United States Environmental Protection Agency
Research and Development

Risk Reduction Engineering Laboratory
Cincinnati, OH 45268

EPA/600/S2-89/024 Jan. 1990

EPA

Project Summary

State of Technology Review: Soil Vapor Extraction Systems

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Extracting vapor from soil is a cost-effective technique for the removal of volatile organic chemicals (VOCs) from contaminated soils. Among the advantages of the soil vapor extraction process are that it minimally disturbs the contaminated soil, it can be constructed from standard equipment, it has been demonstrated at pilot- and field-scale, it can be used to treat larger volumes of soil than can be practically excavated, and it has potential for product recovery.

Unfortunately, there are few guidelines for the optimal design, installation, and operation of soil vapor extraction systems. A large number of pilot- and full-scale soil vapor extraction systems have been constructed and studied under a wide range of conditions. The major objectives of the Report summarized here are to critically review available documents that describe current practices and to summarize this information as concisely as possible. A typical vapor extraction system is briefly described, the experience with existing extraction systems has been reviewed, and information about each system is briefly summarized.

Soil vapor extraction can be effectively used for removing a wide range of volatile chemicals over a wide range of conditions. The design and operation of this system are flexible enough to allow for rapid changes in operation, thus optimizing the removal of chemicals. Although a number of variables intuitively affect the rate of chemical extraction, no extensive study to correlate variables to extraction rates has been identified.

This Project Summary was developed by EPA's Risk Reduction Engineering 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 the back).

Introduction

Soils may become contaminated in a number of ways with such volatile organic chemicals as industrial solvents and gasoline components. The sources of contamination at or near the earth's surface include intentional disposal, leaking underground storage tanks, and accidental spills. Contamination of groundwater from these sources can continue even after discharge has stopped because the unsaturated zone above a groundwater aquifer can retain a portion or all of the contaminant discharge. As rain infiltrates, chemicals elute from the contaminated soil and migrate toward groundwater.

Alternatives for decontaminating unsaturated soil include excavation with on-site or off-site treatment or disposal, biological degradation, and soil flushing. Soil vapor extraction is also an accepted, cost-effective technique to remove volatile organic chemicals from contaminated soils. Among the advantages of the soil vapor extraction process are that it minimally disturbs the contaminated soil, it can be constructed from standard equipment, it has been demonstrated at pilot- and field-scale, it can be used to treat larger volumes of soil than are practical for excavation, and it has a potential for product recovery. With vapor extraction, spills can be cleaned up before the chemicals reach the groundwater table. Soil vapor extraction technology is often used with other clean up technologies to provide complete restoration of contaminated sites.

Unfortunately, there are few quidelines for the optimal design, installation, and operation of soil vapor extraction system. Theoretically based design equations defining the limits of this technology are especially lacking. Because of this, the design of these systems is mostly empirical. Alternative designs can only be compared by the actual construction, operation, and monitoring of each design.

A large number of pilot- and full-scale soil vapor extraction systems have been constructed and studied under a wide range of conditions. The information gathered from these experiences can be used to deduce the effectiveness of this technology. One of the major objectives of the Report is to review available reports describing current practices critically and to summarize this information as concisely as possible. A brief description of a typical vapor extraction system is presented. The experience with existing extraction systems has been reviewed, and information about each system is briefly summarized in a standard form. The information is further summarized in several tables, which form the bases for a discussion of the design, installation, and operation of these systems. Because soil vapor extraction is a relatively new soil remediation technology, this Technology Review document will evolve as more information becomes available.

Process Description

A soil vapor extraction, forced air venting, or in situ air stripping system (Figure 1) revolves around the extraction of air containing volatile chemicals from unsaturated soil. Fresh air is injected or flows into the subsurface at locations around a spill site, and the vapor-laden air is withdrawn under vacuum from recovery or extraction wells.

System Components

Extraction wells are typically designed to fully penetrate the unsaturated zone to the capillary fringe. Extraction wells usually consist of slotted elastic pipe placed in permeable packing.

System Operations

During remediation, the blower is turned on and the air flow through the soil comes to an equilibrium. The flows that are finally established are a function of the equipment, the flow control devices, the geometry of well layout, the site characteristics, and the air permeability of the soil. At the end of operation, the final distribution of VOCs in the soil can be measured to ensure decontamination of the site. Wells may be aligned vertically or horizontally. Vertical alignment is typical for deeper contamination zones and for residue in radial flow patterns. If the depth of the contaminated soil or the depth to the groundwater table is less than 10 to 15 ft, it may be more practical to dig a trench across the area of contamination and install horizontal perforated piping in the trench bottom rather than to install vertical extraction wells. Usually several wells are installed at a site.

System Variables

A number of variables characterize the successful design and operation of a vapor extraction system: site conditions, soil properties, control variables, response variables and chemical properties. The specific variables belonging to these groups include:

Site Conditions: distribution of VOCs, depth to groundwater, infiltration rate, location of heterogeneities, temperature, atmospheric pressure.

Soil Properties: permeability, porosity, organic carbon content, soil structure, soil moisture characteristics, particle size distribution.

Control Variables: air withdrawal rate, well configuration, extraction well spacing, vent well spacing, ground surface covering, inlet air VOC concentration and moisture content, pumping duration.

Response Variables: pressure gradients, final distribution of VOCs, final moisture content, extracted air concentration, extracted air temperature, extracted air moisture, power usage.

Chemical Properties: Henry's constant, solubility, adsorption equilibrium, diffusivity (air and water), density, viscosity.

Well Design and Placement

Well spacing is usually based on some estimate of the radius of influence of an individual extraction well. In the studies reviewed, well spacing has ranged from 15 to 100 ft. Well spacing should be decreased as soil bulk density increases or the porosity of the soil decreases. One of the major differences noted between systems was the soil boring diameter. Larger borings are preferred to minimize extracting liquid water from the soil.

In the simplest soil vapor extraction systems, air flows to an extraction well from the ground surface. To enhance air flow through zones of maximum contamination, it may be desirable to include air inlet wells in the installation. These injection wells or air vents, whose function is to control the flow of air into a contaminated zone, may be located at numerous places around the site. Typically, injection wells and air vents are constructed similarly to extraction wells. In some installations, extraction wells have been designed so they can also be used as air inlets. Usually, only a fraction of extracted air comes from air inlets. This indicates that air drawn from the surface is the predominant source of clean air.

One study investigated the effects of air-flow rate and the configuration of the inlet and extraction wells on gasoline recovery from an artificial aquifer. It was determined that screening geometry only had an effect at the low air-flow rates. At low flow rates, higher recovery rates resulted when the screen was placed near the water table rather than when the well was screened the full depth of the aquifer.

Woodward-Clyde made a similar assessment at the Time Oil Company site. Their engineers suggested that wells should be constructed with approximately 20 ft of blank casings between the top of the screen and the soil surface to prevent the short circuiting of air and to aid in the extraction of deep contamination. At most sites, the initial VOC recovery rates were relatively high then decreased asymptotically to zero with time. Several studies have indicated that intermittent venting from individual wells is probably more efficient in terms of mass of VOC extracted per unit of energy expended. This is especially true when extracting from soils where mass transfer is limited by diffusion out of immobile water. Optimal operation of a soil vapor extraction system may involve taking individual wells in and out of service to allow time for liquid diffusion and to change air flow patterns in the region being vented. Little work has been done to study this.

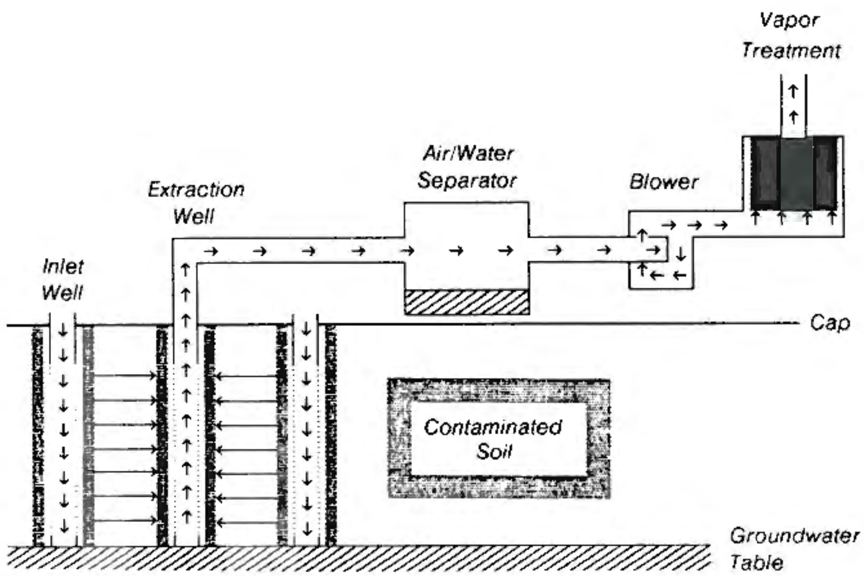

Figure 1. *Soil vapor extraction system.*

One of the major problems in the operation of a soil vapor extraction system is determining when the site is sufficiently clean to cease operation.

The design and operation of soil vapor extraction systems can be quite flexible; changes can be made during the course of operation with regard to well placement, or blower size, or air flows from individual wells. If the system is not operating effectively, changes in the well placement or capping the surface may improve it.

Conclusions

Based on the current state of the technology of soil vapor extraction systems, the following conclusions can be made:

1. Soil vapor extraction can be effectively used for removing a wide range of volatile chemicals in a wide range of conditions.
2. The design and operation of these systems is flexible enough to allow for rapid changes in operation, thus, optimizing the removal of chemicals.
3. Intermittent blower operation is probably more efficient in terms of removing the most chemical with the least energy.
4. Volatile chemicals can be extracted from clays and silts but at a slowerrate. Intermittent operation is cer-tainly more efficient under these conditions.
5. Air injection has the advantage of controlling air movement, but injection systems need to be carefully designed.
6. Extraction wells are usually screened from a depth of from 5 to 10 ft below the surface to the groundwater table. For thick zones of unsaturated soil, maximum screen lengths of 20 to 30 ft are specified.
7. Air/water separators are simple to construct and should probably be installed in every system.
8. Installation of a cap over the area to be vented reduces the chance of extracting water and extends the path that air follows from the ground surface, thereby increasing the volume of soil treated.
9. Incremental installation of wells, although probably more expensive, allows for a greater degree of freedom in design. Modular construction where the most contaminated zones are vented first is preferable.
10. Use of soil vapor probes in conjunction with soil borings to assess final clean up is less expensive than use of soil borings alone. Usually a complete materials balance on a given site is impossible because most sites have an unknown amount of VOC in the soil and in the groundwater.
11. Soil vapor extraction systems are usually only part of a site remediation system.
12. Although a number of variables intuitively affect the rate of chemical extraction, no extensive study to correlate variables to extraction rates has been identified.

The full report was submitted in partial fulfillment of Cooperative Agreement No. CR-814319-01-1 by Michigan Technological University under the sponsorship of the U.S. Environmental Protection Agency.

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The complete report, entitled "State of Technology Review: Soil Vapor Extraction Systems," (Order No. PB 89-195 184/AS; Cost: $15.95, subject to change) will be available only from:
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