

SYNCHRONIZED PULSED SPARGING AND SOIL VAPOR EXTRACTION FOR A COST EFFECTIVE RECOVERY OF RESIDUAL HYDROCARBON

Fahri Daoud Alsawaf¹, Ph.D. GeoWise Consulting

Kenneth K. Hekimian², Ph.D., RCE, REA, HVN Environmental Service Co., Inc.

Abstract

After an initial high vacuum recovery of 683 gallons of hydrocarbons (using a mobile unit) in a heavily contaminated former gas station, a week-long pilot test proved that soil vapor extraction, coupled with pulsed air sparging (AS/SVE), is the fastest and most cost-effective way to mobilize the trapped, dissolved, and residual hydrocarbon within and above the saturated zone. The pilot test results were used to design a network of deep sparging wells, a network of shallow vapor extraction wells and a number of groundwater monitoring wells at the subject site which is about 20 miles east of Los Angeles Airport. The remediation system consisted of above-ground installation of thermal oxidizer, a scroll-type air compressor, and a natural gas powered generator. The below-grade system consisted of 16 dual air sparging/vapor extraction wells, 13 vadose zone vapor extraction wells, 13 groundwater monitoring wells, and five distribution vaults.

Contemporaneous operation of the AS/SVE system was automated according to the following steps: (1) continuous vapor extraction to maintain negative pressure within the remediation zone; (2) intermittent pulsed sparging alternating between two networks of wells whereby resulting groundwater mounding may collapse and stabilize in one set of wells while mounding is taking place in the second set of wells; (3) sequential air-injection followed by a return to static condition should prevent off-site migration of the plume; (4) vapor destruction unit failure should automatically shut down air injection in all wells so that vapor emission is always under control; (5) pressure and flow rate of air into each sparging well is adjustable in one direction only so that no backflow of air or vapors can cause cross-contamination between wells; (6) groundwater levels are monitored during each pulsed sparging episode using down well data loggers. Pulsing response in groundwater indicates the effectiveness of pulsing within the radii of influence and the return of groundwater levels to static level after each pulsing episode.

Compared to well-known high vacuum and pump-and-treat methods, in -situ pulsed air sparging coupled with soil vapor extraction has the following advantages: (1) increases the rate of hydrocarbon recovery by an order of magnitude during initial operation and double the rate at later parts of remediation; (2) mobilizes the trapped, and otherwise inaccessible, liquid hydrocarbon from within the saturated zone to be removed by the vapor extraction system; (3) maintains continuous system operation with minimal maintenance without the need to treat contaminated water; (4) minimizes the number of lab analyses which is limited to vapor samples and quarterly groundwater samples; and (5) reduces the overall capital and operational costs by at least 50% due to shorter operation and elimination of groundwater treatment and discharge.

The remediation system is currently running on a schedule and will be switched, after five quarters of active recovery, to passive bio-sparging only when vapor concentrations are eliminated or reduced below 50 ppmv. The thermal oxidation unit will be replaced by two granular activated carbon canisters during phase two of site remediation.

Introduction

Five (5) underground storage tanks were removed and high levels of petroleum hydrocarbons were detected beneath a former gas station located south of Los Angeles, California (Figure 1), 1998. Groundwater wells were then installed (1999) and, from 2000 to present, twenty (20) quarterly groundwater monitoring episodes have been conducted. As an interim measure, dual phase high vacuum extraction was used to mitigate the high concentrations of hydrocarbon in the vadose and the saturated zone (2001). Approximately 400 gallons of vapor phase and liquid phase hydrocarbons were extracted and destructed on site before the pilot test. In 2003, a pilot test was conducted to demonstrate the feasibility of pulsed air sparging and soil vapor extraction (AS/SVE) and to develop design parameters. After system installation, full-scale pulsed operations were conducted between March, 2004 and April, 2005. Approximately 5,600 pounds of hydrocarbon were destructed and biodegraded during the first nine months of operation. In June, 2005, the thermal oxidizer was replaced with carbon canisters and focused air sparging was conducted at specific "hot spot" locations. In addition, a request for site closure was submitted to the Regional Board in May, 2005.

HVN Environmental Service Co., Inc. (HVN) has installed sixteen (16) dual –purpose air-sparging/vapor extraction wells (ASV), thirteen (13) groundwater monitoring wells (MW) and thirteen (13) vapor extraction wells (V) and connected all wells to the treatment compound through a network of underground piping (Figure 1). The treatment compound contains a natural gas generator, dry air compressor and vacuum/thermal treatment furnace.

Based on the significant reduction of dissolved and vapor phase hydrocarbon during the first four (4) quarters of operation (March, 2004 through April, 2005), intermittent pulsed sparging system, coupled with soil vapor extraction, proved to be a very effective and technically feasible alternative for remediation of the vadose zone Volatile Organic Carbons (VOCs) and dissolved hydrocarbon in groundwater (Figure 2 and Figure 3). A 90% reduction in Total Petroleum Hydrocarbons (TPH gasoline) concentration in groundwater and a 95% reduction in benzene concentration have been achieved within the first three quarters of remediation. The dissolved concentrations continue to decline during the fourth quarter of operation except in some wells where groundwater level has increased, causing dissolution of TPHg and benzene, after this year (2005) high rainy season. However, recent purging and water sampling of deep sparging wells ASV-12, ASV-14 and ASV-15 (Figure 1) indicate that groundwater in the deeper zone (35 to 40 ft bgs) is clean (no dissolved hydrocarbon was detected). However, some periphery wells continue to contain significant concentrations of TPHg, BTEX and MTBE. For this reason, and to direct remediation towards the remaining hot spots, we have implemented the following:

1. Field testing the air sparging well network to investigate the effects of increasing or doubling the amount of the injected air in certain wells without the use of SVE system.

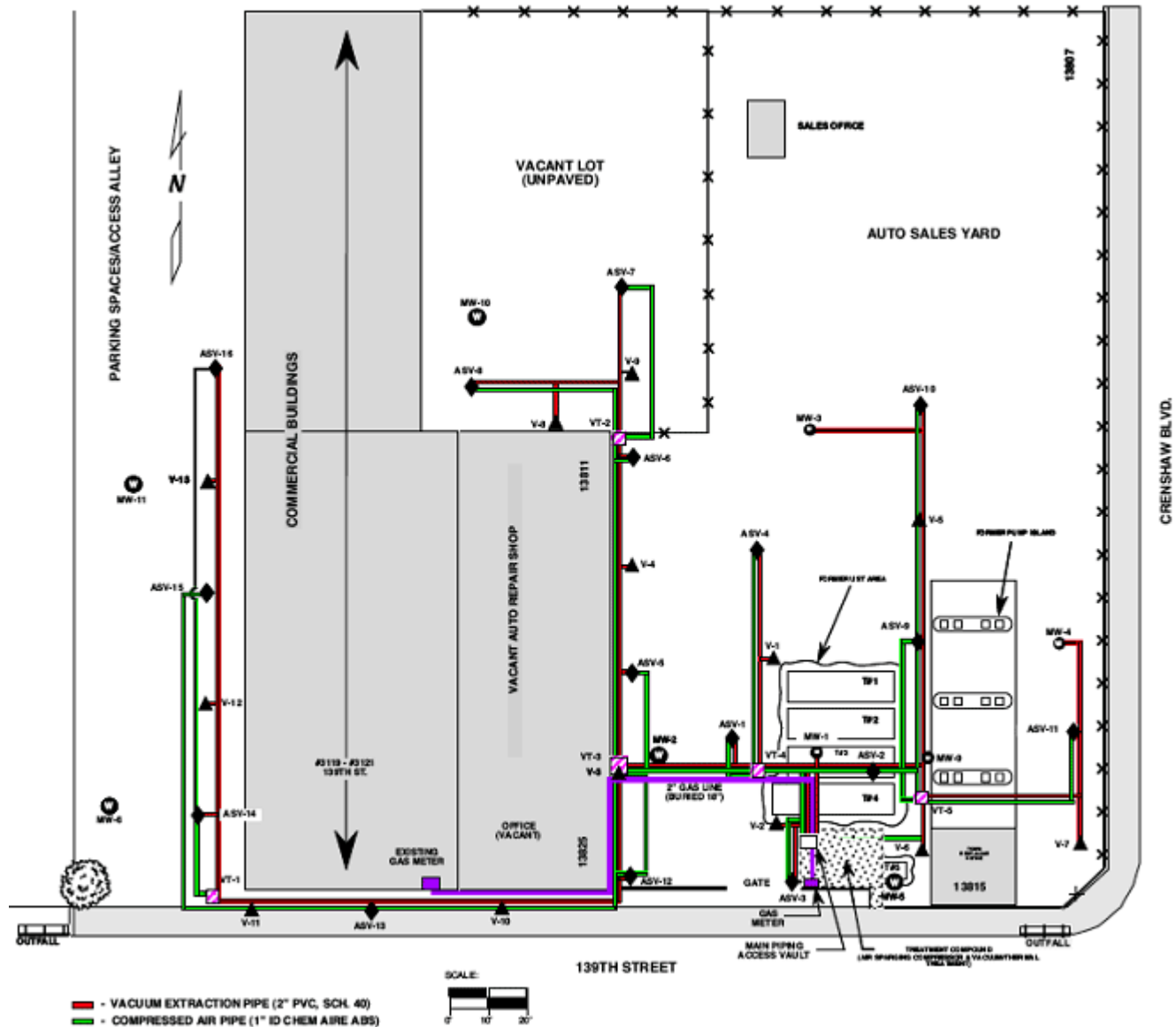


FIGURE 1: AS-BUILT AIR/VACUUM, WATER, AND GAS PIPING LAYOUT

FIGURE 2: CONCENTRATION OF BENZENE AND MTBE IN GROUNDWATER OF MONITORING WELL MW-1

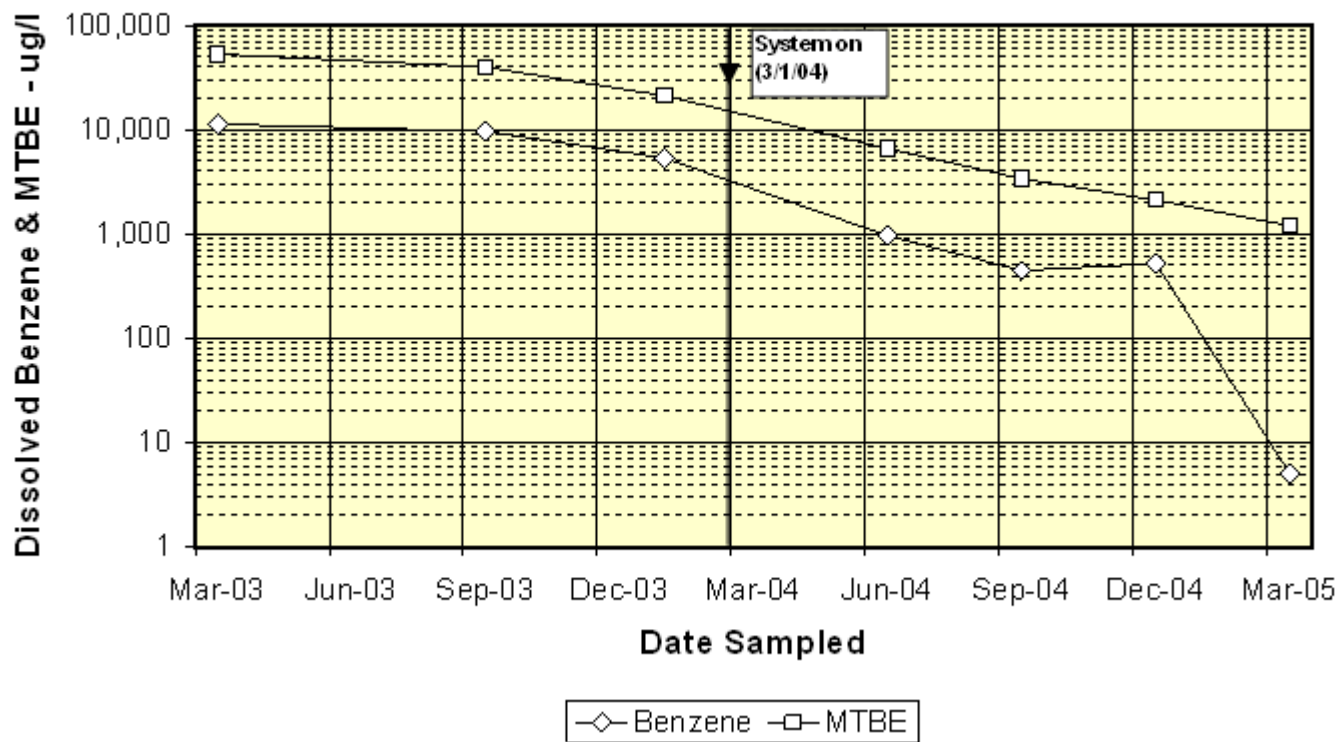
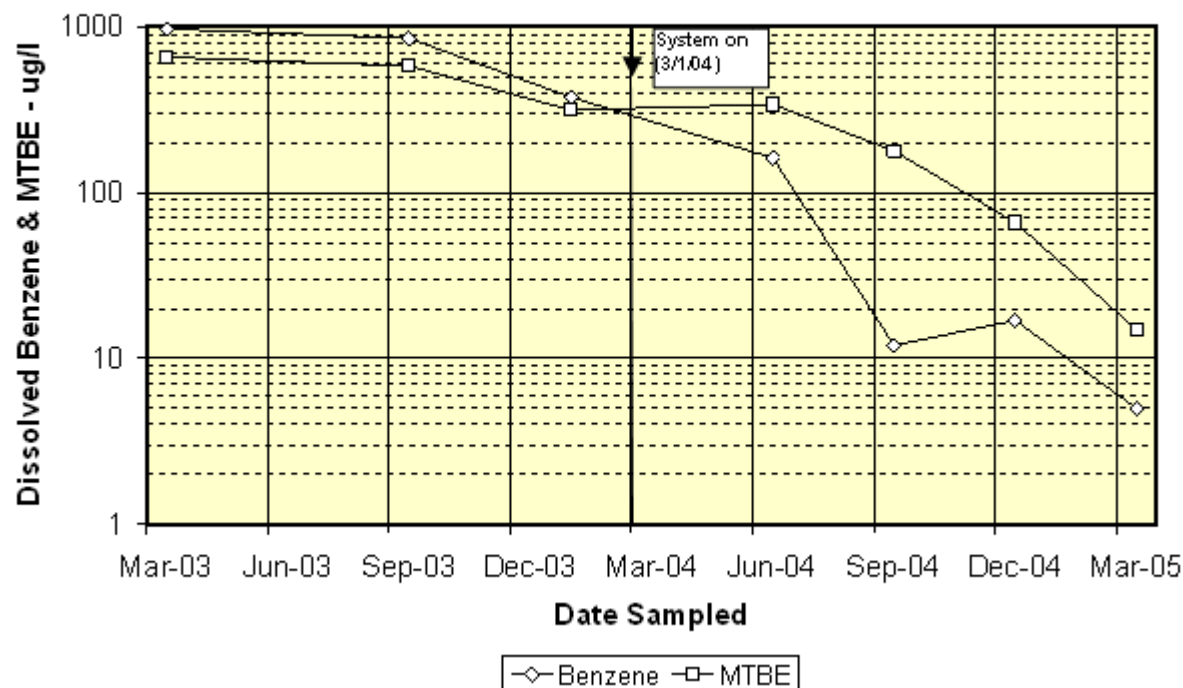


FIGURE 3: CONCENTRATION OF BENZENE AND MTBE IN GROUNDWATER OF MONITORING WELL MW-2



- Investigating intermittent operation of the SVE system in order to: (a) reduce natural gas consumption and (b) allow more time for the hydrocarbon contaminants to desorb from soil and groundwater before extraction.
- Monitor groundwater quality parameters to estimate air and oxygen distribution in the saturated zone particularly in the remaining “hot spots.”

Due to the heterogenous soil properties and chemistry, vacuum extraction alone may not remove the entire plume in the vadose zone. Adsorbed hydrocarbon on clay particles and dissolved phase in water may remain trapped in the soil even after liquid phase removal. This is due to the soil porosity which retains contaminated water of up to 10% to 15% in sand and up to 25% to 40% in silt and clay. Retained contaminants need to be forced (against gravity) through a water or air stream, or biodegraded, in-situ, if abundance of electron donors or oxygen is present in the saturated zone.

The basic idea used in this site is the intermittent pulsing of air, through sparging wells, and the recovery of volatile hydrocarbons through vapor wells. Sixteen (16) dual-nested wells were used to inject air at a depth of 35 ft to 40 ft below grade surface (bgs) and at a rate of 4.0 cubic feet per minute (cfm). The emitted vapors were collected through vapor wells screened at a depth of 10 ft to 20 ft through the vadose zone. In addition, one vapor well was located between each two dual-sparging nested wells to insure total containment of the injected air. Basically, the soil vapor extraction system (SVE) extraction flow rate always exceeds the total volume of injected fresh air through the 16 air sparging wells.

Geology and Hydrogeology

Lithology of the upper 30 ft of subsurface soil, as examined during drilling, consists of olive to brown color silt and clay present in varying proportions with low moisture content in the vadose zone. From about 23 ft to 30 ft below ground surface (bgs), the soil is composed of moist to saturated fine silt or clayey silt. Perched groundwater was initially encountered between 25 to 30 ft bgs during well drilling at the site. The perched water zone has no known beneficial use and is separated from the deeper water

supply aquifer (present below 80 ft bgs). This water supply aquifer was identified as Gage Aquifer and is present at depths ranging between 100 and 200 ft below mean seal level. Depth to groundwater was approximately 20 ft bgs but varied between seasons (within 2 to 4 ft between spring and autumn). Depth to water indicates the saturated zone is unconfined to semi-confined with groundwater elevation ranging between 28 and 30 ft above mean sea level (MSL). Groundwater flow is towards the west and southwest at a gradient of about 0.003.

Groundwater flow and gradient has influenced the migration of the dissolved hydrocarbon plume off site. Significantly high concentrations were detected in the western wells. However, groundwater was clean in the upgradient well and contains relatively low concentrations south of the site.

Additional monitoring well MW-13 was installed west of the site, at the downgradient location of the plume. No detectable concentrations were found in this location. However, presence of significant concentrations in monitoring well MW-12 (northwest of site) indicate that the plume was migrating in the downgradient direction (probably expanding) prior to startup of the remediation system.

Dissolved Plume Containment During Sparging

One of the most critical problems to be considered during air sparging into the groundwater plume is plume containment. If containment cannot be achieved, plume migration and spreading within the saturated zone may impact clean zones and have an adverse effect on site remediation. Therefore, it is necessary to establish plume conditions prior to active remediation so that a comparison could be made during each quarter of remediation to insure containment.

Plume conditions are established during background monitoring and by comparing the historic groundwater levels and quality data. Plume conditions could either be stable, expanding or shrinking with time. Design of the remediation system, including the number and configuration of wells and the capacity of the system will depend on the plume conditions. The least expensive system will actively recover a stable and a shrinking plume within a reasonable length of time. However, a more robust system, with a larger network of recovery wells, is needed for an expanding plume to encompass and contain the entire plume.

Important Considerations During Pulsed Sparging Pilot Test

The following conditions should be met during the pilot testing of the pulsed air sparging into a dissolved plume:

1. Injected air should target the contaminated zone so that air flow through the saturated zone will mobilize the trapped and adsorbed hydrocarbon contaminants. Dissolved and released residual hydrocarbons will volatilize and biodegrade during the remediation process. This condition is critical in stratified sites where permeable zones (like sand) is interbedded with low permeability silt and clay layers. If the low permeability layers are contaminated, air injection should target the permeable zones immediately below the contamination. If the low permeability zones are clean and located below the plume, air injection (sparging wells screen) should be located above these zones. If air injection is directed through and below the clean, low permeability zone, the air may escape laterally beneath these zones with no benefit for the dissolved plume above.
2. Air injection should not cause the dissolved plume to be displaced and spread during testing. This condition could be tested in two ways. Firstly, if wells are available for pumping and could sustain pumping to create a cone-of-depression within the test zone, groundwater pumping could be used to create a concentric, inflow gradient towards the center of the plume during the pilot

testing. This procedure was used during testing of the subject site. Groundwater levels were dropped by more than 6-inches during the pulsed sparging pilot test. Fluctuation of groundwater levels (mounding and collapse) during the pulsed sparging test were within the cone-of-depression and were lower than the drawdown created by pumping. Therefore, the dissolved plume was contained throughout testing. Secondly, if wells are not available for pumping or could not sustain significant production to create a cone-of-depression, closer monitoring of groundwater levels are essential in this case to control groundwater fluctuations and to maintain the plume in place. This could be achieved using data loggers placed in control wells located within and in the periphery of the plume.

3. Groundwater level fluctuations during pulse sparging (mounding during injection and collapse after injection) should be closely monitored so that the average levels should be equal to the static water level before pulsing. This could be achieved during the pilot testing using progressive injection in five steps. For example, if air injection rate was gradually increased from 2 cubic feet per minute (cfm) to 4, 6, 8 and 10 cfm, injection during the first three steps: 2, 4 and 6 cfm may cause a fluctuating water level (in the wells) that represents the average static water level before testing. In this case, 4 or 6 cfm might be the safe flow rate to be used for remediation while maintaining plume stability. Groundwater level mounding during Steps 4 and 5 may not return to the average static level when injection is stopped or three times or longer intersparging period may be required to return the groundwater to static levels. In such cases, when the levels did not return to static (pre-test) levels, the higher flow rates (8 and 10 cfm) should not be attempted during remediation. Most probably, these higher air flow rates will cause plume migration and spreading.

Pulsed Sparging Versus Continuous Air Injection

Numerous attempts have been made in previous studies to continuously inject air in a contaminated saturated zone. That was done to either strip volatile contaminants from water or to promote aerobic biodegradation. However, continuous air injection into a moderately permeable or low permeability zone could potentially displace the plume by causing spreading and, thus, increasing plume migration. For this reason, air injection is not successful in sites where the dissolved plume cannot be contained. Alternatively, pulsed sparging was demonstrated in 1996 (same author) to mobilize the residual hydrocarbon (after free NAPL removal), volatilize and biodegrade dissolved contaminants while monitoring and maintaining the plume in place. Injected air distribution and flow path can be monitored in wells using TV cameras while pressure distribution can be observed and measured in the field. Pressure on well heads may represent vadose zone pressure if the well is screened in the vadose zone while increasing water levels in the monitoring well reflect piezometric pressure or mounding of water table in the saturated zone.

Selection of the Optimum Pulsing Rate

Before pilot testing, the response of the saturated zone to stress (during air injection) is unknown. For this reason, three or more steps are needed to test the saturated zone under various flow and pressure conditions. Five steps were selected for this site at which air was injected in the test (sparging) well at approximately 40 pounds per square inch (psi) pressure and air flow rates of 2, 4, 6, 8 and 10 cubic foot per minute (cfm). During each injection step, air was pumped for about one hour or until a noticeable increase in the surrounding wells is measured. This was monitored using a programmable data logger. After each injection step, groundwater levels were allowed to return to the static water level (collapse) so that the length of the inter-sparging period could be estimated. Each step of testing was monitored to determine the optimum sparging (injection) and inter-sparging (no injection) time required to sustain injection while maintaining the dissolved plume on site. For this particular site, Steps 1, 2 and 3 at 2, 4

and 6 cfm demonstrated plume containment, while Steps 4 and 5 did not.

Examples of Different Pulsing Rates

Based on pilot testing and operating remediation systems designed by the author (for different sites), the following pulsing rates were selected:

1. Two hours of continuous air injection followed by four hours of no injection.
2. One hour of continuous air injection followed by two hours of no injection.
3. Ninety minutes of injection followed by ninety minutes of no injection.
4. Thirty minutes of injection followed by sixty minutes of no injection.

In most conditions of permeable sites consisting of sand and silty sand, inter-sparging period may take twice the time of sparging period. This is because the injected air needs more time to disperse, vent or be consumed in the saturated zone and the upper vadose zone. Only in rare cases can pulsed sparging be successful in a confined saturated zone. In such cases, air flow rate is much lower compared to semi-confined or unconfined zones.

In addition to selecting the pulsing rate, the remediation well network could also be grouped into two or more groups of wells so that one group could be pulsing at specific time and rate, while others are following at different times and rates. For example, the innermost sparging wells of the plume may inject air and cause a groundwater level mounding while the remaining wells are not (within inter-sparging period).

Well grouping was attempted for this site, whereby six inner wells injected air for 90 minutes, while the outer ten wells are returning to static condition. Alternating pulsing between two groups of wells, representing the inner circle and outer (periphery) circle, caused the contaminated water to move back and forth within the plume. This wave-like movement expedited the dissolution of residual contaminants within the soil pore space, mobilized trapped and adsorbed hydrocarbons in the saturated zone and provided dissolved oxygen to promote aerobic life within the saturated zone. Although oxygen dissolution in water is relatively low, continuous pulsing and oxygen consumption by bacteria provided sufficient dissolved oxygen (over 3.5 milligram per liter [mg/l]) to sustain active biodegradation of hydrocarbon in water.

Synchronization of the Remediation System

Site remediation (vadose and saturated zones) was planned in two phases; first is to recover the residual hydrocarbon from the vadose zone and the volatile hydrocarbon from the saturated zone that was being emitted during sparging. This first phase is followed by bio-sparging and venting, whereby vapor recovery may not be needed.

During the first phase of remediation (first year in this site), air injection and vapor extraction were synchronized so that sparging would stop when the vacuum was positive or the soil vapor extraction (SVE) system was off. Initially, the SVE system was operated and the vacuum in the wells was measured to verify negative pressure in the plume area before the air injection was initiated. When the SVE system contains the vadose zone soil vapor, air injection is initiated in the central plume wells; a vacuum switch will then control the air compressor so that the compressor will turn off when the vacuum fails.

During the second phase of remediation, no SVE system may be needed, especially when soil vapors do not contain measurable concentrations of hydrocarbon contaminants. Groundwater levels and quality

parameters, including pH, EC, DO, ORP and temperature, should be monitored to be used as indicators of plume conditions. For example, an active anaerobic condition results in higher temperatures, compared to pre-remediation levels, negative ORP, lower pH (lower than 7.0) and very low concentrations of DO. Alternatively, if an aerobic condition is prevailing in the plume, DO levels will be above 4 mg/l and the Redox is positive. Bio-sparging into the saturated zone should also be pulsed so that plume containment is achieved. The duration of each pulse may remain the same, as was the case during SVE and sparging, or it may be extended in duration providing that the air flow rate is low and the soil vapors are contained in the subsurface (no emission of vapors to the surface).

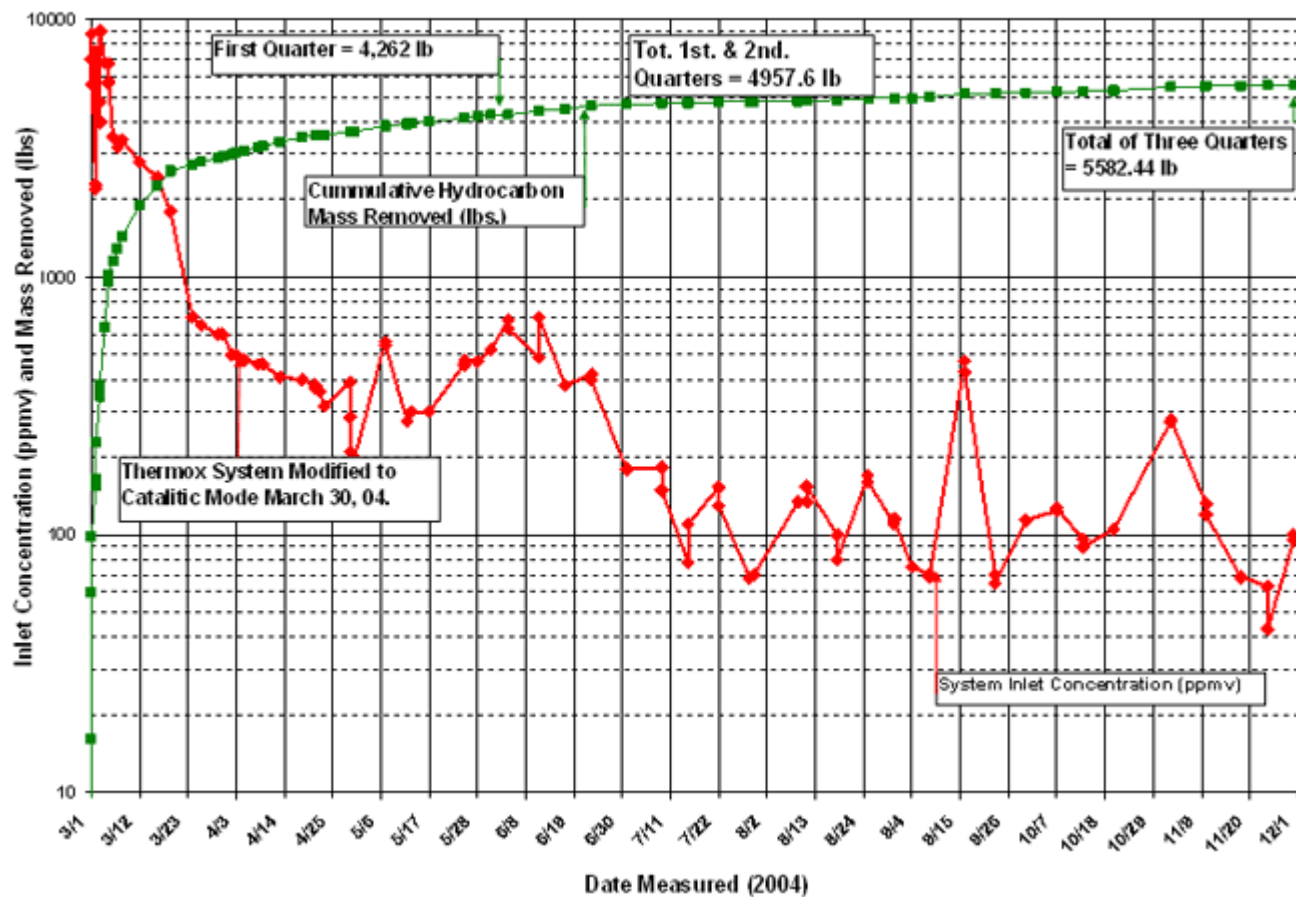
Hydrocarbon Mass Removal Rate

The inlet vapor extraction concentration and flow rates were used to calculate the hydrocarbon mass removal rate, shown in Figure 4. This Figure indicates that inlet (extracted) gasoline hydrocarbons (TPHg) vapor concentration declined by approximately half (from 6,000 ppmv to 3,000 ppmv) after the first week of vapor extraction. Vapor concentrations continued to decline during the second and third week of remediation and essentially down to 600 ppmv during the fourth week at the end of March 2004. For this reason, and to minimize system fuel consumption, it was decided to modify the Thermox system with catalytic converter (March 30, 2004). The relatively low vapor concentration (500 ppmv) continued to decline during April and then reached a stable level at the end of April 2004.

During the 2nd and 3rd quarters, weekly influent vapor concentration and monthly effluent (after treatment) concentration were sampled using tedlar bags and tested by certified laboratory for compounds of concern. The inlet TPHg vapor concentrations averaged 139 ppmv during the 3rd quarter of remediation.

As indicated in Figure 4, a total of 4,262 pounds of TPHg (including BTEX compounds) was removed by volatilization from the subsurface after the first quarter (total of 2,066 hours), a total of 4957.6 pounds of TPHg was removed after the 2nd quarter (total of 3,862 hours of operation), and a total of 5,582 pounds of TPHg was removed after the 3rd quarter (total of 5,920 hours of operation). System inlet concentrations were based on the calculated system

Figure 4: Vapor Extraction System Inlet Concentration (ppmv) and Hydrocarbon Mass Removed During Three Quarters of Remediation, Mahmeister LLC Property, California



log and photoionization (PID) readings of hydrocarbons vapor concentrations. The mass removal rate during the first Quarter of remediation was 46.3 lb/day (for 92 days of active/inactive system period). The cumulative three quarters hydrocarbons mass removal rate represents approximately 21 lb/day of operation (for 268 days of active treatment).

Conclusion

Due to the relatively high cost of dual phase vacuum extraction and pump-and-treat systems, a long-term cost-effective alternative was selected to remediate the vadose zone and the contaminated groundwater beneath a former gas station located east of Los Angeles Airport. A synchronized system of soil vapor extraction, coupled with intermittent pulsed sparging was tested and implemented for this site. Benzene concentrations in groundwater were reduced from 5,000 ppb (pre-remediation level) to non-detect during the first year of operation in the central part of the plume (Wells MW-1 and MW-2) (Figures 2 and 3). Similarly, the dissolved MTBE in groundwater was reduced from 20,000 ppb (pre-remediation level) to approximately 1,000 ppb in Well MW-1 and to 15 ppb in MW-2.

The successful application of pulsed air sparging during phase one of remediation (first year) has led to implementation of phase two in which the thermal oxidation system will be replaced with two carbon canisters and the sparging efforts will be directed to the few remaining hot spots.

During remediation system testing and selection, the proposed dual phase extraction coupled with pump-and-treat system was approximately 58% higher than the actual cost of the pulsed air sparging system.

Considering the additional time needed to complete remediation, it is estimated that the total remediation cost would amount to two-thirds of the dual phase extraction and groundwater pump-and-treat. However, the success rate of pump-and-treat system was much lower than the pulsed air sparging for a similar size and condition of plume.

ABOUT THE AUTHORS

¹*Fahri Daoud Alsawaf, Ph.D., CGWP*

Dr. Alsawaf is a Senior Hydrogeologist for GeoWise Consulting working for a number of environmental companies in Southern California. He obtained his Ph.D. in Hydrogeology from the University of London and taught Hydrogeology for six years. For the past 22 years, he has worked on contaminated sites in California and abroad involving soil and groundwater contamination studies, design, implementation, and operation of various remediation systems. His main expertise is in hydraulic testing and modeling of contaminated sites, site clean-up and closure.

²*Kenneth K. Hekimian, Ph.D., RCE, REA*

Dr. Hekimian is Principal Civil Engineer for HVN Environmental Service Co., Inc., an environmental engineering/contracting firm. A graduate of the University of Southern California, Dr. Hekimian served as a member of the adjunct faculty for 18 years there. With over 40 years of diversified professional experience, Dr. Hekimian has pioneered engineering design and environmental studies for hazardous waste projects such as sanitary landfills, waste transfer station, aboveground and underground fueling facilities, petroleum hydrocarbon and solvent-contaminated soil and groundwater site investigations, risk assessments and remediation, dry cleaning facilities, and underground storage tank (UST) regulatory compliance and case closures. Dr. Hekimian also provides forensic expert witness/consultant services to the legal community.

Kenneth K. Hekimian, Ph.D., RCE, REA

HVN Environmental Service Co., Inc.

15561 Product Lane, Unit D1, Huntington Beach, CA 92649

hvnenvironmental.com

310-984-3229