Performance of a Fracture Enhanced Dual Phase Soil Vapor Extraction System

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ABSTRACT: A Superfund site, consisting of a former manufacturing facility, in South-Central Iowa was contaminated with trichloroethene (TCE) in both the soils in the vadose zone and in the groundwater. Soil concentrations of TCE were detected at highs levels throughout two large areas, requiring source removal in the vadose zone down to depth of 30'. Due to the soil's low permeability and perched water table, a horizontal sand filled fracture enhanced dual phase high vacuum soil vapor extraction (SVE) system was selected for source removal in the vadose zone. The horizontal sand filled fractures were installed beneath the existing building and utilities. The fracture enhanced dual phase SVE system consisted of a high vacuum high flow rate system to maximize the removal of volatile contaminants from the soil formation. The operating SVE system was monitored continuously for vacuum, well head and total flows, condensate level in SVE extraction points, condensate volume extracted and system up time. The instrumentation software automatically up loaded these performance data daily to an internet site for review and analysis. One (1) year of performance data are presented for the system, which illustrate the superior performance of the fracture enhanced dual phase SVE system in the rapid extraction of volatile contaminants from a tight clay formation, and thus the short operating period required for source removal.

SITE BACKGROUND

A former manufacturing facility located in South-Central Iowa was contaminated with trichloroethene (TCE) in both the soils in the vadose zone and in the groundwater. The soil and groundwater contamination are a result of earlier manufacturing activities at the site, with the prime contaminated areas being directly beneath the unoccupied manufacturing building as shown on Figure 1. The site consists of a stiff to very stiff over consolidated clay till of approximately 30' thick, underlain by medium to fine channel sands, which in turn are underlain by an over consolidated stiff to very stiff till. The upper clay tilt, which has an extremely low intrinsic permeability, had high levels of TCE contamination and exhibited a perched water table in the vadoze zone.

The record of decision (ROD) was modified to a fracture enhanced dual phase soil vapor extraction (SVE) system in the vadose zone for the soil remedy, and a iron permeable reactive barrier for groundwater remediation. The horizontal fracture enhanced dual phase SVE system replaced an earlier proposed closely spaced SVE system, because the earlier system would have been ineffective in remediating the soils within the expected time frame. The fracture enhanced dual phase soil vapor extraction

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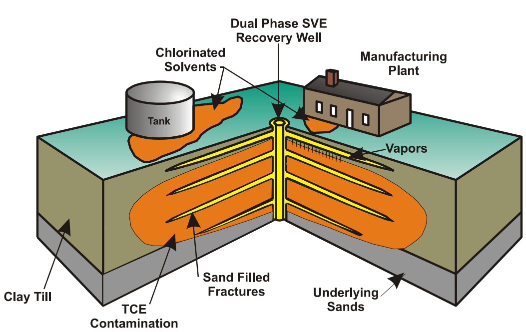
system was installed inside of the building to extract chlorinated solvents in the vadose zone from the upper till unit, from the ground surface down to a depth of 30’.

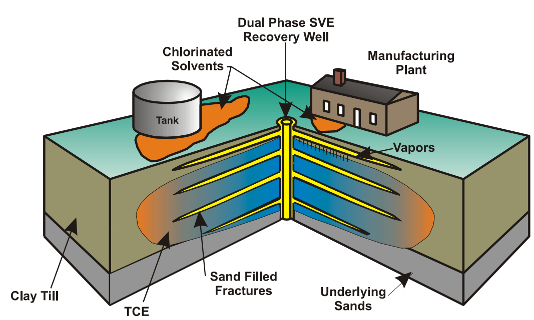
FIGURE 1. Aerial View of Manufacturing Building & Source Areas.

DUAL PHASE FRACTURE ENHANCED SVE

Tight soils such as the clay till at this site are not directly amenable to source removal by conventional SVE due to the soil’s extremely low permeability. During the past 10 years, horizontal hydraulic fracturing of highly impermeable over consolidated clay formations has become standard practice in the environmental remediation industry, primarily from the initiatives of the USEPA Site Program (Murdoch et al, 1990). The horizontal fractures are created by first cutting a horizontal notch at the required initiation depth and then injecting the sand proppant in a highly viscous cross linked guar gum gel. An enzyme is added to the gel prior to injection and ensures the gel’s starches are biodegraded into sugars and water. Upon breaking of the gel a highly permeable sand filled fracture remains, see Figure 2. The horizontal sand filled fractures can be spaced as close as two (2) feet apart vertically, and extend up to fifty (50) feet in diameter. The horizontal sand filled fractures significantly increases the soil’s permeability and greatly enhances the radius of influence of the dual phase SVE extraction wells.



Fracture Enhanced SVE at 0 years



Fracture Enhanced SVE after 1 year

FIGURE 2. Fracture Enhanced SVE System.

SYSTEM DESIGN, CONSTRUCTION & PERFORMANCE

The fracture enhanced SVE system was designed utilizing previous field data and experience, and a transient three dimensional air flow model to predict system performance. Field data from previous fracture enhanced systems have quantified the significant increase in the soil volumetric extent placed under an induced vacuum and the increase in air flow rates due to fracturing, (Banerjee, 1993, Baker and Hocking, 1995). The radial extent of the zone of induced vacuum stress for a fractured system is typically 10 to 20 times that of the unfractured system, with extracted flow rates being significantly greater, at least a factor of 10, in the fractured enhanced system compared to the unfractured system.

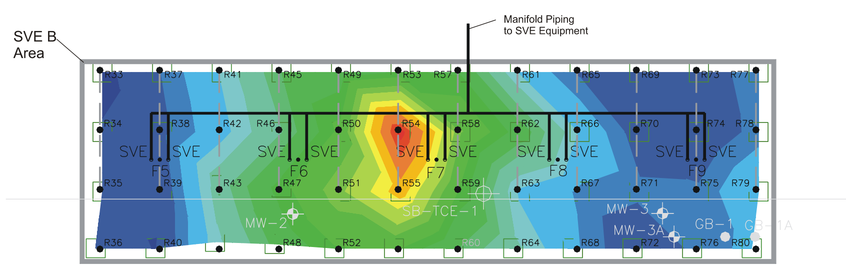
The objective of the fracture enhanced SVE system is to remediate the contaminated soils within a short time frame of approximately one (1) to two (2) years. The fracture enhanced SVE system involves enhancing the permeability and contaminant extraction efficiency by installing SVE extraction points and horizontal fractures at quantified spacings and depth intervals. Design calculations utilizing the three dimensional air flow model determined the optimal fracture frequency and SVE extraction point spacing as to minimize the overall system cost, i.e. combined construction and operating costs.

The fractured enhanced SVE system for the two contaminated source areas consisted of nine (9) SVE extraction points and horizontal sand filled fractures at depths of 6', 11', 15', 19' and 23' below ground surface. The horizontal fractures are filled with –20/+ 40 mesh silica sand with an in placed permeability of 250 Darcy and a porosity of 35%. The system was designed as a high induced vacuum > 20'' Hg and high flow rate > 250 acfm, to ensure the induced well head vacuum is applied throughout the sand filled fractures. The volatile contaminants in the soil are extracted rapidly with such a system, because the induced vacuum is applied throughout the sand filled fractures due to their low storage coefficient and high permeability, and the maximum distance the contaminants need to flow in the soil is only one half of the vertical spacing between the fractures.

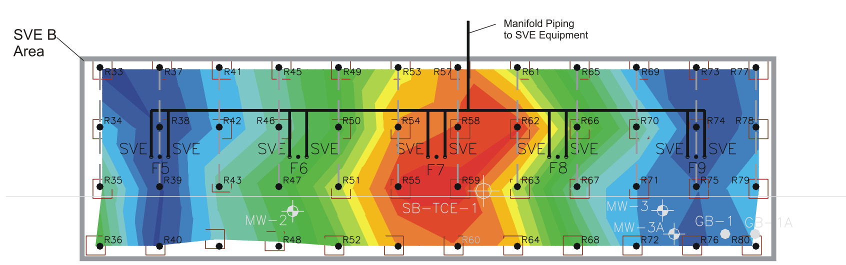
The sand and gel are mixed in a 500 gallon truck mounted mixing system, see Figure 3, with the gel cross-linked in line and the sand gel mixture injected by a frac plunger pumping unit. The horizontal sand filled fractures were constructed by injecting through a driven probe into the horizontal notch created by the fracture initiation device. The quantities of injected sand gel mixture are monitored to ensure sufficient sand is injected into the horizontal fracture at the required depth horizon. The injected geometry of the propagating fracture is monitored in real time by the active resistivity method. During injection the sand gel mixture is electrically energized with a low voltage 100Hz signal. Surface and/or subsurface resistivity receivers are monitored to record the in phase induced voltages by the propagating fracture. From monitoring the fracture fluid induced voltages and utilizing an incremental inverse integral model, the fracture fluid geometry is quantified during the injection process, as shown on Figure 4.

Upon completion of injection of a horizontal fracture geometry at a specific depth, the injection probe is driven down to the next depth horizon and the process is repeated to install the next horizontal fracture at depth. SVE extraction points are generally installed prior to horizontal fracturing activities. By fracturing to the SVE extraction point, the fracture intersects and connects to the sand pack of the SVE extraction point and propagates around the SVE extraction point. This construction method minimizes the skin friction between the fracture and the SVE extraction screen, which is extremely important in clay formations.

FIGURE 3. Horizontal Hydraulic Fracture Installation Equipment



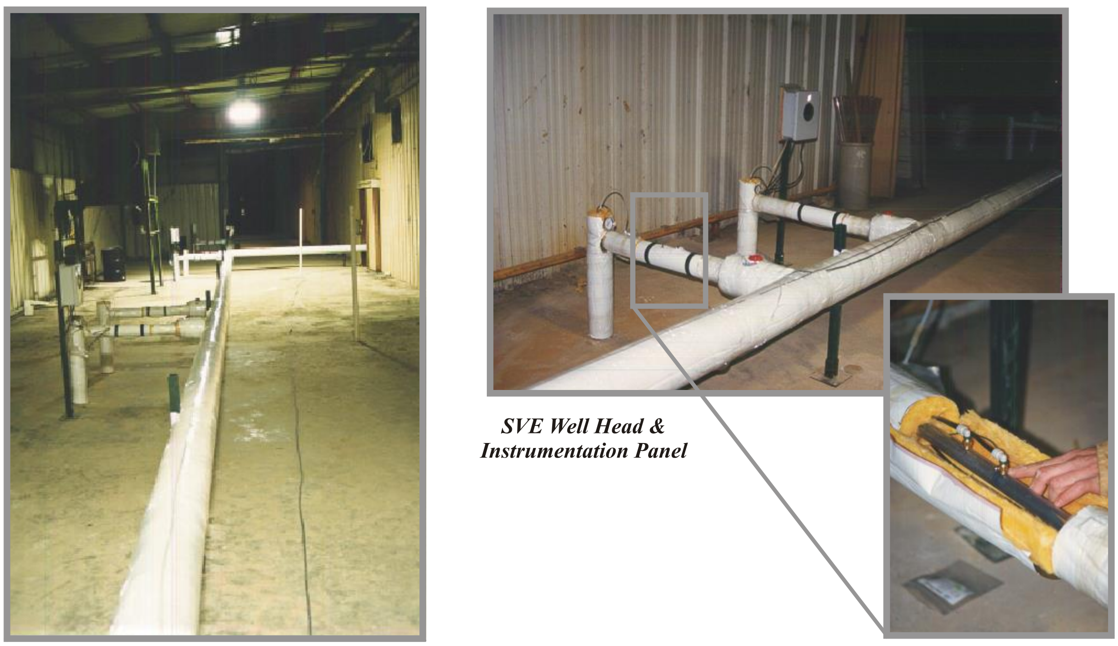
Excitation of Frac Casing & Initial Injection



Excitation of Completed Horizontal Fracture

FIGURE 4. Active Resistivity Monitoring of Fracture Geometry during Injection.

The SVE extraction points consist of a stainless steel well casing with a dual phase drop located inside of the casing. The stainless steel casing and drop pipe connected to the schedule 40 2” PVC wellhead extraction piping, which contains a orifice plate flow measuring device and vacuum pressure gage, as shown on Figure 5. Each extraction point is manifold connected to the 4” schedule 40 PVC extraction piping system, which is graded to enable condensate to drain to the SVE equipment housing. The SVE extraction pump is a closed loop oil sealed liquid ring vacuum pump with an air to oil cooling system. The pump was selected for its high vacuum capability, greater than 20” Hg, and its quality and superior performance in similar applications. The pump selected had a capacity of 275 acfm at 20” Hg using 20 HP. Before the soil gas enters the vacuum pump, condensate is removed in the condensate knockout vessel. When condensate levels reach a predetermined level, a progressive cavity pump is used to remove the condensate to a condensate storage tank for eventual disposal. The soil vapor then passes through a particulate filter before entering the vacuum pump.



SVE Well Head & Instrumentation Panel

Well Head & Piping System

Orifice Plate Measurement Ports

FIGURE 5. Dual Phase SVE Well Head & Instrumentation

The SVE instrumentation system instrumentation provides for continuous monitoring and recording of: 1) the presence of condensate in each extraction point; 2) the flow rate and applied vacuum at each extraction point, and 3) the total system soil gas flow rate, total system applied vacuum and rate and total quantity of condensate produced. The instrumentation provides for an automatic up link to an internet site for eventual review and data analysis. Alert levels are set for a variety of conditions with both internet and dialup capability. The system has sampling ports at each extraction point and for total composite system for air monitoring analysis. System performance for the first year is shown on Figure 6 for both cumulative TCE contaminant recovered and cumulative condensate recovered.

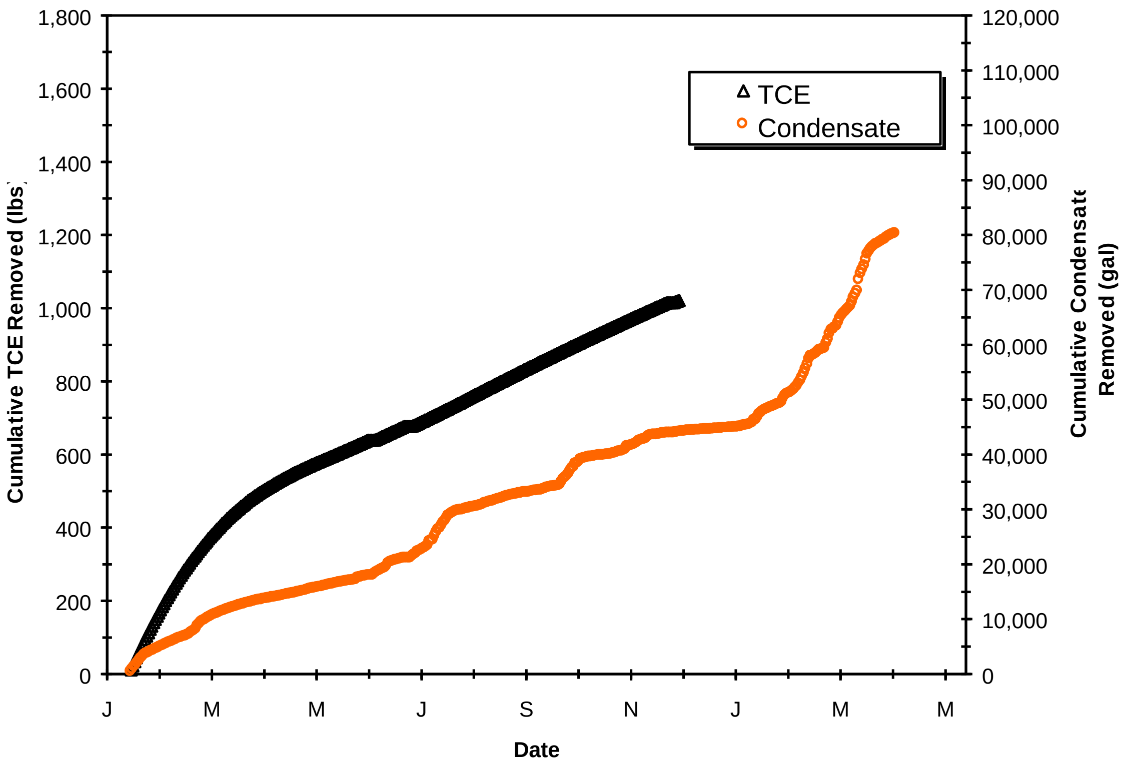


FIGURE 6. System Contaminant and Condensate Recovery for First Year

CONCLUSIONS

The fracture enhanced dual phase soil vapor extraction system was installed inside of the building to extract chlorinated solvents in the vadose zone from the upper till unit, from the ground surface down to a depth of 30'. Due to the soil's low permeability and the perched water table, a horizontal sand filled fracture enhanced dual phase high vacuum SVE system was selected for source removal within the vadose zone. Horizontal sand filled fractures were installed in the tight clay at depths of 6', 11', 15', 19' and 23' below the existing floor slab and building utilities. The geometry of the sand filled fractures were recorded in real time by the active resistivity method during injection. The horizontal sand filled fractures had diameters of approximately 50', and significantly increased the soil permeability by orders of magnitude as determined by vacuum well testing. The fracture enhanced dual phase SVE system consisted of a high vacuum high flow rate system to maximize the removal of volatile contaminants from the soil formation. Due to the high permeability of the sand filled fractures, a high vacuum was applied directly to and throughout the fractures, resulting in the rapid migration of contaminants in the soil towards the fractures and into the SVE extraction points. The operating SVE system was monitored continuously for vacuum, well head and total flows, condensate level in SVE extraction points, condensate volume extracted and system up time. The instrumentation software automatically up loaded these performance data daily to an internet site for review and analysis. One year of performance data illustrate the superior performance of the fracture enhanced dual phase SVE system in the rapid extraction of volatile contaminants from a tight clay formation, and thus the short operating period required for source removal.

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