Minnesota Pollution Control Agency
Voluntary Investigation and Cleanup

Guidance Document #17

Design Criteria and Reporting Requirements (Vapor Extraction, Air Sparging)

1.0 Purpose

This document provides a brief description of soil vapor extraction (SVE) and air sparging technologies, discusses their potential use and feasibility, and outlines minimum design and reporting requirements for SVE and air sparging systems installed at VIC Program sites.

2.0 Objectives

The objectives of this document are:

- to provide guidance on determining the appropriateness of SVE and air sparging systems for a site;
- to provide guidance on the design of SVE and air sparging systems;
- to provide guidance on report submittals for projects utilizing SVE and air sparging systems;
- to minimize MPCA staff time spent on review of documents submitted by the voluntary party; and
- to promote consistency for sites using these technologies within the VIC Program.

3.0 Application of SVE and Air Sparging Systems

SVE is an effective remediation technology for the removal of volatile organic compounds (VOCs) from soil. SVE systems use blowers or vacuum pumps connected to vapor extraction wells to apply a vacuum to the unsaturated zone. The applied vacuum effectively increases the flow of air through the unsaturated zone, enhancing volatilization of VOCs from the soil matrix and transferring the VOCs to the surface via extraction wells. Given the right site conditions, this technology offers a cost effective method for the removal of soil contaminants, thereby reducing or eliminating further leaching of VOCs to ground water.

Air sparging removes VOCs from ground water by injecting air into the saturated zone (sparging). The injected air enhances volatilization of VOCs from ground water and increases dissolved oxygen concentration, which may enhance naturally occurring biodegradation processes. Air sparging systems are always used in conjunction with SVE systems so that VOCs transferred from the saturated zone to the unsaturated zone by air sparging are captured and removed by the SVE system. Air sparging is an attractive remediation technology because, like SVE, it is relatively simple to implement and features fairly modest capital costs compared to other, more complex remediation technologies.

3.1 Site Suitability for SVE and Air Sparging Systems

Site characteristics suitable for the implementation of an SVE or air sparging response action include the following:

- permeable soils to allow vapor flow through the subsurface;
- homogeneous stratigraphy to allow upward movement of vapors to extraction wells and to avoid uncontrolled horizontal migration of vapors;
- soils that feature low to moderate organic matter content, thereby minimizing retention of VOCs in the soil matrix by adsorption;
- ground water table depth greater than five feet to minimize short circuiting of surface air to the extraction wells;
- minimal seasonal ground water fluctuation; and
- contaminants of sufficient volatility to ensure removal by SVE or air sparging systems. As a general guideline, SVE or air sparging is most effective for contaminants with vapor pressures greater than 1 mm Hg and Henry's Law Constants greater that 0.01 (dimensionless).

4.0 Soil Vapor Extraction: Minimum Design and Reporting Requirements

Phase I and II Investigation activities need to be completed prior to commencing detailed design of any remediation system. In particular, the horizontal and vertical extent of soil contamination must be delineated and the site stratigraphy must be characterized prior to initiating the design process for a SVE system. A SVE pilot test is needed in order to obtain the data required to design an effective full scale SVE system. For sites in the VIC Program, a pilot test must be conducted unless it can be shown, to the satisfaction of MPCA project staff, that sufficient data already exist to design a successful system.

The following list describes the reports that should be submitted to the MPCA and the chronology of their submittal, when SVE has been selected as a likely remediation technology for a site.

1. It is recommended that a pilot test design proposal, as outlined in Section 4.1, be submitted to the MPCA for review and approval prior to implementation.

2. The results of the pilot test should be submitted as a pilot test report, as outlined in Section 4.1, for review by MPCA staff before implementation of the final, full-scale SVE system. The pilot test report may be submitted in tandem with the full-scale design proposal, either as part of a Focused Feasibility Study (FFS) or within a Response Action Plan (RAP).

3. A full-scale design proposal, as described in Section 4.2, should be submitted to the MPCA for review prior to installation and operation of the system.

4. It is recommended that a letter of notification be submitted to the MPCA after the system is operating. This letter should include preliminary operation data and should assess the need for emission controls.

5. Quarterly monitoring reports should be submitted to the MPCA in letter format and should include cumulative data as described in Section 4.2.

4.1 The SVE Pilot Test

The pilot test should provide reliable data for the final system design in terms of: 1) sustainable airflow rates; 2) anticipated contaminant vapor removal rates; 3) preferred orientation of subsurface airflow; 4) effective radius of influence; and 5) number of vapor extraction wells required. Besides providing data for the design of the full-scale system, a properly conducted pilot test should aid the consultant in determining whether existing time constraints for project closure can be met, given the achievable vapor removal rates.

The SVE pilot test should be conducted as a step test using at least three air flow rate steps. The duration of each step of the test should be at least as long as it takes for the parameters measured at the vacuum monitoring points to reach steady state. While holding the flow rate and vacuum applied at the vapor extraction well constant (frequent measurements should be taken to ensure this condition) pressure measurements should be taken at the extraction well and all soil vacuum monitoring points. Monitoring should be frequent early in the pilot test (every five to ten minutes); the time interval between vacuum readings may increase over the course of the test.

A minimum of one soil vapor extraction well and three vacuum monitoring points, located at varying distances from the extraction well, is recommended for the pilot test. Dedicated soil vapor extraction wells and monitoring points are recommended, however, ground water monitoring wells may be acceptable if their location and construction are appropriate for the site. MPCA approval of the use of ground water monitoring wells for SVE extraction wells or monitoring points will be made on a site-by-site basis. As a general rule, the vacuum monitoring points should be located at five to ten feet, ten to twenty feet, twenty to forty feet and greater than forty feet from the vapor extraction well. The vacuum monitoring points should be installed radially from the vapor extraction well (i.e. 120^o apart) rather than in a line in order to better evaluate potential preferential airflow pathways at the site. If the soil contamination extends through multiple units of varying permeability, each separate stratigraphic unit should be evaluated with its own soil vapor extraction well and three vapor monitoring points.

Field screening for organic vapors should be conducted with a flame ionization detector (FID) or a combination of a photoionization detector (PID) and an explosimeter. During the pilot test, soil gas samples should be collected from the soil vapor extraction well at each flow rate step for potential laboratory analysis. The frequency and number of samples submitted for laboratory analysis should be based on site-specific conditions; however a minimum of one sample, collected from the step having the highest field instrument reading, should be submitted for laboratory analysis. Vapor sampling should be conducted at the vapor extraction point from a sampling port located between the well head and the blower. A tedlar bag, charcoal tube, or a Summa-type canister may be used to collect laboratory samples for VOC, CO_2, and O_2 analyses although the latter is preferred. The analytical method should be approved by the MPCA project technical staff. Draeger tubes are commonly used for measuring CO_2, and may also be acceptable for monitoring VOC concentration with prior MPCA staff review.

If specific minimum reporting requirements cannot be obtained due to site specific conditions this should be explained or discussed with the MPCA project staff.

SVE Pilot Test Proposal – Minimum Submittal Requirements:

1. Narrative describing how the test will be conducted, including the types of data which will be collected, equipment to be used, and the data collection frequency.

2. Figures:
   - Site map drawn to scale illustrating the location of extraction and vacuum monitoring points, zone of soil contamination, location of buildings, paved area and buried utility trenches.
   - Geologic cross-sections of the site showing major geologic features, contaminant distribution, location of extraction wells and vacuum monitoring points; and
   - Construction diagrams of extraction wells and vacuum monitoring points.
   - Construction schematic illustrating the manifold design, including the following elements: pipes, instrumentation, valves, sampling ports and any other components of the pilot test system.

SVE Pilot Test Report – Minimum Submittal Requirements:

1. Narrative discussing field procedures, the results of the pilot test, including determination of the effective radius of influence, and a discussion of contaminant composition and vapor removal rates.
2. Static (pre-test) data:
   - static water level data (to the nearest 0.01 ft.) if monitoring wells are used as vacuum monitoring points or vapor extraction points;
   - soil and air temperature;
   - static pressure (inches H_2O); and
   - atmospheric conditions (pressure and temperature)

3. Test data collected at the extraction point (reported for specified time intervals):
   - air flow rate [standard cubic feet per minute (scfm)];
   - water level elevations to nearest 0.01 ft. (if monitoring well is used);
   - VOC, CO_2 and O_2 concentrations;
   - FID (or PID and explosimeter) measurements;
   - pressure; and
   - soil and air temperature.
4. Test data collected at vacuum monitoring point (reported for specified time intervals):
   - vacuum (inches H_2O); and
   - water level elevation (to nearest 0.01 ft.).
5. Figures:
   - site maps (drawn to scale) illustrating location of source area(s), extraction and vacuum monitoring points, buildings, paved area and utility trenches, extent of soil and ground water contamination, and water table for the day of the pilot test;
   - geologic cross sections of the site illustrating major geologic features, contaminant distribution and location of extraction and monitoring points;
   - as-built diagrams of extraction wells and vacuum monitoring points; and
   - construction schematic illustrating the manifold design, including the following elements: pipes, instrumentation, valves, sampling ports, and any other components of the pilot test system.
6. Graphs:
   - normalized vacuum (monitoring point vacuum/extraction point vacuum) versus distance from the extraction well for each flow rate step (plotted on semi-log paper);
   - applied vacuum (inches H_20) versus air flow (scfm) at the extraction well for each step in the air flow rate;
   - total VOC vapor concentration versus time; and
   - ground water elevation versus time.
7. Appendices:
   - Analytical methods, analytical results, and lab reports.

4.2 The SVE Full Scale System

After completion of the SVE pilot test, a full scale SVE design proposal shall be prepared and shall include descriptions of the system design, operation and monitoring. This full scale design proposal may be submitted in conjunction with the pilot test report or may be submitted as a RAP. The full scale system should be comprised of a sufficient number of extraction wells to address the entire extent of contamination, based upon the effective radius of influence determined during the pilot test. The need for emission controls shall be evaluated during the first two to three weeks following startup of the full scale system.

If specific minimum reporting requirements cannot be obtained due to site specific conditions this should be explained or discussed with the MPCA project staff.

SVE Full Scale Design Proposal – Minimum Submittal Requirements:

1. Narrative describing the proposed design and implementation of the system, including: blower capacity, air flow rates, estimated duration of treatment, expected mass removal rates, the types of data which will be collected, the data collection frequency, and clean-up goals.
2. Figures:
   - site maps drawn to scale, illustrating location of source area(s), buildings, paved areas and utility trenches, extraction and vacuum monitoring points and associated equipment, estimated radius of influence, soil and ground water contaminant distribution, and ground water elevations;
   - geologic cross-sections of the site showing major geologic features, contaminant distribution, location of extraction wells and vacuum monitoring points;
   - construction diagrams of extraction wells and vacuum monitoring points; and
   - construction schematic illustrating the manifold design, including the following elements; pipes, instrumentation, valves, sampling ports, and any other components of the full scale system.

Full Scale SVE Reporting – Minimum Submittal Requirements

1. Narrative discussing results, field procedures, system operation details, data trends and recommendations.
2. Data collected at extraction point (reported for each specified time interval):
   - air flow rate (scfm);
   - water level elevations to nearest 0.01 ft. (if monitoring wells are used);
   - VOC, CO_2 and O_2 concentrations collected at selected time intervals;
   - FID (or PID and explosimeter) measurements;
   - soil and air temperature; and
   - pressure.
3. Data collected at vacuum monitoring point (reported for each specified time interval):
   - vacuum (inches H_20); and
   - water level elevation (to nearest 0.01 ft.).
4. Figures:
   - site maps (drawn to scale) illustrating location of source area(s), extraction and vacuum monitoring points, extent of soil and ground water contamination, and water table elevation;
   - geologic cross-sections of the site illustrating major geologic features, contaminant distribution and location of extraction and monitoring points;
   - as-built diagrams of extraction wells and vacuum monitoring points (submit with first monitoring report only); and
   - construction schematic illustrating the manifold design, including the following elements: pipes, instrumentation valves, and sampling ports (submit with first monitoring report only).

5. Graphs:
   - vacuum (inches H_2O) and flowrate versus time (scfm versus time) plotted on same graph;
   - VOC removal rate (Kg per day) versus time and cumulative removal rate versus time;
   - VOC composition of exhausted vapors versus time;
   - total vapor concentration (mg/l) versus time; and
   - ground water elevation versus time.
   - vacuum at extraction point (inches H_2O) vs. flow rate (scfm).
6. Appendices
   - Analytic methods, analytical results and lab reports.

5.0 Air Sparging – Minimum Design and Reporting Requirements

The Phase I and Phase II Investigation activities need to be completed prior to commencing detailed design of any remediation system. In particular, the vertical and horizontal extent of soil and ground water contamination must be delineated and the site stratigraphy, permeability and heterogeneity must be characterized prior to initiation of the design process. It is crucial that a pilot test be conducted at each site to assess the feasibility of air sparging and to determine the design parameters for the full scale system unless it can be shown to the satisfaction of MPCA project staff that sufficient data already exist to design the system.

Although air sparging can effectively remediate VOCs in ground water, there are several potential concerns associated with air sparging applications. Utility lines and other backfilled areas can act as preferential flow pathways for the vapors produced by air sparging and may cause uncontrolled vapor migration well beyond the expected zone of influence of the air sparging system. Vapors may accumulate in basements where they may pose a health and/or an explosive hazard.

It is strongly recommended that air sparging only be conducted in conjunction with SVE in order to capture and remove vapors generated by the air sparging system. If this is not to be the case, an explanation must be provided to the MPCA stating why soil venting is not being included in the system design. The vapor extraction system air removal rate should be at least five times greater than air sparging system air injection rate to help ensure that explosive hazards do not develop. Furthermore, during pilot test design, all possible conduits for vapor migration, such as basements, utilities, and backfilled areas, should be identified. All identified receptors should be addressed in the pilot test design and full scale system design. The Site Safety and Contingency Plan should also address the potential for explosive hazard.

An improperly designed air sparging system may cause dissolved contaminants and light non-aqueous phase liquid (LNAPL) free product plumes to spread beyond the initial extent of contamination. The movement of dissolved contaminants beyond the initial extent of the plume is a problem primarily in settings where vertical air flow is restricted.

Consequently, MPCA staff recommend that site stratigraphy be fully characterized prior to initiating the design of the air sparging pilot test or full scale system. Where LNAPL plumes are present, air sparging will be approved only if the proposed system design and operation eliminate the possibility for uncontrolled movement of the LNAPL plume, or if a separate component of the proposed Response Action Plan addresses the removal of the LNAPL plume prior to the implementation of the air sparging system.

The following list describes the reports that should be submitted to the MPCA, and the chronology of their submittal, when air sparging has been selected as a likely remediation technology for a site:

1. It is recommended that a pilot test design proposal, as outlined in Section 5.1, be submitted to the MPCA for review and approval prior to implementation.

2. The results of the pilot test should be submitted as a pilot test report, as outlined in Section 5.1, for review by MPCA staff before implementation of the final, full-scale air sparging system. The pilot test report may be submitted in tandem with the full-scale design proposal, either as part of a Focused Feasibility Study (FFS) or within a Response Action Plan (RAP).

3. A full-scale design proposal, as described in Section 5.2, should be submitted to the MPCA for review prior to installation and operation of the system.

4. It is recommended that a letter of notification be submitted to the MPCA after the system is operating. This letter should include preliminary operation data and should assess the need for emission controls.

5. Quarterly monitoring reports should be submitted to the MPCA in letter format and should include cumulative data as described in Section 5.2.

5.1 The Air Sparging Pilot Test

A pilot test will provide the data necessary to assess the feasibility of air sparging and to determine the design parameters for the full scale system. Except in rare circumstances, an air sparging system must be run in conjunction with an SVE system. It is recommended that the SVE pilot test be conducted first. Once the SVE pilot test is completed, the SVE system should be shut down and the air sparging pilot test should be conducted in isolation from the SVE system in order to collect data specific to the air sparging system design. This section of the guidance document explains the types of submittals expected for the air sparging portion of the pilot test; Section 4.1 explains the types of submittals expected for the SVE pilot test.

It is generally recommended that the air sparging test be conducted as a step test and that a minimum of three air flow rates be tested. MPCA staff recommends that the pilot test consist of a minimum of one sparge point and three monitoring wells located at various distances from the sparge point. If water table monitoring wells are already present at the site, they may be used as part of the monitoring network for the air sparging pilot test if their distance and azimuth from the sparge point is appropriate for the test and if the screened intervals are appropriate. It is imperative that all possible conduits for vapor migration be identified and that vapor monitoring points be installed to identify vapor impacts associated with the conduits. All nearby basements should be assessed and monitored before and after pilot test start-up with a FID or a combination of a PID and an explosimeter. If vapors are detected in a basement, the test should stop immediately and the MPCA project staff should be notified.

If the minimum reporting requirements cannot be obtained due to site specific conditions this should be explained to, or discussed with, the MPCA project staff.

Air Sparging Pilot Test Proposal – Minimum Submittal Requirements:

1. Narrative describing how the test will be conducted, what air flow rates will be employed, the duration of the test, the types of data which will be collected, and the frequency of data collection.
2. Figures:
   - site maps, drawn to scale, illustrating the location of source area(s), injection points, monitoring points, buildings and paved areas, all possible conduits for vapor migration (basement, utility lines, backfilled areas), ground water elevation, and soil and ground water contamination distribution;
   - cross-section(s) of the proposed sparging area showing major geologic features, contaminant distribution, and location of injection and monitoring points;
   - air injection and monitoring point construction diagrams;
   - construction schematic illustrating the manifold design, including the following elements: pipes, instrumentation, valves, sampling ports, and any other components of the pilot test system.

Air Sparging Pilot Test Report – Minimum Submittal Requirements:

1. Narrative describing field procedures and the outcome of the test, including a description of how the effective radius of influence was estimated.
2. Static (pre-test) data collected at the injection point:
   - static water level; and
   - dissolved oxygen in mg/l.
3. Static (pre-test) data collected at the monitoring points:
   - static water level;
   - static pressure;
   - dissolved oxygen (mg/l);
   - FID (or PID and explosimeter) field screening measurements collected at the well head (data may be collected from both soil venting and air sparging monitoring points);
   - VOC, CO_2 and O_2 concentrations representing initial conditions (data may be collected from both soil venting and air sparging monitoring points); and
   - atmospheric conditions.

4. Test data collected at the injection point (reported for each specified time interval):
    - flow rate (scfm);
    - pressure at well-head in inches of water; and
    - water level (collected only if well is properly sealed).
5. Test data collected at the monitoring well points (reported for each specified time interval):
    - water level;
    - pressure;
    - FID (or PID and explosimeter) field screening measurements (data may be collected from both soil venting and air sparging monitoring points);
    - dissolved oxygen (mg/l); and
    - VOC, CO_2 and O_2 concentrations collected at selected time intervals from all monitoring points (data may be collected from both soil venting monitoring and air sparging monitoring points).
6. Graphs:
    - pressure at the injection point versus time for each step in the air flow rate;
    - pressure (in inches of water) versus distance from the injection point for each step in the air flow rate (semi-log graph);
    - maximum dissolved oxygen concentration versus distance from the injection point for each step in the air flow rate;
    - change in PID or FID reading versus time for each soil venting point at each step in the air flow rate; and
    - water level rise versus distance from the injection point for each step in the air flow rate. Note that water level at the air injection point can only be accurately collected from a sealed well.
7. Figures:
    - site maps, drawn to scale, illustrating the location of source area(s), injection points, monitoring points, buildings and paved areas, all possible conduits for vapor migration (basements, utility lines, backfilled areas), ground water elevation; and extent of soil and ground water contamination;
    - cross-section(s) of the proposed sparging area showing major geologic features, contaminant distribution, and location of injection and monitoring points; and
    - as-built air injection point and monitoring point construction diagrams.
    - construction schematic illustrating the manifold design, including the following elements: pipes, instrumentation, valves, sampling ports, and any other components of the pilot test system.
8. Appendices:
    - Analytical methods, analytical results, and lab reports.

5.2 Air Sparging Full Scale System

The full scale air sparging system should be comprised of a sufficient number of wells to address the entire extent of contamination, based upon the effective radius of influence determined in the pilot test. The SVE system should be in operation prior to start-up of the air sparging system. Once VOC concentrations have reached a steady state following SVE system start-up, sparge wells may be activated. A vapor extraction system air removal rate of at least five times greater than the air sparging system air injection rate is recommended to help ensure that explosive hazards do not develop during system operation. Section 4.2 establishes the minimum data submittal requirements for the SVE full-scale system. The need for emission controls should be evaluated during the early phase of the full scale system implementation.

If the minimum reporting requirements cannot be obtained due to site specific conditions this should be explained to, or discussed with, the MPCA project staff.

Air Sparging Full Scale Design Proposal – Minimum Submittal Requirements

1. Narrative describing the proposed installation and implementation of the system, including: system activation procedures, blower capacity or compressor size, air flow rates to be employed, estimated duration of treatment, expected mass removal rates, the types of data which will be collected, ground water monitoring network and sampling schedule, monitoring frequency, clean-up goals, and emission controls, if required.
2. Figures:
   - site maps, drawn to scale, showing the location of source area(s), injection points, monitoring points, all possible vapor migration conduits, ground water elevation, and soil and ground water contamination distribution;
   - cross-section(s) of the proposed sparging area showing major geologic features, contaminant distribution, and location of injection and monitoring points; and
   - air injection point and monitoring point construction diagrams; and
   - construction schematic illustrating the manifold design, including the following elements: pipes, instrumentation, valves, sampling ports, and any other components of the full scale system.

Full Scale Air Sparging Reporting – Minimum Submittal Requirements

1. Narrative discussing results, field procedures, trends and recommendations.
2. Data collected at the injection point (reported for each specified time interval):
   - flow rate in standard cubic feet per minute;
   - pressure at well-head in inches of water; and
   - water level (collected only if well is properly sealed).
3. Data collected at the monitoring points (reported for each specified time interval):
   - water level;
   - pressure;
   - FID (or PID and explosimeter) field screening measurements (data may be collected from both soil venting and air sparging monitoring points);
   - dissolved oxygen;
   - VOC, CO_2, and O_2 concentrations at selected time intervals from all monitoring points (data may be collected from both soil venting and air sparging monitoring points);
   - ground water contaminant concentrations; and
   - ground water elevation in wells.

4. Figures:
   - site maps, drawn to scale, showing the location of source area(s), injection points, monitoring points, all possible vapor migration conduits; ground water elevation, and extent of soil and ground water contamination;
   - cross-section(s) of the proposed sparging area showing major geologic features, contaminant distribution, and location of injection and monitoring points; and
   - as-built air injection point and monitoring point construction diagrams (submit with first monitoring report only); and
   - construction schematic illustrating the manifold design, including the following elements: pipes, instrumentation, valves, sampling ports, and any other components of the full scale system (submit with first monitoring report only).
5. Graphs:
   - VOC removal rate (Kg per day) versus time and cumulative removal rate versus time;
   - VOC composition of vapors removed versus time for multi-contaminant sites;
   - total vapor concentration (mg/l) versus time; and
   - ground water elevations versus time.
6. Appendices:
   - analytical methods, analytical results and lab reports.