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# SITE Demonstration of the SVVS Technology

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## INTRODUCTION

The Subsurface Volatilization and Ventilation System is an integrated technology used for attacking all phases of volatile organic compound (VOC) contamination in soil and groundwater. The SVVS technology promotes in-situ remediation of soil and groundwater contaminated with organic compounds through the injection of air into the saturated and unsaturated zones, and extraction of vapors from the vadose zone. Through this process, volatile and semivolatile organic compounds are stripped from the soil and groundwater. The subsurface circulation of air also increases dissolved oxygen concentrations in the saturated zone, capillary fringe, and vadose zone, thereby promoting aerobic microbiological processes. The contaminated air extracted from the wells can be treated at the surface before being discharged to the environment.

The SVVS process was evaluated under the SITE program at the Electro-Voice, Inc. (EV) facility in Buchanan, Michigan. The soils were contaminated with aromatic hydrocarbons, and halogenated and non-halogenated volatile and semivolatile organic compounds (SVOCs) through discharge into a dry well. Baseline data indicated that approximately 1,000 kg of VOC and SVOC contamination was present in the dry well area soils, principally in a subsurface sludge layer. The developer claimed that their technology would reduce the sum of seven target VOCs by 30% over a one year period.

## TECHNOLOGY

The SVVS process utilizes soil vapor extraction in conjunction with in-situ bioremediation to clean soil, sludge, and groundwater. A typical SVVS installation is comprised of a series of air injection and vacuum/extraction wells designed to circulate air below ground to 1) increase the flow of oxygen in the soil to enhance the rate of organics destruction by indigenous soil microbes and 2) volatilize and remove volatile organic contaminants from the soil. This system consisted of three individually plumbed rows of alternating vacuum extraction and air injection wells referred to as reactor lines. Each reactor line is plumbed to a single central vapor control unit (VCU) used to house air injection and vacuum pumps and gauging, as well as emissions control equipment.

The injection wells are installed below the groundwater table and are used to inject air into the groundwater. The Developer claims that the air strips volatile contaminants from the soil and water as it percolates through this saturated zone. Extraction wells installed in the vadose zone pull the percolated air through the soil under vacuum, further stripping contaminants. In addition, the increase in air circulation in the soil, specifically oxygen, increases the rate of biodegradation by soil microbes, according to the developer, and transforms contaminants into harmless end products such as carbon dioxide and water. To aid in the circulation process, sand chimneys can be installed. These are sand-packed borings which provide passive airflow between the subsurface layers, increasing both the soil vapor extraction and the biodegradation rates.

The SVVS process generates one major wastestream - vapors from the vacuum extraction wells. Depending upon regulatory requirements, the extracted air may be treated above ground or released directly to the atmosphere. In the early stages of SVVS implementation, the overall rate of mass transfer of contamination to the vapor phase may exceed biodegradation rates. It is during this period, which lasts anywhere from two weeks to a few months, that extracted vapors may need to be treated above ground before release to the atmosphere. However, the magnitude of treatment will decrease steadily over this period until biodegradation rates surpass the net rate of transfer of contaminant mass into the circulating air. When this point is reached, the vapor extraction off-gas will consist predominantly of carbon dioxide, which is the major gaseous by-product resulting from the biodegradation process. To reduce these costs further and promote additional VOC destruction, the SVVS design employs the use of proprietary biofilters for treatment of the extracted vapors.

If required by permits, off-gas extracted from the vacuum extraction wells can be routed through a configuration of Biological Emissions Control™ (BEC™) units (a patent pending system which, according to the developer, through biodegradation, achieves up to 80% reductions in concentrations of VOCs in stack emissions at approximately 20% of traditional emission control costs). The off-gas is then expelled to the atmosphere through a vent pipe affixed to the extraction pump. Vacuum extraction emissions may also be favorably controlled within regulatory limits by adjusting the air injection and vacuum extraction rates. However, if the levels of VOCs in the off-gas are in excess of acceptable levels, the off-gas exiting the BEC™ units can then be routed through an activated carbon adsorption unit as a final polishing step prior to discharge.

METHODOLOGY

The SVVS process was evaluated for its ability to reduce volatile organic contaminants in the vadose zone soil of the "dry well" area at the Electro-Voice, Inc. site in Buchanan, Michigan. The primary objective of the demonstration was to evaluate the developer's claim of a 30% reduction in the sum of seven specific volatile organic compounds (i.e., benzene, toluene, ethylbenzene, xylene, tetrachloroethene, trichloroethene, and 1,1-dichloroethene) in vadose zone soils of the treatment plot over a 12 month period of operation. A one year time frame was chosen for testing purposes only, and the reduction claim does not reflect the limits of the technology. Under an actual remedial clean-up, the system may require a longer time than was possible during the present study.

Reductions in the volatile organics were proposed to occur through the combined effects of in-situ biodegradation and soil vapor extraction. These reductions were evaluated by comparing the sum of the concentrations of the select volatile organic contaminants in the matrix prior to system startup and after 12 months of system operation. Secondary objectives were established to determine the relative contributions of in-situ biodegradation and vapor extraction to the removal and degradation of volatile organics from the subsurface.

Soil samples were collected from borings within the physical boundaries of the SVVS system and sampled in a manner such that the entire vertical section of the vadose zone was represented. Five distinct subsurface zones were identified based on lithology and contaminant occurrence. These included the upper horizon (above the contaminant source), sludge layer (predominant source of contamination), and lower horizons A1, A2, and B (below the contaminant source).

Since the developer's claims were to reduce seven volatile organic contaminants by 30%, benzene, toluene, ethylbenzene, and xylenes (BTEX), tetrachloroethene (PCE), trichloroethene (TCE), and 1,1-dichloroethene (1,1-DCE) were considered the critical analytes for this demonstration. Analyses were also performed on select samples for the following non-critical parameters: total carbon (TC), total inorganic carbon (TIC), nutrients (nitrate, phosphate), total metals plus mercury, cyanide, pH, and particle size distribution (PSD). An additional objective of this demonstration was to develop data on operating costs for the SVVS technology.

The extracted vapor streams were analyzed by continuous emission monitoring (CEM) for $O_2$, $CO_2$, and total hydrocarbons (THC). Grab samples of the extracted vapor stream were collected for determining the concentration and distribution of individual volatile organic compounds.

Shut-down tests were periodically performed to assess the presence and magnitude of biological processes in the destruction of organic constituents in the subsurface. During a shut-down test, the injected air stream is temporarily turned off resulting in the cessation of oxygen delivery to the subsurface. If there is a robust aerobic microbial population in the subsurface, the available oxygen will be quickly depleted. The shut-down test tracks the magnitude and rate of oxygen drop-off over a twenty-four hour period.

## RESULTS

At the Electro-Voice site, the SVVS process achieved an overall 80.6% reduction of the sum of the seven critical VOCs over a one year period from vadose zone soils. This level of reduction greatly exceeded the developer's claim of a 30% reduction over a one year time frame. The average concentration of the sum of the seven analytes from the hot zone in the study area, prior to installation of the SVVS, was 341.5 mg/kg. The average concentration of the sum of the seven analytes after one year of operation was 66.20 mg/kg.

The data reveals that the most contaminated zone, the sludge layer, had an average reduction of 81.5%. The other less contaminated horizons exhibited reductions ranging from 97.8% to 99.8%. The reductions over the areal extent of the site, as determined from the individual boreholes, ranged from 71% to over 99%. This indicates the system operated relatively uniformly over the entire vadose zone of the treatment plot, and no significant untreated areas were encountered, regardless of VOC concentration or lithology.

The shut-down testing indicates that microbiological activity was stimulated at the site. Due to the inherently high organic content of the soil, it was not clear how much of this stimulation was due to contamination. The microbiological activity, as determined from the first shut-down test, was greatest in portions of the site where the VOCs were greatest, and least active in areas of the site where the contamination was small or absent. Seasonal variations as evidenced in the background wells, where presumably no contamination existed, introduced uncertainty in data interpretation. A comparison of three shut-down tests indicates that biological activity was greatest during the beginning of remediation and progressively decreased throughout the remainder of the demonstration, but at a rate that was less than the VOC mass removal rates attributed to vapor extraction alone. This would indicate that biological processes play an increasingly important but not a dominant role, relative to vapor extraction, as the remediation proceeds.

An analysis of the volatiles from the vapor extraction outlet reveals that the highest mass of volatiles was removed during the early phase of the project. Furthermore, the mass of volatiles in the off-gas stream gradually decreases to a low and constant level after approximately 230 days of operation.

The SVVS experienced no major operational problems over the twelve month study period. Once implemented, the system was easy to monitor and required minimal maintenance and/or operator attention.

The Biological Emissions Control™ (BEC™) unit, installed to biologically degrade VOCs from the off-gas stream, was removed from the system after a few months of operation and was not evaluated. Dispersive air modelling results showed that contaminant concentrations were below established air quality standards and discharge criteria for the site were met without any additional treatment.

The SVVS was installed at the site based on contaminant distribution information derived from remedial investigation data. During the baseline sampling event under the SITE Demonstration, it became evident that a portion of the system was installed within a clean area of the site. Operation of the system was easily adjusted while maintaining the existing hardware to concentrate remedial action in more contaminated areas. However, installation of the system in the non-contaminated area impacted costs since materials and labor were expended. The excess installation did not in any way impact the performance of the system. This situation stresses the importance of accurately defining the extent and magnitude of contamination prior to the implementation of in-situ technologies. In-situ technologies may require site characterization in greater detail than is commonly available from remedial investigations.

CONCLUSIONS

The results from the demonstration indicate the SVVS technology greatly exceeded their reduction claims by providing a site average 80.6% reduction of volatile organics in the vadose zone. Furthermore, aerial and vertical reductions across the site did not indicate the presence of any zones that were not treated by the system. The SVVS process proved to be reliable and required minimal operator oversight. The technology did not experience significant operational difficulties during the evaluation period.

The SVVS process is applicable to sites contaminated with gasoline, diesel fuels, and other hydrocarbons, including halogenated compounds. The system is very effective on benzene, toluene, ethylbenzene, and xylene (BTEX) contamination. The process can also be used to contain contaminant plumes through its unique vacuum and air injection techniques. The technology should be effective in treating soils contaminated with virtually any material that has some volatility or biodegradability. The technology can be applied to contaminated soil, sludge, free-phase hydrocarbon product, and groundwater. By changing the injected gases, anaerobic conditions can be developed, and a microbial population can be used to remove nitrate from groundwater. The aerobic SVVS can also be used to treat heavy metals in groundwater by raising the redox potential of the groundwater and precipitating the heavy metals.

The cost to remediate 21,300 $yd^3$ of vadose zone soils during a full-scale cleanup over a 3-year period at the Electro-Voice Superfund site in Buchanan, MI was estimated to be \$192,237 or \$9/$yd^3$, not including effluent treatment and disposal. The majority of this was incurred in the first year, primarily due to well drilling and associated site preparation. If effluent treatment and disposal, using vapor phase granular activated carbon, had been included, this would have added \$164,500 to the first year of remediation and brought the total cleanup figure to \$356,737 (\$16.75/$yd^3$). This would have accounted for over 45% of the total cleanup costs.