Vacuum extraction of volatile organic solvents from soils

L'extraction par le vide des solvants organiques volatiles dans les sols

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SYNOPSIS: Many of the volatile organic solvents utilized in electronic manufacturing processes are considered hazardous. Cleanup excavation and removal of soils contaminated by such compounds is extremely costly, exposes workers to health risks, and is sometimes technically unfeasible. In-situ vacuum extraction of these compounds is a remediation alternative which can be 3 to 5 times cheaper and infinitely less disruptive in comparison to any of the non in-situ alternatives. This paper discusses geotechnical considerations, system installation, operational monitoring, and cleanup verification for two such projects, one of which is the first of its kind to receive completion approval by the highly stringent California regulations. In both cases the concentration of chemicals decreased by over two orders of magnitude in one year, and cleanup costs were one third of the next cheapest alternative.

1 INTRODUCTION

Many industrial processes utilize halogenated hydrocarbons as solvents, organic synthesizers, fumigants and refrigerants. Many of these chemicals are hazardous; e.g. they are highly toxic in low concentrations. The recent Federal and state regulations require comprehensive testing and evaluation of such systems to prevent potential public health endangerment or degradation of the environment (i.e. water or air resources). This paper discusses the soil clean-up of two sites in California. In both sites, the vadose zone soils were cleaned of volatile organic solvents using vacuum extraction systems.

2 SITE CONDITIONS

Site A- This site is located in Northern California, and had been occupied by an electronic manufacturing firm. In the early 1970's, two subsurface tanks were used for storage of wastes (mostly solvents). In 1982 the tanks were no longer needed due to processing modifications; therefore they were removed. The soils under the tanks showed high levels of volatile organic compounds, primarily trichloroethylene (TCE) at 130mg/kg.

Further subsurface investigations showed that the site is underlain by predominantly gravelly sand/sandy gravel soils and lenses or layers of silty or clayey gravel. One such lens with a thickness of 3m occurs at a depth of 3.5m, another with a thickness of 6m occurs at a depth of 15m. Further exploration indicated that much of the TCE was retained by the silty clayey gravel layers and little TCE was found between the sandy layers. Exploration also set the limits of solvents in the soil and it was estimated that about 32kg of TCE was in the upper 22m of vadose zone.

A perched water zone was found at a depth of 29m. The water table fluctuates due to local pumping and is generally encountered at a depth of [illegible]m. The groundwater sampling did not indicate any TCE.

Site B- This site is located in central California, and had been occupied by a chemical manufacturing company. There were two underground tanks containing 1,2-dichloroethane (DCA).

Subsurface investigations at the site included drilling of 19 borings and obtaining soil samples for classification and chemical tests. Subsurface conditions at the site consist of alluvial deposits of interbedded silty sand and clayey sand layers with occasional lenses of gravel containing clay and silt. The near surface soils are generally finer grained than the soils at depth; frequency of occurrence of gravelly soil lenses increased with depth, especially below a depth of 20m. Groundwater is at a depth of 44m. The nearest well is 800m downgradient of the site. Water from this well contained no DCA.

The subsurface soils contained concentrations of DCA which varied from zero to 85mg/kg. The highest concentration generally occurred at a depth of 6.5m to 15m. No DCA was detected below 18m. Integration of all test results over the affected volume indicated that about 150kg of DCA may be present in the vadose zone.

3 EVALUATION OF REMEDIAL ALTERNATIVES

Interim remedial measures at both sites consisted of removal of the underground tanks and the adjacent soil containing high concentrations of solvents. The excavations were backfilled and compacted with clean imported soil. The surfaces of both sites were then paved and sealed. These interim measures were taken to prevent further migration of chemicals by surface water infiltration. This allowed time for careful evaluation of site and alternatives.

Of the numerous alternatives initially listed, two excavation and soil removal schemes and one chemical vapor removal (vapor stripping) scheme were considered technically feasible. These are briefly discussed as follows.

Braced and Open Excavation - Since the underground tanks in both cases were near an existing building, excavation and removal of soils containing high concentrations of chemicals would require tied-back, braced excavation to protect the existing buildings. The cost of this alternative was estimated at about $1,500,000 and $1,700,000 (U.S. 1985) for sites A and B, respectively. This alternative was also considered to cause disruption of site operations.

Excavation by Drilling - This method consisted of drilling of large diameter (90cm) boreholes side-by-side and overlapping, to remove contaminated soil, and backfilling of each hole with clean imported fill soil. This alternative precluded the need for bracing of the adjacent buildings, and was considered to cause less disruption. The costs were estimated at about $1,000,000 (U.S. 1985) for each of the two sites.

Vapor Stripping - Stripping of volatile organic compounds from water and adsorption onto activated carbon has been utilized and described in many previous cases (e.g. Althoff, et. al., 1981; Dyksen, et. al., 1982). However, no published literature was found on the subject of in-situ vapor stripping of volatile organic compounds from the vadose zone in early 1984 when this alternative was being evaluated for site A. The only case history in California was at a site near Site A, where trichloroethylene was being slowly removed by this technique.

To test the theoretical feasibility of this technique at Site A, three sets of experiments were performed.

1) A 7-day air stripping test, where soil boring samples with the highest initial concentrations of TCE were left exposed to the elements and their final concentrations of TCE were measured;
2) A 24-hour air-flood test, where air was injected into a soil column and extracted from the other end to simulate subsurface injection and extraction; and
3) A 45-day baseline decay test, where the soil sample was wrapped, sealed and stored at 4°C.

Gas permeability tests were also performed to assess the ability of the soils to transmit gases. Table 1 summarizes the data from these tests. Based on these results, it was concluded that in-situ air stripping of TCE was feasible if effectively engineered and operated.

4 VAPOR EXTRACTION SYSTEM CONFIGURATION

Site A- For this site the vapor stripping system consisted of four borings drilled to a depth of 21m just below the lower clay lens. The borings were in a star formation (one at center and three on the perimeters at approximately 6m from the center, see Figure 1). Borings had a diameter of 36cm and were converted to wells by installing 10cm diameter schedule 80 polyvinylchloride (PVC) casing. The lower 6 meters of the casings were screened with 3.2cm slot widths at 50mm spacing. The backfill for the lower 14m consisted of clean pea gravel. The upper 5m of wells were sealed with neat cement and bentonite. The soil-gas extraction rate was set at $0.045 m^3/s$ using a 3.5kw blower pump. Two nested lysimeters were also

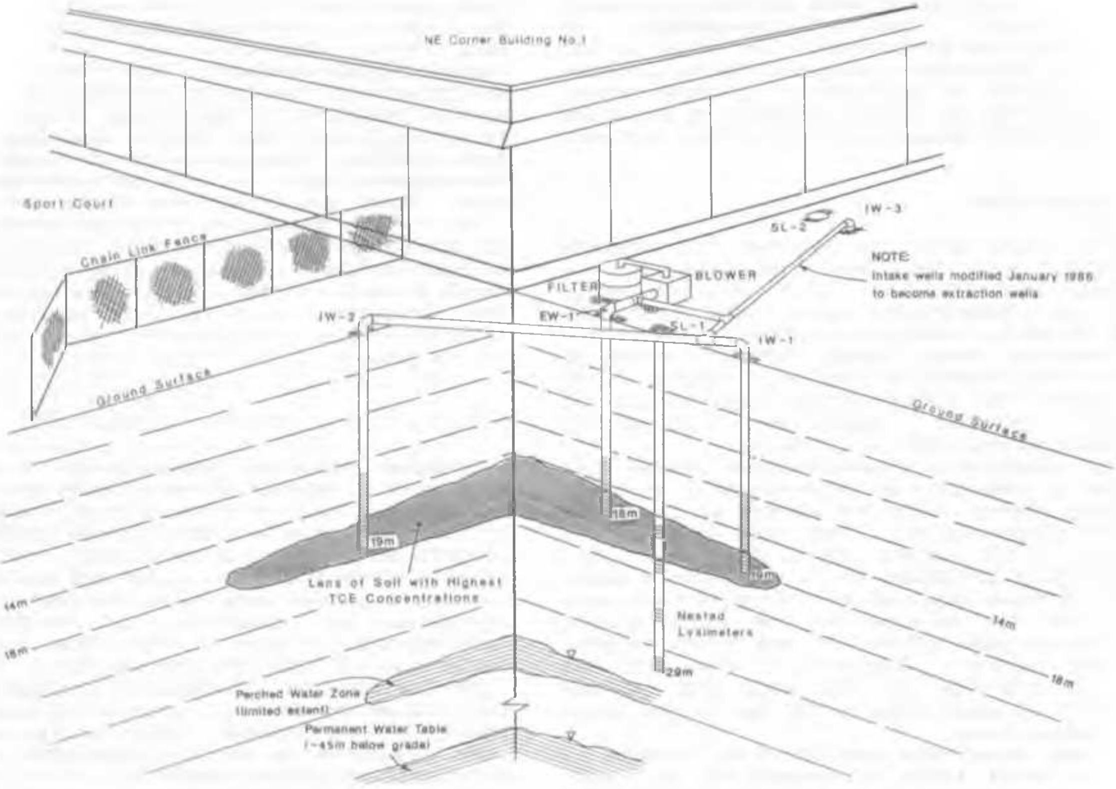

Figure 1. Configuration of vapor extraction system for Site A

Table 1. Results of air stripping experiments

	TCE Concentration (mg/kg) Initial	Final	Porosity (%)	Air Permeability (10^{-8} cm^2)
7-day air stripping				
clayey sand	11.9	ND*	34.4	64
sandy clay	1.6	ND		
gravelly sand	0.8	ND		
silty clay	---	---	26.8	107
24-hour air flood				
clayey sand	3.8	0.0014		
silty sand	2.9	ND		
45-day baseline decay				
sandy clay	12.7	0.0153		

*ND: Not detected (Detection limits approximately 0.001 mg/kg)

installed within the affected area to monitor concentrations of the constituents of soil-gas at different depths.

A carbon adsorption filter unit with 180 kg of activated charcoal was attached to the blower exhaust line to satisfy a 10g/day TCE emissions limit issued by the local air quality district. Gas samples from the filter inlet and exhaust were obtained regularly to check filter efficiency.

Site B- For this site the vapor extraction system consisted of eight extraction wells, a 5.5kw variable speed pump, and a 200kg activated carbon filter canister. Extraction wells consisted of 33cm diameter borings with 10cm diameter schedule 40 PVC casings. The casing slots and backfill were as in Site A. The upper 3m of extraction wells were sealed. Two nested lysimeters were also installed to monitor the effectiveness of the system.

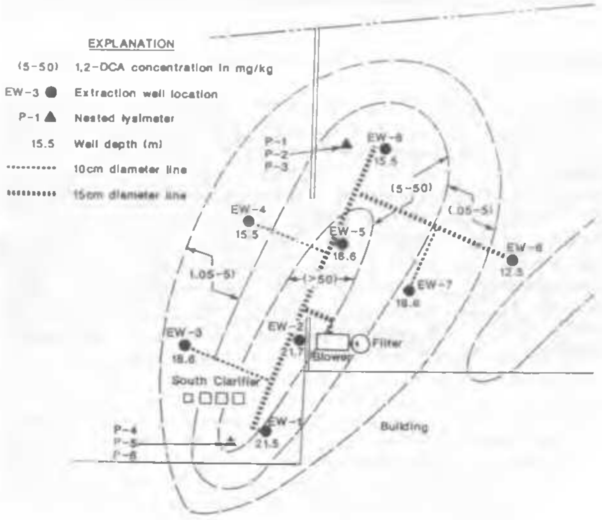

Figure 2. Plan view of Site B vapor extraction system configuration

5 RESULTS

Site A- The vapor extraction system at Site A operated for 440 days. The results of soil-gas samples analyzed from the two soil-gas lysimeters, as well as samples taken from ports in the above-ground system piping, showed continuous decreases in TCE concentrations.

Table 2 presents a synthesized summary of over 200 data points for this site. After 440 days, five post-cleanup borings were drilled and soil samples were analyzed for volatile organic constituents to confirm the cleanup. All soil samples showed significant decreases in TCE concentrations over all depths (see Table 2).

It was estimated that about 30 kg of TCE had been removed from the soils, and that about 2 kg remained. Subsequently, at the request of regulatory agencies, a "fate analysis" was performed to evaluate the potential consequences of the approximately 2 kg of TCE remaining in the vadose zone. The results of the fate analysis (Ellgas & Marachi, 1988) indicated insignificant potential for any health hazard or groundwater degradation. Subsequently, a permit was issued for the system to be dismantled.

The total cost of remediations, including testing and verification, fate analysis, reports and meetings with the regulatory agencies, was about $350,000 (U.S. 1987) which was one third of the next level remedial alternative.

Site B- Cleanup operations at this site commenced on 10 March, 1987. Qualitative field samples of the extracted vapors at the inlet and outlet of the filter canister indicated that carbon filter neared its capacity after only 16 hours of operations at $0.31 m^3/s$ (e.g. 50kg of DCA was removed in this interval). Hence, the system was shut down and the carbon filter renewed. During the subsequent days of operation, the flow rate was lowered to afford an adequate time interval between changing of the filter to allow for proper testing and monitoring of the system. The local air quality district also required lowering of the extraction rate to $0.08 m^3/s$ until concentrations decreased substantially.

Table 3 presents the summary of the monitoring data on the operation of the system from its startup until the writing of this paper.

Table 2. History of TCE concentrations in soils and soil-gas

(a) Soil sample concentrations (mg/kg)*

Date	Maximum	0 to 27.5m	9m to 18m
April '83	7.00	0.116	0.98
May '83	8.96	0.106	0.46
April '85	3.20	-----	0.53
Dec. '86**	0.54	0.034	0.06

(b) Soil-gas sample concentrations (ppmv)

July 11, '85	639.5	Start of operations
July 15, '85	203.0	After 4 days
Jan. '86	32.6	
Feb. '86	18.5	
May '86	8.6	
Aug. '86	1.9	
Dec. '86**	1.7	
July '87	1.5	

Notes: *Geometric mean across the verticle range
**Cleanup confirmation borings

Table 3. DCA extraction data summary at Site B

Date	DCA Concentration ppmv	Flow Rate m^3/s	Remarks
March 10, 87	1470	0.31	Started @ 16:50
March 11, 87	601	0.31	Read @ 10:20 flow reduced to 0.23 for 72 hrs, then system off.
Nov. 10, 87	670	0.15	Started 14:10
Nov. 11, 87	410	0.15	@ 12:40
Nov. 12, 87	530	0.23	1-hour test @ 12:15 then rate changed to 0.13
Nov. 13, 87	240	0.13	@ 13:25
Nov. 19, 87	160	0.13	@ 13:10, then lowered rate to 0.084
March 10, 88	23	0.084	
May 11, 88	18	0.084	
June 17, 88	15	0.084	
Aug. 8, 88	13	0.084	
Aug. 10, 88	58	0.23	rate changed @ 15:30
Aug. 17, 88	15	0.23	
Aug. 31, 88	13	0.23	

The results presented in Table 3 demonstrate that DCA concentrations decreased significantly during the first few days of operation. Increasing the rate of extraction also increased the concentration of extracted DCA. The results further suggest that much of the cleanup is already achieved, and that a fate analysis in 1989 may prove that system can be shut down without further environmental concern. The cost of cleanup so far has been $150,000 (U.S. 1988) and may increase to $250,000 by completion of the project. This is about one fourth of the next lowest cost alternative.

After nearly 9 months of operations the pump rate was increased resulting in increased suction pressure inside the wells and increased volume of flow. This was accomplished in three stages and the system was allowed to reach equilibrium at each stage. During this process, suction pressure in extraction wells EW-1 and EW-8 and each of the lysimeters near these two extraction wells were measured. The results are presented in Figure 3. Note that lysimeters 4, 5, and 6 are 2.4 meters from EW-1, and lysimeters 1, 2, and 3 are 2.4m from EW-8, and that the extraction wells EW-1 and EW-8 have a depth of 21.5m and 15.5m, respectively.

The results in Figure 3 (a) and (b) show that the vacuum at the lysimeters were one half of the vacuum at the extraction wells. For the lysimeters which were at a depth below the bottom of both extraction wells, the vacuum in the lysimeters were one order of magnitude less than the vacuum in the extraction wells. These data suggest that vacuum in soils drops substantially in the vertical direction, perhaps due to anisotropy in air-permeability of natural soils.

6 CONCLUSION

The monitoring of in-situ vapor extraction operations for cleanup of vadose zones of the two sites described in this paper show that:

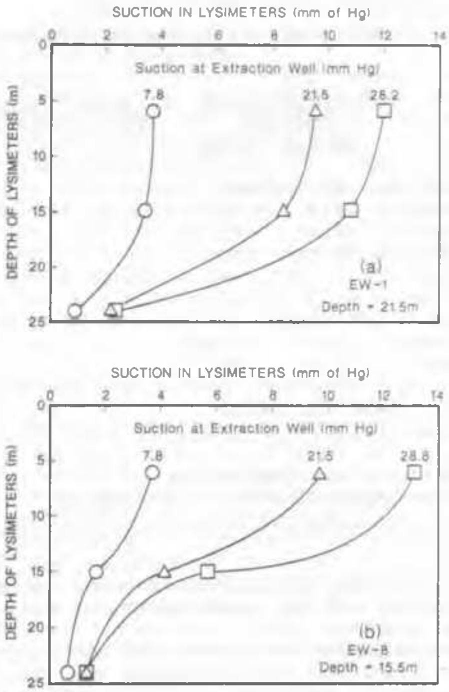

Figure 3. Results of vacuum tests at Site B

a) Vacuum extraction systems can remove volatile organic compounds from the subsurface soils with no disruption of the facility;

b) Cleanup can be achieved within one to two years of operations;

c) Vacuum heads in the soil to achieve effective vapor removal vary from about 30mmHg at the extraction wells and decrease rapidly with depth below the bottom of extraction well;

d) Cost of in-situ cleanup of vadose zone using vacuum extraction system is 2 to 4 times less than other remediation alternatives.

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