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Project Summary

Assessing UST Corrective Action Technologies: Diagnostic Evaluation of *In situ* SVE-Based System Performance

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The objective of the report summarized here is to present the data, methods, and tools required for evaluating the performance of *in situ* systems for cleaning up leaking underground storage tanks sites. Soil vapor extraction (SVE), *in situ* air sparging (IAS), bioventing and intrinsic biodegradation are *in situ* corrective action technologies that are being proposed and installed at an increasing number of underground storage tank (UST) sites that are contaminated with petroleum products. It is often difficult to accurately assess the performance of these systems for remediating soils and groundwater. This is due in part to the complexity and heterogeneous nature that exist in the subsurface at each site. In response to the need for accurate tests and tools for evaluating the appropriate application and remediation performance of these corrective action technologies, the U.S. Environmental Protection Agency (EPA) Office of Research and Development National Risk Management Research Laboratory (NRMRL) provided technical support to EPA regions for evaluating *in situ* corrective action technologies.

This Project Summary was developed by EPA's National Risk Management Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The five test procedures presented herein can be used as diagnostic tools to evaluate *in situ* remediation performance. Three of the procedures (SVE air flow, IAS air recovery, and IAS air distribution) are tracer tests that can be used to evaluate air flow in the subsurface. The tracer tests are new procedures that have been tested at a small number of sites and can be expected to undergo revisions to improve their diagnostic capabilities. The other two procedures (bioventing and natural attenuation) are designed to evaluate biodegradation in the subsurface. These procedures have been demonstrated at a much larger number of sites and are therefore likely to require fewer changes.

SVE Air Flow Tracer Tests

SVE is a remediation technique that has been demonstrated to effectively remove volatile contaminants from a wide variety of soil types. In many cases, SVE has sufficiently remediated sites to allow their closure. In other cases, however, remediation has proved difficult. The reason for failure in these cases can often be traced to nonuniform air flow due to soil characteristics (heterogeneity, high water content, etc.). The procedures described in this section of the manual provide a means of assessing air flow pathways and, as a consequence, evaluating the remediation performance using SVE.

At most sites where SVE and/or bioventing using vapor extraction (BV) is used, it is difficult to relate measured soil vacuum data to the air flow field. Vacuum data are frequently used to define the radius of influence; however, the vacuum data do not provide much insight into the structure of the soil or the airflow pathways through the soil. Vacuum data tend to present a picture of the flow field that is much more uniform than is generally the case. Small strata of lower or higher permeability can have profound effects on flow patterns, and these effects may not be reflected in the vacuum data. At many sites, there is more flow from the surface than is commonly assumed, and at many sites there is less flow near the water table than is commonly assumed. As a consequence, at many sites the time required for soil cleanup using SVE/BV is much longer than predicted, based on simple calculations or analytical models.

Tracer tests to directly measure the air flow field are easy to perform and have the potential to significantly improve the conceptual model of how air is actually flowing at a site. Both naturally occurring and introduced compounds can be used as tracers. Oxygen and carbon dioxide concentrations can be used to assess where air is flowing in the subsurface. Inert gases such as helium or sulphur hexafluoride can be injected into the subsurface and tracked *in situ* and in SVE/BV off-gas.

IAS Air Recovery Tests

IAS is a groundwater remediation technique in which air is injected directly into a water-saturated medium to remove contaminants by volatilization and to enhance aerobic degradation. IAS is used both to remediate aqueous groundwater plumes and to treat sources that contain nonaqueous-phase liquids (NAPLs).

To prevent off-site migration of vapors during IAS, combined IAS/SVE systems are often designed in such a way that extracted air flow exceeds air injection by some multiplicative factor (e.g., 5X). In addition, to demonstrate that the design is working, soil gas vacuum surveys in the vicinity of the IAS/SVE system are usually conducted. It is generally concluded that if no pressures greater than ambient are observed, all of the IAS air is being captured by the SVE system. However, it is generally difficult to relate vacuum data to recovery of IAS air. This is the case because numerous potential air flow patterns in the groundwater zone can exist. For example, if IAS air is injected into sand below a continuous clay layer, the air may move laterally beyond the radius of influence of the SVE well before it has the opportunity to reach the water table. In this case, the sparge air might not be captured by the SVE system.

The previous example implies that under some circumstances pressure measurements alone will not conclusively demonstrate that IAS air is being captured. As a consequence, it is important to conduct tests that can unambiguously determine if all of the IAS air is being captured by the SVE system.

The principle underlying the tracer recovery tests is simple. A tracer (e.g., helium) is injected along with the IAS air into the subsurface at a known rate and the rate of recovery at the SVE system is calculated from the observed tracer concentration in the SVE effluent and the SVE flow rate.

IAS Air Distribution Tests

IAS air flow tests are conducted by injecting a gas-phase tracer, such as SF6, along with the IAS air and determining the distribution of tracer in the subsurface by collecting water samples from discrete locations and depths and determining the concentration of the tracer in the water. In the approach described in this manual, tracer can be injected for a period of one week, followed by groundwater sampling in the vicinity of the IAS well.

Vertical groundwater profiling (VGP) is a technique that allows water samples to be collected at a number of discrete depths in the subsurface. It is generally accomplished by driving a small (e.g., 1-inch) -diameter pipe into the ground. The leading edge of the pipe usually consists of a drive point followed by a screened interval through which water can be drawn. The pipe assembly can be advanced by hammering, vibrating, or pushing.

Water samples can be drawn to the surface using a variety of devices. If the water table is within the suction limit, water can be drawn to the surface through a tube connected to a peristaltic pump. If the water table is deeper, a small-diameter bailer or bladder pump may be used. Vertical profiles are generally made at a number of locations and distances around the IAS well to create a three-dimensional picture of the air distribution.

Bioventing Field System Design and Evaluation

Bioventing is a modification of the conventional, gas based soil remediation technology that has been successfully applied and documented for the remediation of hydrocarbon contaminated soils either used alone or for the "polishing" of residual, semivolatile contaminants remaining in soil following high rate SVE. Bioventing entails the use of SVE systems for the transport of oxygen to the subsurface, where indigenous organisms are stimulated to aerobically metabolize contaminants located there. Bioventing systems are designed and configured to optimize oxygen transfer and oxygen utilization efficiency and are operated at much lower flow rates and with significantly different configurations from those of conventional SVE systems.

This evaluation procedure has been developed to provide an integrated approach for the evaluation of air flow/air permeability (characteristics of gas phase remediation systems common to both SVE and bioventing systems), along with biodegradation rates (characteristic of the biologically based bioventing technology) quantified from respiration measurements collected under field conditions for use in the design and evaluation of field-scale in situ bioventing systems. Both air flow data, relating to oxygen supply, and biodegradation rate data, relating to oxygen utilization, are required for the rational design and evaluation of bioventing systems, and both types of data can be collected in the field procedure described in the manual.

The bioventing test procedure presents an approach to the site specific determination of the feasibility of bioventing technology that is integrated with system monitoring and performance evaluation from initial site assessment activities through final confirmatory soil core analyses. The procedure is composed of five phases of activity that include the following:

Assessment of the Potential for Contaminant Biodegradation Under Actual Field Conditions

In this first phase of the procedure respiration gas (O_2/CO_2) characterization is incorporated into conventional soil gas survey activities to detect the magnitude and extent of biological activity, and consequently, oxygen depletion/carbon dioxide enrichment of the soil gas at the site. If bioactivity is evident from soil gas survey results, the next phase of the procedure is carried out.

Assessment of Air Flow and In situ *Respiration Rates Under Actual Field Conditions*

With biodegradation evident at the field site, air flow/air permeability distribution and actual oxygen uptake rates must then be determined. The test procedure describes a combined air flow/tracer-*in situ* respiration test procedure that takes advantage of monitoring probes and subsurface oxygenation provided during the air flow test for collecting site wide respiration data. Procedures are described to reduce the respiration data to generate respiration rates and to assess their statistical significance relative to site background respiration rate levels. Finally, procedures for converting respiration rates into equivalent hydrocarbon degradation rates are provided, along with estimation procedures for the time to site remediation.

Bioventing System Design

Based on air flow and *in situ* respiration rate result, the potential oxygen supply rate (air flow) is matched with the oxygen demand rate (*in situ* respiration rates) in rational bioventing system design. The nature of the respiration rate law observed from the assessment-phase results are used to recommend either a pulse operating mode system (zero order reactions) or continuous mode system (first order reactions) to optimize overall system performance.

Full-Scale System Monitoring and Performance Evaluation

The procedure describes the use of routine shutdown tests to monitor the changes taking place in respiration rates over time as contaminants are removed from the site. These respiration rates are statistically compared to background respiration levels so that when only background activity is detected throughout the site, soil core samples may be taken to confirm system performance.

System Performance Verification

The final phase of the procedure describes the use of soil core samples, collected from locations near those used for initial site characterization based on quarterly *in situ* respiration results, as the ultimate proof that soil remediation has proceeded to the point where site closure is possible.

Evaluation of Natural Attenuation in Groundwater

Natural attenuation is a risk management strategy that invokes intrinsic bioremediation, dilution, dispersion, sorption, and other physical loss mechanisms to control exposure to contaminants and restore the environment.

Intrinsic bioremediation is the preferred term to describe the natural biological processes that lead to contaminant biodegradation (Wiedemeier et al., 1994). Intrinsic bioremediation can occur in any environment that supports microbiological activity; however, the rate of biodegradation may be slow due to the lack of a suitable respiratory substrate (such as oxygen) or inorganic nutrients (such as fixed nitrogen), an extreme pH, low soil moisture, or limited contaminant bioavailability. Accurate delineation of contamination, understanding subsurface conditions and characteristics, and contaminant migration rates and direction are critical for evaluating the success of natural attenuation and for establishing regulatory support for its use at a site.

The procedure presents a logical progression of data collection, evaluation, and interpretation for quantifying and applying natural attenuation. The approach is highlighted in the stepwise process for evaluating, selecting, and monitoring natural attenuation for groundwater remediation presented below:

- Collect and evaluate existing site data.
- Identify exposure points, water use practices, and receptors of the aquifer (RBCA).
- Determine groundwater flow direction, velocity, and distance to nearest receptor.
- Define the risk associated with the current groundwater conditions (RBCA).
- Assess potential for natural attenuation using existing data and preliminary risk evaluation.
- Construct a conceptual model for natural attenuation on site:
  - If preliminary site data provide evidence that natural attenuation is occurring, proceed.
  - If risk of human exposure or further environmental damage is unacceptable or if adequate site data indicate the natural attenuation is not or cannot occur, evaluate other remedial strategies.
- Conduct site characterization to specifically support natural attenuation:
  - Contaminant mass
  - Contaminant concentration
  - Presence of source areas
  - General groundwater monitoring parameters, e.g., electron acceptors, respiration products, pH, alkalinity, etc.
  - Define abiotic mechanisms that result in change in concentration, e.g., dilution, dispersion, dissolution from a source area, retardation, etc.
- Refine the conceptual model, incorporating new site data.
- Determine if supplemental treatment technologies (e.g., NAPL recovery/ source removal) are required to ensure successful and expedient natural attenuation.
- Project performance of natural attenuation using analytical or numerical methods.
  - Analytical modeling includes the application of the calculations presented in this document and other emerging analytical approaches such as multivariate statistical analysis.
- Compare natural attenuation model predictions with long-term risk:
  - If risk is acceptable, proceed.
  - If risk is unacceptable, evaluate a more protective remedial strategy.
- Develop a long-term monitoring plan:
  - Revise attenuation model as data become available.
  - Sample and analyze to verify continuing site remediation.
  - Locate “sentry” wells to delimit the maximum allowable extent of contaminant migration before a contingency plan is executed.
  - Define a contingency plan in case natural attenuation does not meet expectations or otherwise fails to protect human health and the environment.
- Execute monitoring plan:
  - Sample and analyze sentry wells.
  - Sample and analyze groundwater from selected monitoring wells.
  - Evaluate results and compare with expectations.
  - Close site when cleanup goals are reached.
  - Default to contingency if sentry wells become contaminated, or if natural attenuation otherwise fails to protect human health and the environment.

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The complete report, entitled "Assessing UST Corrective Action Technologies: Diagnostic Evaluation of In Situ *SVE-Based System Performance," (Order No. PB96-163597; Cost: $35.00, subject to change) will be available only from:*

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