system performance, (2) general issues that need to be considered when optimizing a system, (3) and common issues and system improvements encountered during optimization studies for each of the three types of remedial systems. Some of the key goals of optimization include reduction in labor costs, increased system reliability, reduction in power consumption, enhanced contaminant capture, and enhanced reduction of contaminant mass.


Figure 1.–Typical Above Ground Treatment Technology

For any of these systems, it is important to take the time to evaluate the conceptual site model and verify if it is accurate and reflective of the actual site conditions and the expected remedial goals. It should be noted that not all systems are the same and thus some optimization techniques will be more effective than others. It is also important to keep in mind the cost of system modifications. Figure 1. is an example of a typical, and very common, above ground treatment system: granulated activated carbon for the treatment of contaminated ground water.

Who We Are and the Intended Audience

The ITRC is a state-led coalition of regulators, industry experts, citizen stakeholders, academics, and federal partners that work to achieve regulatory acceptance of innovative environmental technologies. This coalition consists of 46 states and a network of some 7,500 people who work to break down barriers, reduce compliance costs, and make it easier to use new technologies. Furthermore, ITRC helps maximize state resources by creating a forum where innovative technology and process issues are explored. Together, the team members are building the environmental community's ability to expedite quality decision-making while protecting human health and the environment.

This overview has the following intended audience who are involved in either remediation process (RPO) or PBM of hazardous site remediation projects:

- State and federal regulators
- Facility owners and operators
- Engineers and consultants
- Interested stakeholders

States and federal agencies play multiple roles in the RPO and PBM processes: as regulators and as facility owners and operators when public funds are used to conduct site remediation work. As regulators, state and federal agencies are charged with protecting human health and the environment. Also, facility owners, private or public, have the greatest interest in achieving the goals of the specific site remediation project. In addition, the engineering and consulting community who guide and provide professional opinions to the owners must have a deep working knowledge of techniques that can ensure fast and effective site remediation. Public stakeholders must understand not only technologies to be deployed at sites but the decision-making behind the process in order to be full partners in the clean up.

This overview is part of a five booklet series: *Performance-based Management, Analysis of Above Ground Treatment Technologies, Exit Strategy Analysis, Data Management, Analysis and Visualization Techniques*, and *Life Cycle Cost Analysis*; each is an excellent resource for moving forward on their RPO and PBM projects.

Review of Relevant Operational Information

To evaluate remedial performance, operational information is analyzed and compared with the cleanup criteria established in the Remedial Action (RA) objectives and with cost-to-complete and time data that should be documented in the feasibility or corrective measures study and the decision document. Common information used for performance evaluations includes the following:

- Contaminant concentrations through time in the affected media and the treatment system influent and effluent streams
- Ground water elevations
- Nonaqueous-phase liquid (NAPL) thickness (for fuel-contaminated sites)
- Geochemical parameter concentrations/readings (e.g., dissolved oxygen and other gases, alkalinity, pH, oxidation/reduction potential)
- System operating parameters (e.g., design and actual flow rates, throughput rates, pumping cycles, mass-removal rates, and secondary waste-stream generation
- Operational history (performance problems, basis for and details of any system modifications, notices of violation)

The preceding data are typically analyzed to evaluate remedial performance using several analysis tools:

- Graphs of remedial performance data for each extraction well through time to identify operation and maintenance and remedy issues (e.g., hydrogeological or geochemical/biofouling constraints)
- Potentiometric surface maps under pumping and nonpumping conditions to analyze capture zones and assess containment
- Maps and cross sections illustrating contaminant and geochemical parameter concentrations and distributions through time and space to assess plume dynamics and containment, evaluate natural attenuation processes, identify preferential migration pathways, verify compliance with protective criteria at points of compliance, and document progress toward RA objectives
- Time-series plots of contaminant and geochemical data for each monitoring and extraction
- Evaluation of natural attenuation and mass removal comparisons of treatment system influent and effluent concentrations through time to assess effectiveness (e.g., relative to design expectations), identify asymptotic conditions indicating potential technology limitation for contaminant removal, and assess compliance with discharge requirements
- Consumption of resources including electricity, on-site fuel usage and transportation fuel and simple analytical models to predict future trends and progress based on trends observed to date

For many of these assessments, readily available geographical information system (GIS) software and simple trend-analysis statistical tools are very useful for data visualization and performance assessment; such tools can enhance data analysis capabilities. To assess the effectiveness of a remedial decision, the RPO evaluation typically can be organized into two general assessment areas: performance of remedial components and effectiveness of the monitoring program. More details on these evaluations can be found in the Technical/Regulatory Guideline document entitled *Remediation Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation* (ITRC 2004).

General Issues to Consider

- **Evaluation of Unnecessary or Inefficient Treatment Steps or Equipment**
  The function of each process in the treatment train is evaluated in light of current contaminants concentrations. The RPO analysis typically requires data on the influent, effluent, and intermediate concentrations. The intermediate concentrations should be measured between each process to assess the impact of each and the effectiveness of each piece of equipment should be critically evaluated to determine if it meets current needs. Typically, the original design basis report provides the original rationale for the current process equipment. Often, the concentrations of parameters targeted by specific equipment or processes are less than anticipated in design. This results in either the needlessly continuing use of a process or an unnecessary use of certain pieces of equipment. For example, if influent metals concentrations are at or below the current effluent standards, metals precipitation equipment (e.g., flocculation tank, settling tanks, filter press) may not be needed. If volatile organic compound (VOC) concentrations are lower than the design assumptions, one of two air strippers plumbed in series could be bypassed and the plant would still meet effluent standards. In other cases, the concentrations of parameters following a treatment process may not be adequately reduced or not reduced at the expected efficiency. This may result in the inefficient operation of downstream equipment. As an example, feeding excessive chemicals into a precipitation, flocculation, or clarification unit may result in incomplete settling and carryover of solids into the filtration units that may result in the need for frequent backwash of liquid-phase carbon units.

- **Reduction in Labor Costs**
  An evaluation of the level of staffing provided for the treatment plant should be performed. The level of effort required to operate the treatment system is high at plant startup, but will decrease with time until the plant

equipment begins to fail due to age and usage, at which time the labor requirements will likely rise again. Since the use of automation can decrease the required operating labor, the capital costs for control systems (e.g., computers, programmable logic controllers, automated valves, dedicated communication lines) are generally small in comparison to the labor savings created by greater automation when considering operating periods of many years. The labor requirements can be assessed by either carefully interviewing the current operators about the breakdown of their time (operation, repair and maintenance, sampling, reporting, material and supplies handling and procurement), or by review of detailed cost records for labor. The RPO can potentially substantially reduce labor costs by targeting those processes or activities that account for much of the operator's time for optimization. In this case, a review from a Certified Industrial Hygienist may be of benefit when assessing the role of a part-time or full-time operator. In many cases, the simplification of the treatment processes by the RPO recommendations can reduce the labor costs. Labor for repairs can be reduced by good maintenance, operating only needed equipment, maintaining an adequate spare parts inventory, and timely replacement of aging equipment.

- **Reduction in Power Costs**
  Electrical use is typically strongly related to pump usage, both for ground water and soil vapor extraction and water transfer between above-ground processes. The horsepower of each pump is identified, either through review of design drawings, or more appropriately by recording nameplate information about each major pump. The RPO also records the degree to which each pump is throttled back and the differential pressure required at each pump. These data are very useful for assessing the impact of proposed changes to the treatment processes on electrical use and cost. Alternative process sequencing should be considered to reduce the number of operating pumps. Also, the optimization review should consider the replacement of existing throttled electric pump or blower motors with properly sized units or variable-frequency drive motors that can be operated at lower flows without throttling and are more efficient. Other factors should be noted, such as under-designed piping, plugged filters or vessels, or pipe scaling/fouling that may increase the head against which pumping would be conducted, thus raising the electrical use. Thus, recommendations to reduce these constrictions should be evaluated. Since electricity is also commonly used for space heating and outdoor pipe heat tracing, the need for space heating should be reviewed especially if there is not a freeze risk and if the plant is not manned on a full-time basis.

Furthermore, in a ground water treatment plant, the process tanks filled with relatively cool ground water can provide a moderating influence on plant temperatures. Other electrical equipment can be assessed for need and possible alternatives. The EPA has issued an Engineering Forum Issue Paper entitled *Introduction to Energy Conservation and Production at Waste Cleanup Sites*, (USEPA 2004). The paper provides a general checklist for conducting an energy audit at cleanup sites.

- **Modification to Treatment Process Monitoring**
  There usually are rigorous requirements for sampling influent and effluent from the treatment system, including analytes and sampling frequency. Other samples are taken at intermediate locations within the treatment train to support decisions on plant operations. An assessment of the need for the sampling and analysis in light of the project-specific objectives should be performed. The EPA Data Quality Objective Process (USEPA 2000) or the USACE Technical Project Planning Process (USACE 1998) provides an excellent framework for assessing the sampling program in light of the decisions that will be made. Only data that meets the needed quantity (sample frequency and location) and quality should be collected. Intermediate sampling should only be conducted if needed to maintain or optimize specific treatment processes. The optimization review should carefully consider the frequency, location, and list of analytes for intermediate sampling since fixed-laboratory quality data is not always needed for treatment operations. Alternatives may include on-site test kits (e.g., immunoassays or Hach kits) or meters measuring indicator parameters such as total organics (e.g., total organic carbon (TOC) monitors, organic vapor monitors). For time-critical and frequent effluent or emission data, on-site analytical equipment, including real-time analyzers and auto-samplers may be appropriate in lieu of quick-turnaround off-site analyses. However, in most cases, such elaborate equipment is unnecessary and it is much more cost-effective to use fixed-laboratory methods. The required sampling program may be open to optimization, especially if there is a large historical database of sampling results. Discharge permit requirements may include analytes that have never been detected over several years of operations. In these cases, the optimization evaluation may suggest the regulatory agency be petitioned to allow dropping the analyses.

- **Reduction in Consumables**
  One of the first items to consider is the potential for replacing equipment such as bag filters with sand filters (although the choice of any equipment should be practical for the application), which do not rely on a consumable product such as a filter bag. Implementation of multi-vessel systems

over a single vessel may extend breakthrough times thus decreasing the consumption of a filter medium, such as carbon. Furthermore, a change in the definition of breakthrough in a multi-vessel system (full breakthrough in lead vessel versus initial detection) could extend the operable life of the filter medium. In addition, a review of the fuel costs (such as propane or natural gas) associated with operating equipment should be performed to determine if a change in fuel or equipment could result in decreased fuel consumption and/or costs. The dosage of chemical additives should be evaluated to determine if they can be decreased or be adjusted based on varying contaminant concentration. The storage and purchasing of bulk chemicals should be reviewed to see if there are opportunities to minimize costs.

- **Modifications to Disposal Practices**
  There are a number of waste streams that are potentially generated by above-ground treatment processes that require disposal; these include spent carbon, ion-exchange resin, bag filters, sludge (pressed or unpressed), and treated ground water. The disposal costs for these media can be substantial. For example, the sludge may be considered hazardous and require disposal in a RCRA Subtitle C landfill or treated ground water may be discharged to a sanitary sewer at a high unit cost. Alternatives should be reviewed that reduce waste-stream volume and disposal costs and assure that the materials are appropriately disposed. Injection of treated water may be less costly, provided adequate consideration is given to maintenance costs for injection wells or trenches. Surface water discharge may be an alternative, but the administrative costs for obtaining a permit (or for filing a permit equivalent) must be considered, as must costs for necessary streambed modifications or hydraulic studies. Injection of treated water may be a way to preserve ground water in areas of scarce water resources. In some cases, the “delisting” of a waste stream such as a sludge, may be appropriate and allow less expensive disposal, but the administrative costs could be substantial. The optimization review may recommend other measures to reduce waste volume, such as substituting a technology that generates only limited volumes of waste for one that generates a great deal.

- **Need to Coordinate Changes in Above-Ground and Subsurface Operations**
  Since the changes discussed above cannot be made in isolation, the relationship of the above-ground and subsurface modifications is considered by the individual(s) performing the optimization effort. Sometimes the changes in the subsurface operations will change flows and concentrations in the influent such that changes to the above-ground equipment

may be unnecessary or must be reconsidered. Also, changes to the above ground system may allow changes to the subsurface operations that couldn't previously be considered (improved capacity, etc.). These considerations are site-specific.

Common Optimization Issues

Groundwater Extraction and Treatment

Based on a large number of optimization studies conducted at a variety of ground water contamination sites, there are a number of common issues that require consideration during an optimization effort. An EPA fact sheet on the effective management of pump and treat systems is available at the CLU-IN website (http://clu-in.org/download/remed/rse/factsheet.pdf) that covers these topics in more detail.

- **Metals precipitation systems**
  Many ground water treatment systems were designed to include metals precipitation either based on the need to treat site metal contaminants or to remove metals such as iron and manganese prior to other treatment processes (e.g., air stripping) where iron scaling may reduce treatment effectiveness or increase maintenance costs. The need for these systems has been often based on monitoring well samples that may have yielded turbid water during sampling. In many cases, the plant influent concentrations of metals are never near the design values. Continued operation of the metals precipitation processes has contributed to unnecessary costs for consumables such as polymers, caustic, etc. as well as to labor costs. Therefore, systems with metals precipitation equipment should be carefully evaluated and consideration given to elimination of the process or replacement of the equipment with other means to achieve the same end.

- **Redundancies in processes**
  Systems with equipment such as air strippers plumbed in series, multiple filtration steps, or carbon polishing following other treatment may be candidates for optimization. The intermediate sampling results must be examined to determine if the redundancy is needed. One air stripper may be adequate, or carbon alone may be all that is needed.

- **Lower than expected flows and concentrations**
  In many cases, ground water treatment systems have been run at rates and concentrations less than those assumed in design. Lower flow rates often result in throttled or cycling pumps and energy inefficiency. The plant may be operated in batch mode, but this may increase maintenance costs if periods of zero flow degrade the performance of the equipment.

The replacement of throttled pumps with pumps driven by variable-frequency drive motors should be considered. Re-circulation of some treated water may allow constant operations. Lower concentrations may allow the cessation of certain processes, or the reduction in certain chemical feed flows. The fundamental task for the optimization effort is to assess needed changes to match the plant operation to the influent flow and concentration in lieu of operation according to the original design.

- **Carbon adsorption management**
  The optimization effort may evaluate the handling of carbon adsorption processes. This may include the analysis of the economics of alternative carbons, including using regenerated carbon instead of virgin carbon. The definition of "breakthrough" for purposes of ordering carbon changes is also assessed to assure the adsorptive capacity of the carbon is fully used. For many contaminants, the change of the lead carbon may be done near the point of full breakthrough (discharge concentrations is almost the same as the inlet concentrations). Other contaminants may require earlier change out to avoid unacceptable breakthrough of the lag vessel or the use of three carbon vessels in series. Finally, the basis and means for conducting carbon vessel backwashing is assessed. Inappropriate backwashing may accelerate carbon breakthrough.

- **Off-gas treatment**
  At many ground water treatment plants, air strippers and vapor-control systems for process tankage generate an off-gas stream that is treated by thermal oxidation or vapor-phase carbon adsorption. If the influent concentrations were never as high as design values or if the influent concentrations have dropped as the remediation has progressed, the need for the continued treatment of the off-gas should be evaluated. Direct discharge of the off-gas to the atmosphere may be possible. This will involve identification of the acceptable mass loading on the atmosphere and consultation with regulatory agencies and stakeholders. The replacement of thermal oxidation with vapor-phase carbon adsorption may be considered if the contaminant concentrations make the change economical and the sorption characteristics are appropriate.

- **Inadequate maintenance of equipment**
  The optimization review should note the condition of the treatment equipment and verify the amount of effort needed for repair (See Figure 2.). Recommendations for changes to the preventative maintenance schedules can be offered after evaluating the requirements developed in the Operations and Maintenance manuals. This can reduce labor costs (for

overtime and late-night callouts) and reduce plant downtime. A good spare parts inventory may also decrease downtime.


Figure 2. Example of scaling

- **Fouling of Pumps, Well Screens, Piping**
  The subsurface performance of ground-water extraction systems is often degraded by the growth of biomass in the well filter pack, well screen, pumps and piping. Thus, optimization of the system should consider the occurrence of fouling and recommend approaches to dealing with the problems. Also, well rehabilitation may consider the use of organic acids, dispersants, and oxidants as well as mechanical surging and brushing; for instance, pumps would likely require disassembly.

- **Plume Capture**
  The primary subsurface optimization issue for ground water extraction systems is the capture of the contaminant plume(s) which must be adequate in three dimensions. There are a number of lines of evidence for capture zone extent that may be considered in an optimization effort, including chemical concentration trends in wells near and downgradient of the extraction wells, water level contours, and computed or modeled capture zone widths based on estimated hydraulic conductivity values. On this note, there is a forthcoming EPA-sponsored fact sheet (on the assessment of capture zones for extraction wells) that discusses these issues in more detail.

Soil Vapor Extraction/Air Sparging (SVE/AS)

It is important to review the treatment objectives which were originally defined when the SVE/AS system was designed to ensure that they are still applicable and achievable. Many SVE/AS systems have been installed without the degree of subsurface characterization that is required to determine how the subsurface soil geology will impact contaminant recovery. A more complete understanding of site geology and the profile of the contamination (a well-defined Conceptual Site Model) will help to optimize extraction well screen placement. The following issues are some of the routine and common problems associated with SVE/AS systems and optimization efforts that can be taken to address them. One potential resource available for optimization of these systems is the *Engineer Manual on Soil Vapor Extraction and Bioventing* (USACE 2002)

- **Inadequate treatment of the contaminated soil volume**
  One common performance problem is inadequate treatment of the contaminated soil volume. Some of the typical optimization techniques include developing a better understanding of soil moisture conditions and their relationship to ground water, reducing areas of stagnation within the system caused by competing zones of vacuum influence by turning off competing extraction wells or varying extraction rates among neighboring wells, and determining if the presence of a surface cap or cover is preventing flow in the shallow vadose zone, which can be corrected by creating penetrations in the cap. If extracting air at higher rates does not increase the mass removal rate, the system may be moving more air than necessary or if there is evidence of short-circuiting along the well casing or through nearby utility corridors or soil fractures then well replacement or relocation should be considered. Increasing air extraction rates from either targeted wells or adding additional wells to the network to address inadequate airflow in the target zone must be considered. As higher permeability layers clean up, it may be desirable to close off screens open to those units, leaving screens in lower permeability units open for vapor extraction.

- **Submerged Nonaqueouse Phase Liquid (NAPL)**
  Another known problem for SVE/AS systems is the presence of submerged NAPL in the capillary fringe or below the water table. This is indicated by stable ground water concentrations in the source area that seem to be unaffected by mass removal in the unsaturated zone and also by large rebound in concentration at vapor monitoring points located nearest the ground water. Possible optimization efforts may include implementing additional approaches such as bioslurping and multi-phase extraction to treat NAPLs at or just below the water table, in order to dewater the source area see Figure 3. . Dual-phase extraction can be used to treat dense nonaqueouse phase liquid (DNAPLs) below the water table if the soil volume can be effectively dewatered. Also, applying heat to the upper layers of the ground water, in the form of steam injection or resistive heating, can create steam from the ground water, which in turn can extract VOCs from the soil.

- **Asymptotic VOC Concentrations**
  If there is a situation in which the trend of VOC concentrations in the extracted gas (either from combined wells or a majority of individual wells) has become asymptotic, then consider whether reduced flows, system pulsing, additional wells, thermal methods, or bioventing may remove source contami-

nant mass. Typical causes for such situations are diffusion limitations, continuing source material, or poor well placement.

- **Varying VOC Concentrations**
  Significant variations in VOC concentrations in the extracted gas may be due to ground water fluctuations, soil moisture changes, or a periodic continuing source. Consider controlling ground water levels, installing a surface cover, or other source removal methods. If total extraction rates have failed to reach the design rates or the rates needed for efficient operation, consider replacing wells, adding wells, rebalancing the air extraction flows through the system, controlling ground water levels, or resizing blowers. Furthermore, if there are very high concentrations of volatiles, at or near explosive levels, then consider adding dilution air, reducing flow from the wells with highest concentrations, or replacing the SVE off-gas treatment with an internal combustion engine (ICE) system.

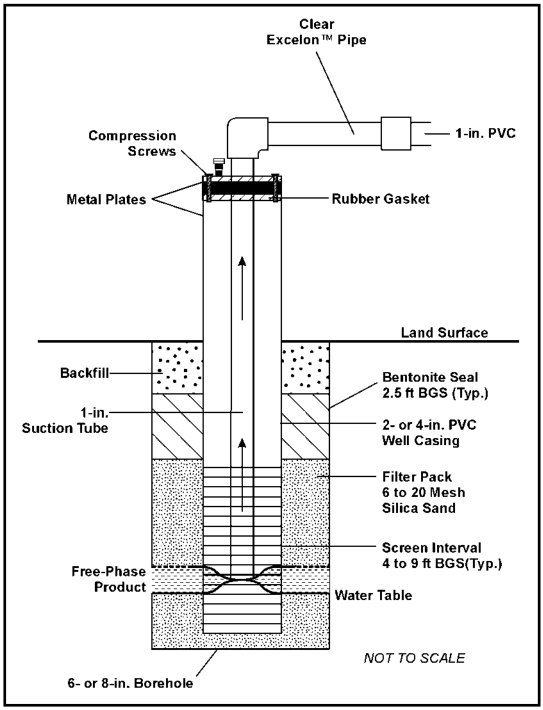


Figure 3. Diagram of Extraction Well

- **Condensate Issues**
  A common problem found in extraction systems is buildup of condensate in the inlet piping, which may cause surges in air flow, low air flow, or restriction of pipe volume due to freezing. The solutions to these problems include sloping the pipelines back to the extraction wells, installing the piping underground to reduce temperature affects, and periodically reversing flow to blow condensate back into the well. Because frequent system shutdowns may be caused by high water levels, options for preventing this would be installing an automatic pump controlled by the liquid level, increasing the capacity of the transfer pump, reducing the vacuum level, and installing either a surface seal or a larger pipe diameter just above the well outlet.

- **Overall System Modifications**
  Other system modifications may include taking the off-gas treatment system off line due to decreased levels of contaminants within the vapor stream or removal of individual wells. There may be cases in which removal of unproductive wells may result in higher airflow capacity through more contaminated parts of the site. Another consideration would be the installation of additional wells or to increase extraction rates from existing well networks so that remediation can be expedited, thus reducing the overall time of system operation. It is always worthwhile to consider other technologies, which may be able to achieve the remedial objectives but at a reduced time of operation and reduced cost. Some examples of additional technologies to consider are: multi-phase extraction; soil excavation; bioventing; soil fracturing, and thermal enhancement. Finally, it is important to consider if the SVE operation itself is still necessary based on the concentrations of the remaining contaminants. Even if the remedial goals have not yet been met with SVE, it may be prudent to turn off the SVE system and allow monitored natural attenuation to complete cleanup while remaining protective of human health and ecological receptors.

Multi-Phase Extraction

This is an in-situ technology also referred to as two-phase extraction and bioslurping that combines vacuum-assisted free product recovery with bioventing and soil vapor extraction. Multi-phase extraction (MPE) thus simultaneously recovers free-product or light non-aqueous phase liquids (LNAPL) from the water table and capillary fringe while promoting aerobic bioremediation and stripping of hydrocarbons in the vadose zone of subsurface soils. This is typically accomplished by the use of a drop tube positioned in a well so the end of the tube is at or just above the water-LNAPL interface. A vacuum is applied to the drop tube using a vacuum blower to simultaneously extract ground water, LNAPL and soil vapor. The aboveground components must be capable of generating a moderate to high vacuum, separating mixtures of contaminated ground water, LNAPL, and VOC laden soil vapor and treating ground water and soil vapor to appropriate limits. Issues that arise during the operation of MPE systems and how these can be addressed are discussed below.

- **Fluid extraction**
  MPE relies on the ability of a mechanical device to generate a sufficient vacuum and volumetric flow rate to induce the extraction of liquids and vapor and to propagate a pneumatic response in the unsaturated zone. LNAPL recovery tends to increase as the extraction vacuum is increased.

However, water recovery also increases at higher vacuum rates. Hence, the overall cost per gallon of LNAPL recovered may be greater at higher vacuums. In addition, overdrawing from an extraction well could cause the LNAPL layer to become discontinuous, which then decreases the further movement of LNAPL towards the extraction well. At each site, there is the need to make adjustments and monitor performance to optimize the vacuum under which the system is operated to maximize LNAPL recovery while minimizing water recovery.

Issues that often arise that limit the effectiveness of MPE include: a) insufficient vacuum in drop tube to lift water and LNAPL, b) insufficient vacuum response in formation to induce fluid flow and increase oxygen content in the formation, and c) high downtime.

a) Insufficient vacuum in drop tube to lift water and LNAPL
Various types of mechanical devices are available to induce a vacuum. Commonly used devices in the environmental industry include: regenerative blowers, positive displacement blowers (i.e., rotary lobe or rotary vane), and liquid ring vacuum pumps (LRPs). Regenerative blowers are generally not applicable to MPE because the vacuum level generated is often insufficient to lift liquids from the formation. Positive displacement blowers can typically operate at a vacuum level of 15 inches mercury (Hg). LRPs can generate the greatest vacuum levels of all available devices, often operating at a vacuum of 29 inches Hg. It is because of this high vacuum capability that LRPs are most widely use for MPE. For tight formations or great depths to ground water, LRPs are recommended. In some cases, depth to water may exceed 33 feet, which is the theoretical maximum vacuum level that can be achieved. In these cases, a column of water or LNAPL may reach the stagnation point inside the drop tube, thereby cutting off the flow of any fluids. To address this issue, a small hole can be drilled in the drop tube at a level above the liquid level in the well. This will allow air to flow into the drop tube, which will break up the static slug. The flow of vapor will then entrain droplets of ground water and LNAPL, thereby establishing flow of all three fluids. Alternately, adjusting the setting of the drop pipe to create the "slurping" of liquids along with the air / vapor mixture can be achieved.

b) Insufficient vacuum response in formation
This is typically not caused by the maximum vacuum capability of the mechanical device but rather the volumetric flow rate the vacuum blower or pump can generate. The flow rate needed is a function of formation characteristics and the number of wells on-line. For high per-

meability formations, a greater flow rate per well is needed in order to induce a vacuum response. If the flow rate is not sufficient, this can be addressed by either increasing the capacity of the system or by reducing the number of wells that are on-line at a given time. For most sites, it is recommended that wells be cycled to reduce the capacity of the above ground devices and to increase operating efficiency by allowing wells to re-equilibrate after an on-line operating period. For high permeability sites, a positive displacement (PD) blower may be more suitable than an LRP as PD blowers can generate a greater flow rate for a given motor size at vacuum levels below 10 inches Hg.

c) High downtime
Preventive maintenance is critical to minimize downtime. In addition, it is important to operate within the recommended operating conditions. This is particularly important for LRPs. If these devices are operated at too low a vacuum, the process oil (required for oil-sealed pumps) can be blown out of the unit, which can then create maintenance issues. For oil-sealed pumps, it is important to ensure that the oil is checked and replaced in accordance with manufacturer recommendations. Also, condensate accumulation in the seal tank can create frequent shutdown conditions if this is not addressed by either: installation of an automated method of removing condensate from the seal tank using a pump and level controls; reducing the vacuum level at the LRP inlet; or for warm weather conditions, reducing the temperature at the LRP inlet by installing manifold piping underground. For water-sealed devices, either a large heat exchanger and/or a continuous supply of water is needed.

- **LNAPL and Water Separation**

In general, LNAPL and water can be separated gravimetrically, however gravimetric separation is often complicated by physical emulsification, chemical emulsification, low differences in specific gravity, and fouling of separation media.

a) Mechanical emulsions can be formed by the high shear and mixing within the drop tube and within the LRP (if process liquids enter the LRP directly) It is preferred to place the vapor/liquid separator before the LRP; however, when this is done the vapor/liquid separation vessel is under a high vacuum and a progressive cavity pump would typically be used to pump liquid from this vessel. The progressive cavity pump, although considered low-shear compared to other devices, would also contribute to mechanical emulsification, see Figure 4. Mechanical emulsifications can be addressed by either over-sizing the gravity separator to increase retention time or by adding a holding tank just prior to the gravity separator (with gravity flow out of the holding tank) to provide time for separation.

b) Chemical emulsification and low differences in specific gravity are less common but can occur at sites where there are mixtures of various contaminants. These issues are more difficult to address and can lead to increased treatment costs. It may be necessary to use chemical treatment combined with dissolved air flotation. This has been found to be effective, but the cost to implement this technology can be high. The use of a dual drop tube design (NFESC, 1998) can reduce the amount of product that needs to be separated from the water by removing product separately in one drop tube while water and vapor are removed in the other. If the quantity of LNAPL is moderate, organoclay filtration has been found to be an effective technology for removal of emulsified product. Organoclay does not rely on gravity separation but rather the adsorption of the oil droplets onto a hydrophobically modified bentonite clay that is supported in an anthracite media. If polishing of the aqueous stream using granular activated carbon (GAC) is required, the use of organoclay is beneficial in protecting the GAC from emulsified product and will extend the life of the GAC.

Figure 4.–Emulsification Tank

c) Fouling of the oil/water separator often becomes an issue with the coalescing medium that is used in many gravimetric separators. To mitigate the impacts of fouling, the medium spacing should be relatively wide and the impact on performance then addressed by over-sizing the unit. In addition, a valve in the effluent can be used to periodically shutdown the effluent and cause an upward flow across the medium to help cleanup accumulated material. Also, the unit can be designed with an air diffuser installed under the medium to allow periodic air sparging to be used to cleanout the media.

d) Vapor Treatment

The off-gas treatment of an MPE system is an important aspect in designing and operating the extraction system effectively. In some instances, off-gas treatment may not be required if the concentrations of contaminants of concern (COCs) have low volatility and thus are present at low concentrations in the off-gas. However, MPE is often used to remediate site contaminated with LNAPLs that contain a high fraction of highly volatile compounds, such as benzene; hence, vapor treatment is needed. In designing an MPE system, it is important to note that the concentrations of VOCs in the off-gas are significantly greater during initial operation compared to the later phases of operation. Thus, vapor phase GAC may not be a cost-effective choice during the beginning of operation. In some cases, the concentration is so high that a thermal oxidizer is the most appropriate choice. At these sites, it is important to address the changes that occur during the life-cycle operation of the MPE system. This can be addressed by first using a thermal oxidizer that can be modified later to operate catalytically once concentrations have decreased to a certain level and then have a transition plan to switch to GAC at the appropriate time and then to switch to direct discharge once treatment is no longer necessary.

If vapor phase GAC is used, proper conditioning of the vapor entering the GAC is an important consideration. Vapors from the LRP tend to be warm and moist, which are conditions that are not favorable for vapor-phase GAC and can cause inefficient use of the GAC media. To increase efficiency, the vapors should be cooled which will cause moisture drop out of the vapor stream and then partially reheated to reduce the relative humidity.

Conclusions

Although the focus of this overview was limited to the topics of treatment of extracted ground water, soil vapor extraction/air sparging, and multi-phase extraction, there are many other areas in which optimization efforts may be taken. The general issues discussed at the beginning of this overview can be carried over to other technologies and there are many resources available to assist in properly optimizing a treatment system. For more information on the overall optimization process, the document *Technical and Regulatory Guideline for Remedial Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation* (ITRC 2004) is recommended.

References

Interstate Technology Regulatory Council. 2004. *Technical and Regulatory Guideline for Remedial Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation*

Naval Facilities Engineering Service Center. 1998. *Application Guide for Bioslurping, Volume II, Principles and Practices of Bioslurping*, TM-2301-ENV.

United States Army Corps of Engineers. 1998. *Technical Project Planning (TPP) Process*, EM 200-1-2. Available on the internet at http://www.usace.army.mil/inet/usace-docs/eng-manuals/em200-1-2/toc.htm.

United States Army Corps of Engineers. 2002. *Engineering and Design-Soil Vapor Extraction and Bioventing*, EM 1110-1-4001.Available on the internet at http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4001/toc.htm.

United States Environmental Protection Agency. 2000. *Guidance for the Data Quality Objectives Process*, EPA QA/G-4, EPA/600/R-96/055. Available on the internet at http://www.epa.gov/quality/qs-docs/g4-final.pdf.

United States Environmental Protection Agency. 2004. Introduction to Energy Conservation and Production at Waste Cleanup Sites, *Engineering Forum Issue Paper*, EPA 542-S-04-001. Available on the Internet at http://www.epa.gov/tio/tsp/download/epa542s04001.pdf.)

Resources

Interstate Technology Regulatory Council. 2005. *Technical and Regulatory Guideline for In Situ Chemical Oxidation of Contaminated Soil and Groundwater*. 2nd Edition.

United States Air Force Environmental Restoration Program. 1999. *Remedial Process Optimization Handbook.*

United States Air Force Environmental Restoration Program. 2001. *Guidance on Soil Vapor Extraction Optimization.*

United States Army Corps of Engineers. 1999. *Multi-Phase Extraction, Engineering and Design*, EM 1110-1-4010.

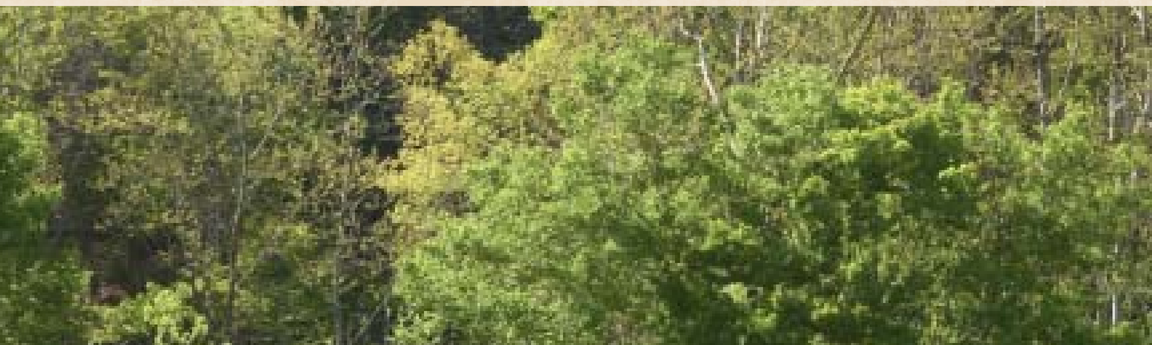
United States Environmental Protection Agency. 2002. *Elements for Effective Management of Operating Pump and Treat Systems.* 542-R-02-009, OSWER 9355.4-27FS-A.

United States Environmental Protection Agency. 2005a. *Cost-Effective Design of Pump and Treat Systems.* OSWER 9283.1-20FS, EPA 542-R-05-008.

United States Environmental Protection Agency. 2005b. *Effective Contracting Approaches for Operating Pump and Treat Systems.* OSWER 9283.1-21FS, EPA 542-R-05-009.

United States Environmental Protection Agency. 2005c. *O&M Report Template for Ground Water Remedies (With Emphasis on Pump and Treat Systems).* OSWER 9283.1-22FS, EPA 542-R-05-010.

www.itrcweb.org



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