Soil Vapor Extraction (SVE)

Soil vapor extraction (SVE), also known as "soil venting" or "vacuum extraction", is an *in situ* remedial technology that reduces concentrations of volatile constituents in petroleum products adsorbed to soils in the unsaturated (vadose) zone. In this technology, a vacuum is applied through wells near the source of contamination in the soil. Volatile constituents of the contaminant mass "evaporate" and the vapors are drawn toward the extraction wells. Extracted vapor is then treated as necessary (commonly with carbon adsorption) before being released to the atmosphere. The increased air flow through the subsurface can also stimulate biodegradation of some of the contaminants, especially those that are less volatile. Wells may be either vertical or horizontal. In areas of high groundwater levels, water table depression pumps may be required to offset the effect of upwelling induced by the vacuum.

Application

This technology has been proven effective in reducing concentrations of volatile organic compounds (VOCs) and certain semi-volatile organic compounds (SVOCs). SVE is generally more successful when applied to the lighter (more volatile) products such as gasoline and chlorinated hydrocarbons such as PCE. Diesel fuel, heating oils, and kerosene, which are less volatile than gasoline, are not readily removed by SVE alone. Because almost all petroleum products are biodegradable to a certain degree, these heavier petroleum products may be suitable for removal by bioventing. In-situ heating can be used to enhance the volatility and remediation of these heavier petroleum products (and lighter products) because vapor pressure generally increases with temperature.

SVE is generally not appropriate for sites with a groundwater table located less than 3 feet below the land surface. Special considerations must be taken for sites with a groundwater table located less than 10 feet below the land surface because groundwater upwelling can occur within SVE wells under vacuum pressures, potentially occluding well screens and reducing or eliminating vacuum-induced soil vapor flow. For these cases SVE may be enhanced by use of Electrical Resistance Heating (ERH) to treat the shallow groundwater table. Pilot testing of soil vapor extraction is not always required but can provide important design information.

SVE may also be appropriate near a building foundation to prevent vapor migration into the building. Here, the primary goal may be to control vapor migration and not necessarily to remediate soil.

Operation Principles

In this technology, a vacuum is applied to the contaminated soil matrix through extraction wells which creates a negative pressure gradient that causes movement of vapors toward these wells. Volatile constituents in the vapor phase are readily removed from the subsurface through the extraction wells. The extracted vapors are then treated, as necessary, and discharged to the atmosphere or possibly reinjected to the subsurface (if permitted by applicable state laws).

Some of the factors that determine the effectiveness of SVE are:

- permeability of the soil,
- soil structure and stratification,

- soil moisture, and
- depth to groundwater.

The permeability of the soil affects the rate of air and vapor movement through the soil; the higher the permeability of the soil, the faster the movement and (ideally) the greater the amount of vapors that can be extracted.

Soil structure and stratification are important to SVE effectiveness because they can affect how and where soil vapors will flow within the soil matrix under extraction conditions. Structural characteristics (*e.g.*, layering, fractures) can result in preferential flow behavior that can lead to ineffective or significantly extended remedial times if the Soil Vapor Extraction wells are positioned (screened) so that the induced air flow occurs mainly in higher permeability zones and remediation in lower permeability zones may be neglected. Soil Vapor extraction can also be enhanced in the lower permeability zone by using pneumatic fracturing or other fracturing technologies.

High moisture content in soils can reduce soil permeability and, consequently, the effectiveness of SVE by restricting the flow of air through soil pores. Fine-grained soils create a thicker capillary fringe than coarse-grained soils. Soil Vapor Extraction Pilot Testing should be performed in these types of soils to more accurately determine moisture production rates, as well as the expected radius-of-influence.

SVE is generally not effective in treating soils below the top of the capillary fringe unless water table depression pumps are used to draw down the water table. In the vicinity of the extraction wells the water table responds to the vacuum by rising, or "upwelling", which can cause the well screen to become submerged thereby reducing airflow. Soil Vapor Extraction combined or enhanced by other technologies such as Electrical Resistance Heating (ERH) may be more effective.

System Design

Design Radius of Influence (ROI) is the most important parameter to be considered in the design of an SVE system. The ROI is defined as the greatest distance from an extraction well at which a sufficient vacuum and vapor flow can be induced to adequately enhance volatilization and extraction of the contaminants in the soil. Extraction wells should be placed so that the overlap in their radii of influence completely cover the area of contamination. ROI is typically determined by a soil vapor extraction pilot test.

Fluctuations in the groundwater table should also be considered when designing an SVE system. Significant seasonal. upwelling or daily (tidal or precipitation-related) fluctuations may, at times, submerge some of the contaminated soil or a portion of the extraction well screen, making it unavailable for air flow. This is most important for horizontal extraction wells, where the screen is parallel to the water table surface.

Surface seals might be included in an SVE system design to prevent surface water infiltration that can reduce air flow rates, reduce emissions of fugitive vapors, prevent vertical short-circuiting of air flow, or increase the design ROI. These results are accomplished because surface seals force fresh air to be drawn from a greater distance from the extraction well. If a surface seal is used, the lower pressure gradients result in decreased flow velocities. This condition may require a higher vacuum to be applied to the extraction well.

Pilot studies are an extremely important part of the design phase. Data provided by pilot studies is necessary to properly design the full-scale SVE system. Pilot studies also provide information on the concentration of volatile organic compounds (VOCs) that are likely to be extracted during the early stages of operation of the SVE system.

A pilot test is recommended for evaluating SVE effectiveness and design parameters for any site, especially where SVE is expected to be only marginally to moderately effective. Pilot studies typically include short-term (1 to 30 days) extraction of soil vapors from a single extraction well, which may be an existing monitoring well at the site. However, longer pilot studies (up to 6 months) which utilize more than one extraction well may be appropriate for larger sites. Different extraction rates and wellhead vacuums are applied to the extraction wells to determine the optimal operating conditions.

Vapor concentrations are also measured at two or more intervals during the pilot study to estimate initial vapor concentrations of a full-scale system. The vapor concentration, vapor extraction rate and vacuum data are also used in the design process to select extraction and treatment equipment.

In some instances, it may be appropriate to evaluate the potential of SVE effectiveness using a screening model such as HyperVentilate (EPA, 1993). HyperVentilate can be used to identify required site data, decide if SVE is appropriate at a site, evaluate air permeability tests, and estimate the minimum number of wells needed. It is not intended to be a detailed SVE predictive modeling or design tool.

Advantages and Disadvantages

Advantages	Disadvantages
Proven performance; readily available equipment; easy installation.	Concentration reductions greater than about 90% are difficult to achieve using this technology alone.
Minimal disturbance to site operations.	Effectiveness less certain when applied to sites with low-permeability soil or stratified soils. Requires enhancement.
Short treatment times (usually 6 months to 2 years under optimal conditions).	May require costly treatment for atmospheric discharge of extracted vapors.
Cost competitive: $20-50/ton of contaminated soil.	Air emission permits generally required.
Can be applied at sites with free product, and can be combined with other technologies.	Only treats unsaturated-zone soils; other methods may also be needed to treat saturated-zone soils and groundwater.

References

U.S. Environmental Protection Agency (EPA). 1991a. Soil Vapor Extraction Technology: Reference Handbook. Cincinnati, OH: Office of Research and Development. EPA/540/2-91/003.

U.S. Environmental Protection Agency (EPA). 1991b. Guide for Treatability Studies Under CERCLA: Soil Vapor Extraction. Washington, DC: Office of Emergency and Remedial Response. EPA/540/2-91/019A.

Wisconsin Department of Natural Resources (DNR). 1993. Guidance for Design, Installation and Operation of Soil Venting Systems. Madison, WI: Emergency and Remedial Response Section. PUBL-SW185-93.

Johnson, P.C., Stanley, C.C., Kemblowski, M.W., Byers, D.L., and J.D. Colthart. 1990. A Practical Approach to the Design, Operation and Monitoring of In Situ Soil-Venting Systems. Ground Water Monitoring Review, Vol. 10, No. 2, pp. 159-178.