United States Environmental Protection Agency

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EPA

SITE Technology Capsule

Subsurface Volatilization and Ventilation System (SVVS)®

Abstract

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 insitu 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 EV facility in Buchanan, Ml. 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 1-yr period.

The results from the demonstration indicate the SVVS® technology greatly exceeded their 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® remediation technology was evaluated based on seven criteria used for decision making in the Superfund feasibility study (FS) process. Results of the evaluation are summarized in Table 1.

Introduction

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, committed to protecting human health and the environment from uncontrolled hazardous waste sites. CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA) in 1986. These amendments emphasize the achievement of long-term effectiveness and permanence of remedies at Super-fund sites. SARA mandates implementing permanent solutions and using alternative treatment technologies or resource recovery technologies, to the maximum extent possible, to clean up hazardous waste sites.

State and federal agencies, as well as private parties, are now exploring a growing number of innovative technologies for treating hazardous wastes. The sites on the National Priorities List total over 1,700 and represent a broad spectrum of physical, chemical, and environmental conditions requiring various types of remediation. The U.S. Environmental Protection Agency (EPA) has focused on policy, technical, and informational issues related to exploring and applying new remediation technologies to Super-fund sites. One such initiative is EPA's Super-fund Innovative Technology Evaluation (SITE) program, which was established to accelerate development, demonstration, and use of innovative technologies for site cleanups. EPA SITE Technology Capsules summarize the latest information available on selected innovative treatment and site remediation technologies and related issues. These Capsules are designed to help EPA remedial project managers, EPA on-scene coordinators, contractors, and other site cleanup managers understand the types of

SITE
SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

Table 1. FS Criteria Evaluation For The SVVS® Technology

			FS Criteria			
Overall Protection of Human Health and the Environment	Compliance with Federal ARARs	Long-Term Effectiveness and Permanence	Reduction of **Toxicity, Mobility, or** Volume Through Treatment	**Short-Term Effectiveness**	**Implementability**	**Cost**
Provides both short- and long-term protection by eliminating organic contaminants in soil.	Requires compliance with RCRA treatment, storage, and /and disposal regulations (of a hazardous waste).	Effective/y removes contamination source.	Significant/y reduces toxicity, mobility, and volume of soil contaminants through treatment.	Presents potential short-term risks to workers and community from volatiles released during system installation.	involves few administrative difficulties.	$192,237 to clean 21,300 yd^3 ($9/ yd^3) over 3 yr excluding effluent treatment & disposal
Prevents further groundwater contamination and off-site migration.	Excavation, construction and operation of on-site treatment unit may require compliance with location specific ARARs.	involves well demonstrated technique for removal of contaminants.			System is easy to install and operate.	$356,737 ($16.75/ yd^3) including vaporphase GAC for effluent treatment & disposal
Requires measures to protect workers and community during excavation, handling, and treatment.	Emission controls may be needed to ensure compliance with air quality standards if VOCs are present.	Involves some residuals treatment, i.e. extracted air and minor soil from installation.				

data and site characteristics needed to effectively evaluate a technology's suitability for cleaning up Superfund sites.

This Capsule provides information on the Subsurface Volatilization and Ventilation System (SVVS)® process, an insitu technology developed to increase oxygen flow to subsurface materials, to facilitate microbial decomposition of organics while volatilizing and removing volatile organic contaminants. The SVVS® process was evaluated under EPA's SITE program during a 12-month period from April 1993 to April 1994 at the Electra-Voice, Incorporated (EV) facility in Buchanan, MI. The evaluation focused primarily on assessing the effectiveness of the SVVS® process for remediating the "dry well" area soils contaminated with aromatic hydrocarbons, and halogenated and non-halogenated volatile, and semivolatile organic compounds. Information in this capsule emphasizes specific site characteristics and results of the SITE field demonstration at the EV facility. This capsule presents the following information:

- Abstract
- Technology description
- Technology applicability
- Technology limitations
- Process residuals
- Site requirements
- Performance data
- Technology status
- Source of further information

Technology Description

The SVVS® process utilizes soil vapor extraction in conjunction with insitu bioremediation to clean soil, sludge, and groundwater. A typical SVVS® installation comprises 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. The configuration of the SVVS® is presented in Figure 1. A schematic cross-section of the system is presented in Figure 2. 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.

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

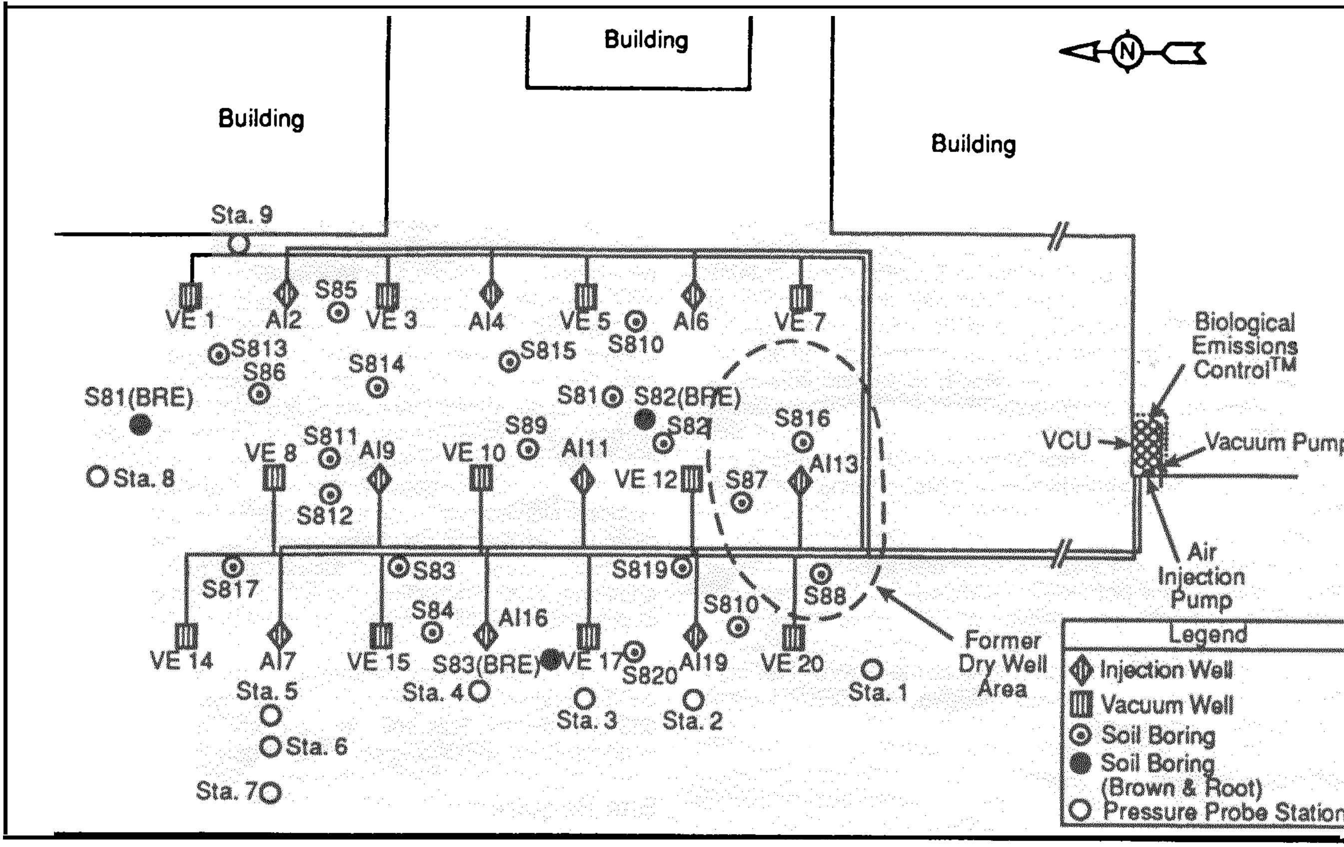

Figure 1. SVVS® configuration at the Electro-Voice site.

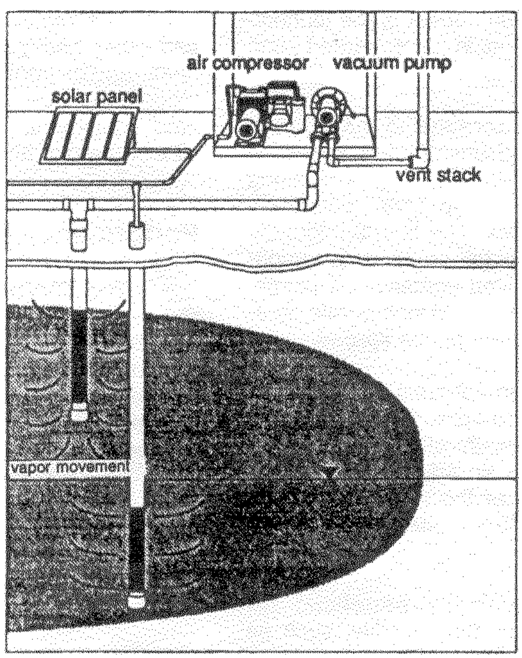

Figure 2. Cross-sectional schematic of the SVVS?

are in excess of acceptable levels, the off-gas exiting the BEC™ units can be routed through an activated carbon adsorption unit as a final polishing step prior to discharge.

Technology applicability

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.

Over the past five years, SVVS® has been employed at over 130 sites where petroleum hydrocarbons have been released. The soil and groundwater at several of these sites have been cleaned to applicable regulatory standards within and before the predicted remedial time frame. SVVS® has also been implemented to remediate halogenated aliphatic compounds in the subsurface.

Technology Limitations

In the application of any insitu air sparging technology, the potential exists for migration of contaminant vapors off site. It is imperative that the overall site remediation plan include a properly engineered soil vapor extraction (SVE) system to capture the contaminated vapors emanating from the saturated zone. Therefore, the application of this technology is generally limited to sites where SVE is feasible. One possible exception to this is a site that relies on a remediation system that maximizes the insitu biodegradation component of the technology to destroy less volatile contaminants in the saturated zone and vadose zone.

The effectiveness of SVVS® is sensitive to the lithology and stratigraphy of the saturated and unsaturated zones. In highly stratified soils, air may travel far from the well along coarser strata before reaching the vadose zone, potentially bypassing the target contaminant areas. The lateral migration of the air within the saturated zone will generally be accompanied by a lateral spread in the dissolved contaminant plume. The overall remediation system design should incorporate measures to control the potential contaminant plume spread.

In situations in which dense non-aqueous phase liquids (DNAPLs) are present, it is possible to spread the immiscible phase and increase the size and concentrations of the VOC plume. This may actually be used as an advantage in a site remediation through the mobilization of the residuals and, in conjunction with groundwater control, the realization of a more efficient mass removal process.

SVVS® may not be economically beneficial for remediation of materials of a very low permeability, such as stiff clay. Additionally, potential inorganic geochemical changes incurred through the application of the technology may cause clogging of the aquifer. The potential for fouling may be evaluated using available geochemical models, and avoided by using a more appropriate gaseous medium.

Process Residuals

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. Consequently, the extent of exsitu treatment is reduced significantly over that required by conventional SVE systems, resulting in decreased capital and operations costs to the implementer. 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.

A minor process residual from the implementation of a SVVS® system is soil generated during system-well installation drilling activities. This soil can be containerized and disposed in accordance with the appropriate regulatory criteria.

Site Requirements

The SVVS® soil remediation system consists of several major mechanical components and requires the installation of injection/extraction wells, and, possibly, sand chimneys. The system includes a positive displacement blower or air compressor, vacuum pump(s), emissions control equipment, and various monitoring equipment.

The remediation area must be accessible to drill rigs and other heavy equipment such as front-end loaders, back hoes, and/or trenching equipment. The site must also accommodate the VCU used to house the SVVS® pumps and associated equipment. System installation time depends upon the size of the plot and the depth to groundwater.

Performance Data

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 Electra-Voice, Inc. site in Buchanan, Ml. 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 ,l-dichloroethene) in vadose zone soils of the treatment plot over a 12-mo period of operation. A 1-yr 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 insitu 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 mo of system operation. Secondary objectives were established to determine the relative contributions of insitu 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 Al, 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 0_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 24-hr period.

At the Electra-Voice site, the SVVS® process achieved an overall 80.6% reduction of the sum of the seven critical VOCs over a 1-yr period from vadose zone soils. This level of reduction greatly exceeded the developer's claim of a 30% reduction over a 1 -yr 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.

Reductions for each subsurface horizon are presented in Table 2 and graphically depicted in Figure 3. The data reveal that the most contaminated zone is the sludge layer, with 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 is presented in Figure 4. The graph 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 12-mo 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

Table 2. SVVS® Performance Summary Zone 1 ('Hot Zone")

Treatment Plot Horizons	*Critical VOCs* Concentration (mg/kg)*		*% Reduction*
	Before	***After***	
Upper Horizon	*321.77*	*0.74*	*99.77%*
Sludge Layer	*1661.03*	*307.69*	*81.48%*
Lower Horizon A 1	*96.42*	*0.98*	*98.99%*
Lower Horizon A2	*37.68*	*0.42*	*98.88%*
Lower Horizon B	*13.57*	*0.30*	*97.79%*

Sum of Benzene, Toluene, Ethylbenzene, Xylene, **1, 1-Dichloroethene, Trichloroethene, and Tetrachloroethene*

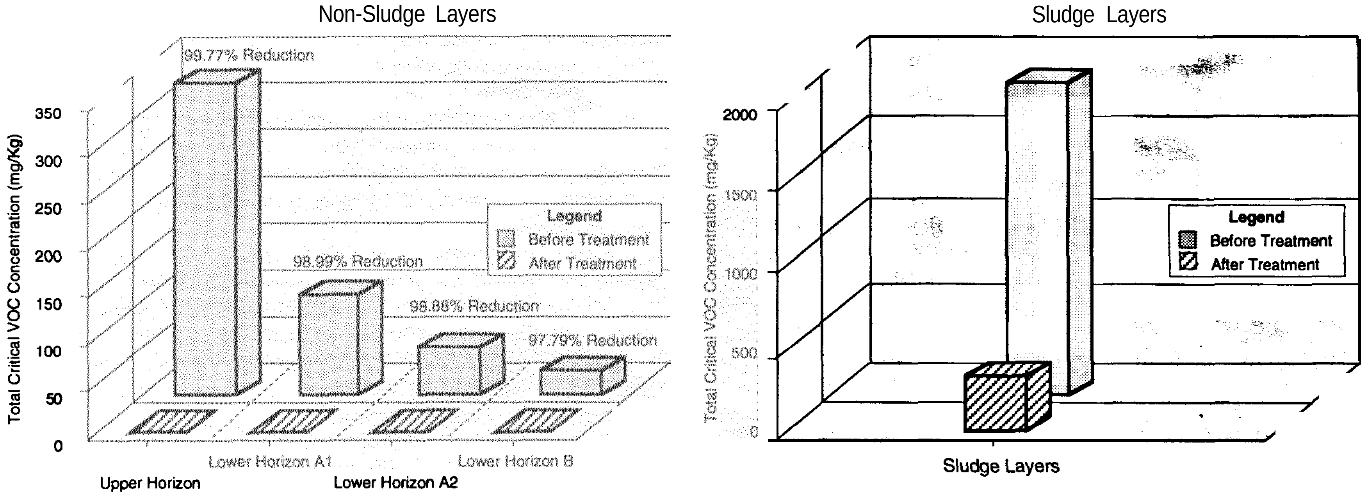

Figure 3. SVVS® performance.

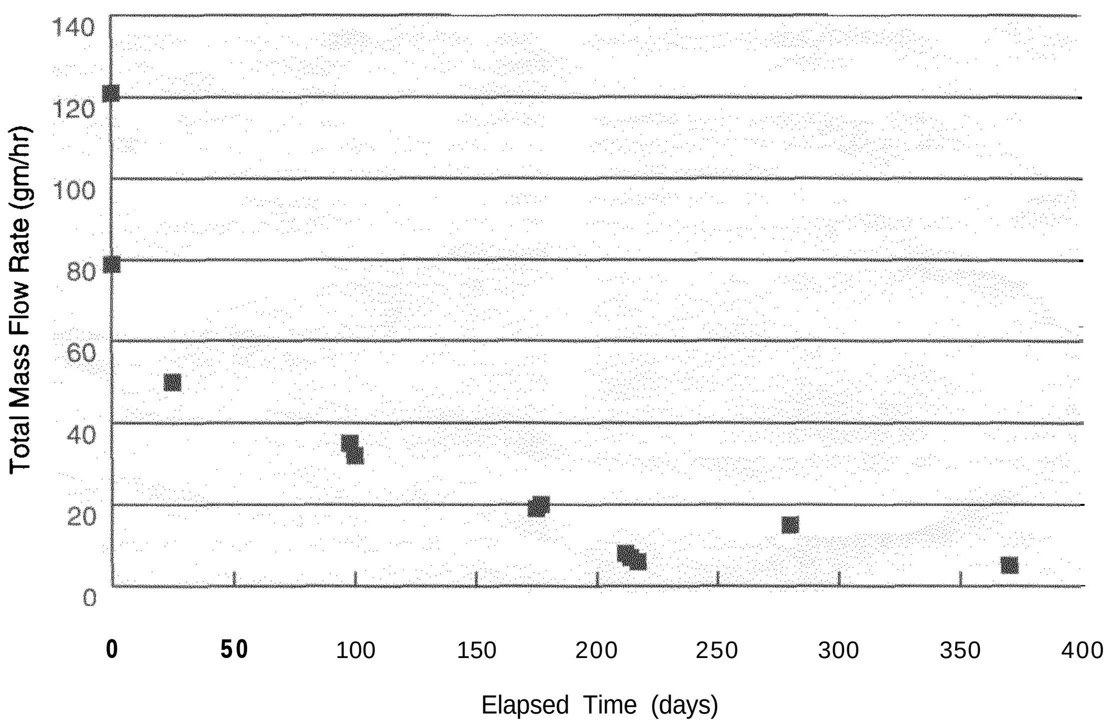

Figure 4. Total Mass Flow Rate of Critical VOCs Versus Time.

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 insitu technologies. Insitu technologies may require site characterization in greater detail than is commonly available from remedial investigations.

The cost to remediate 21,300 yd^3 of vadose zone soils during a full-scale cleanup over a 3-yr period at the Electro-Voice Super-fund 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.

Technology Status

The SVVS® has been implemented at over 130 underground storage tank (UST) sites in New Mexico, North Carolina, South Carolina, and Florida.

Disclaimer

While the technology conclusions presented in this report may not change, the data have not been reviewed by the EPA Quality Assurance/Quality Control office.

Sources of Further Information

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