AIR SPARGING IN CONJUNCTION WITH VAPOR EXTRACTION FOR SOURCE REMOVAL AT VOC SPILL SITES.

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ABSTRACT

Effective source removal is the singularly most important activity in achieving remediation at a contaminated site. Vapor extraction (soil venting) has been demonstrated to be a successful and cost effective remediation technology for removing VOC's from vadose (unsaturated) zone soils. However, in many cases, seasonal ground water table (GWT) fluctuations, GWT drawdown associated with pump and treat remediation techniques, and spills involving dense, non-aqueous phase liquids (DNAPLS) create residually saturated soils below the water table. Vapor extraction alone is not considered to be an optimal remediation technology to address these contamination.

Artificial water table drawdown is one approach that may be utilized to expose the contaminated soils, thereby increasing the efficiency of the soil venting process. However, in some cases, this is not a practical, nor cost effective approach. An alternative approach is the use of sparging (injection) wells to inject a hydrocarbon free gaseous medium (standardly air) into the saturated zone below the areas of contamination. The contaminants dissolved in the ground water and sorbed on the soil partition into the advective air phase effectively simulating an in-situ air stripping system. The stripped contaminants are transported in the air phase to the vadose zone, within the radius of influence of the vapor extraction system. The contaminant vapors are drawn through the vadose zone to a vapor extraction well where they are treated utilizing standard vapor extraction off-gas control system(s).

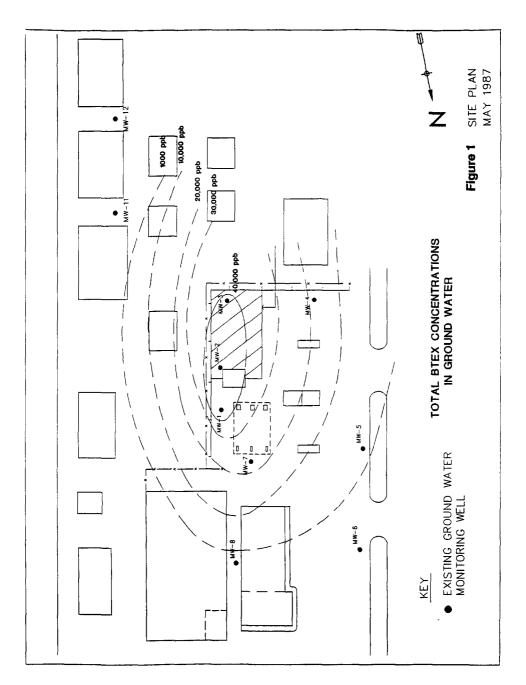
The following paper presents the application of air sparging in conjunction with vapor extraction in the remediation of contaminated soils both above and below the water table at a VOC spill site.

INTRODUCTION

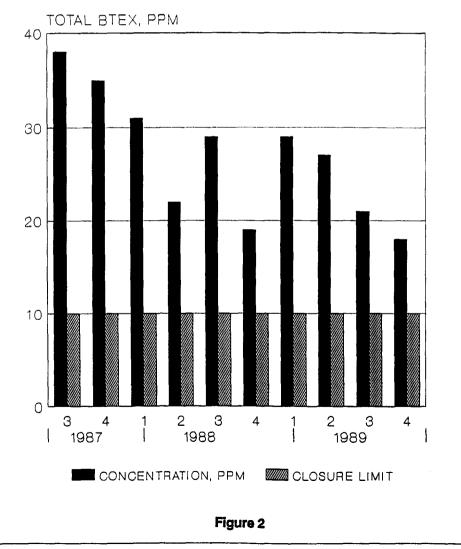
In 1985, remedial activities were implemented at a gasoline spill site in Pawtucket, Rhode Island. engineering company contracted to perform the remedial activities designed, installed and operated a free gasoline product recovery system and a ground water pump and treat system. An air stripping tower was utilized to remove volatile organic hydrocarbons (VOC's) dissolved in Gasoline hydrocarbon vapor migration into ground water. nearby basements was controlled through the operation of a soil gas containment system (SGCS), also installed in 1985. The ground water treatment and free product recovery systems were shut off in May, 1987; the SGCS was upgraded, through the installation of additional vacuum wells, to a soil vapor extraction system (SVES) to remediate gasoline contaminated vadose zone soils and to recover hydrocarbon vapors in the vicinity of the spill location (the former underground storage tank area). Approximate locations of the monitoring wells, vacuum wells, treatment equipment, and the total BTEX ground water plume existing on the site as of May, 1987 are presented in Figure 1.

The Rhode Island Department of Environmental Management (DEM) set closure limits of 10,000 parts per billion (ppb), 500 ppb, and 500 ppb total BTEX for MW-3, MW-11 and MW-12, respectively. While BTEX levels at MW-11 and MW-12 have remained below the closure limit prior to VAPEX's involvement at the spill site, levels at MW-3 fluctuated around 25,000 ppb total BTEX with a relative deviation of 16 percent over the period from July 1988 through July 1989, displaying a high of 29,000 ppb in July 1988 and a low of 19,000 ppb in October 1988. The last sample reported during that period was 21,000 ppb (in July 1989). Figure 2 demonstrates the fluctuations observed in the BTEX concentration levels in MW-3 over the period from July 1987 through December 1989.

VAPEX were contracted in August of 1989 by the site owner to evaluate site conditions for the purpose of developing a specific strategy to expedite clean-up, while meeting the DEM's total BTEX closure limits for MW-3. An evaluation of the existing soil vapor extraction system concluded that the SVES was influencing and had reduced gasoline concentration levels in the vadose zone soils in the area of concern to below standard analytical detection limits. It was concluded that the local source of ground



TOTAL BTEX CONCENTRATION AT MW-3 QTRLY. SAMPLING PRIOR TO AIR INJECTION



water contamination existed on the soils below the water table level in that area.

Under non-active remediation conditions, transport of immiscible phase hydrocarbons from the saturated zone to the vadose zone requires dissolution of the hydrocarbons into the aqueous phase followed by diffusion/dispersion of the dissolved hydrocarbons through the aqueous phase to the airwater interface, where volatilization into the vadose zone The hydrocarbon vapors would then be removed from occurs. the vadose zone by the SVES. Where total hydrocarbon concentrations in the saturated zone are moderately low, as was the case at this site, and conditions are relatively static, the intraphase transport of hydrocarbons occurs very slowly, requiring long periods of time for hydrocarbon source reduction. Therefore, utilization of the soil vapor extraction system alone would be expected to be a very inefficient means of achieving the DEM closure criteria at MW-3.

clients requirements Based on the of expedient remediation of the site a cost/benefit analysis was performed on three potential treatment methodologies to achieve the DEM Closure Criteria in the vicinity of MW-3. a) re-activate The three proposed treatment methods were: the existing ground water pump and treat system, b) install and operate a new pump and treat system centrally located within the area of concern, and c) in conjunction with the existing SVES, install and operate an air sparging system centrally located within the area of concern. As a result of the cost/benefit analysis it was proposed that an air sparging system be designed, installed, and operated at the site.

AIR SPARGING TECHNOLOGY

The air sparging process involves the introduction of hydrocarbon free air to the saturated zone below the contaminated soils in order to expedite transfer of saturated zone hydrocarbons to the SVES influenced vadose zone. Air flow in a previously water saturated soil involves a displacement process. The air displaces the water filling the soil pore spaces. When a continuous air phase through the previously water filled pores is attained, the air permeability of the soil will be a function of the degree of water saturation of the pore. The sparging system would be designed to ensure that the air would pass through the contaminated soils providing the hydrocarbons with a more efficient transfer pathway to the vadose zone.

Limited references exist in the literature as to the design and/or success of the laboratory or field application of the air sparging process. Apparently the process was

first utilized as a remediation technology in Germany in 1985, predominantly to enhance the clean-up of chlorinated solvent contaminated groundwater (Gudemann and Hiller, More recently the technology has been utilized in 1988). Mexico in the enhanced remediation of gasoline contaminated soils and groundwater (Ardito and Billings, 1990). Apparently, in each of these cases the design of the air sparging systems have been empirically based. VAPEX are currently involved in a joint venture with a leading university research center in performing both laboratory and field studies to determine and evaluate the major design parameters for this process. A multi-phase fluid flow model is being developed to be utilized as an engineering design tool for the application of air sparging technology.

SYSTEM INSTALLATION AND OPERATION

Site Geology

The general stratigraphy of the investigated area is defined by a fine to coarse brown sand with no silt and 5 to 15 percent fine to medium gravel extending from grade to 19 to 20 feet below grade. The coarse, highly permeable material is underlain by a much less permeable brown/grey, well sorted, dense, fine sand. Ground water was observed at 15.5 to 16.0 feet below grade, and displays a seasonal fluctuation of approximately 3 feet. Figure 3 presents a typical geological cross section of the site.

Design Parameter Evaluation

To verify the presence of the contaminated soils below the water table level and to develop design parameters for a full scale air sparging system, eight borings were advanced in the proposed remediation area. Soil samples were taken during the advance of the borings and were analyzed utilizing EPA Method 8020 for volatile aromatics. The results of the analysis confirmed the presence of low levels of weathered gasoline components on the saturated soils from feet to approximately 25 feet below grade. compounds detected ranged in concentration from micrograms per kilogram (ug/kg) to non-detectable, with levels generally decreasing with depth. BTEX concentrations detected in the vadose zone soils by EPA Method 8020 displayed non detectable levels indicating that the soil vapor extraction system had performed as designed. Figure 3 presents the results of soil jar headspace and the EPA Method 8020 analysis of the soils.

Two test air injection wells, (AIW1S and AIW2S), and three monitoring points (VP-1, VP-2, and VP-3) were installed at the site where the soils analyses had indicated the presence of relatively high levels of hydrocarbons in

	JAR	SOIL HEADSPACE (ppm)	SOIL TOTAL BTEX (ppb)
0		OVA	EPA METHOD 8020
5	FINE TO COARSE SAND, SOME FINE TO MEDIUM GRAVEL		
10		ND	
15	COARSE SAND AND	10	ND_
	FINE TO MEDIUM GRAVEL		
20		250	835
	VERY FINE TO FINE SAND		
25		200	528
30			563
	Figure 3		

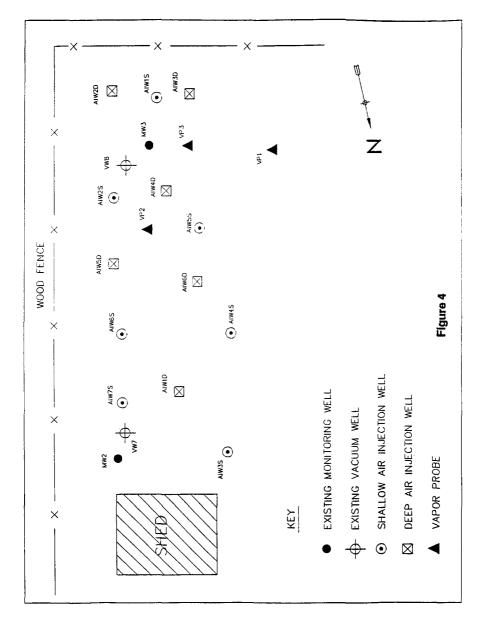
the soil and/or ground water. The approximate locations of the test injection wells and monitoring points are shown on Figure 4.

Major design parameters to be evaluated were: achievable contaminant removal rates, air entry and operation pressure requirements at the injection wells, achievable injected air flow rates, achievable effective radius of influence of the injection system and an evaluation of pulsed versus continuous air injection.

A one day pilot test was performed on the test wells (screened from 18 feet to 20 feet below surface grade). Pressures and achievable air flow rates were measured at each well and monitoring point during the pilot test. The discharge from the SVES was monitored prior to, during, and after the pilot test.

A portable gas chromatograph (HNU Model 321, equipped with a photoionization detector) was utilized to analyze the discharge data from the soil gas venting system. initiation of the injection test, the background discharge reading from the soil vapor extraction system was 13 parts per million by volume (ppm-v/v) as gasoline. During the injection tests, the discharge from the soil vapor extraction system reached a maximum level of 300 ppm-The SVES was operating at an air flow rate of approximately 100 cubic feet per minute (cfm) injection air flow rates varied between 10 and 20 cfm, providing a minimum withdrawal to injected air flow ratio of five to one. SVES discharge concentrations, generally, decreased relatively rapidly during the conduct of the injection test at a well, reflecting the potential mass transfer limiting conditions that exist during this in situ stripping process. Approximately 0.7 pounds of gasoline range hydrocarbons were removed from the ground water and saturated zone soils during the short term test.

Relatively low air entry and operation pressures of 1 to 2 pounds per square inch (psi) were required to achieve air injection flow rates of 5 to 10 cfm. As expected, during the air injection event, slight positive pressures were measured at the monitoring points in the vadose zone and a rise (0 to 1 inches) in the water table level was detectable within the area local to the injection well. As the shallow injection well screen was located 3 to 5 feet below the water table level in a coarse sand it was anticipated that the radius of influence of the injection wells would be relatively small. Based on the air pressure readings at the monitoring points and the local water table rise, the radius of influence was calculated to be approximately five feet. No significant differences were observed in mass removals during the injection test under pulsed versus continuous operation. However, with respect



to energy conservation and to prevent the development of short circuiting pathways for the air flow under continuous operation, pulsed injection was considered to be the most advantageous mode of operation.

Full Scale System Installation and Operation

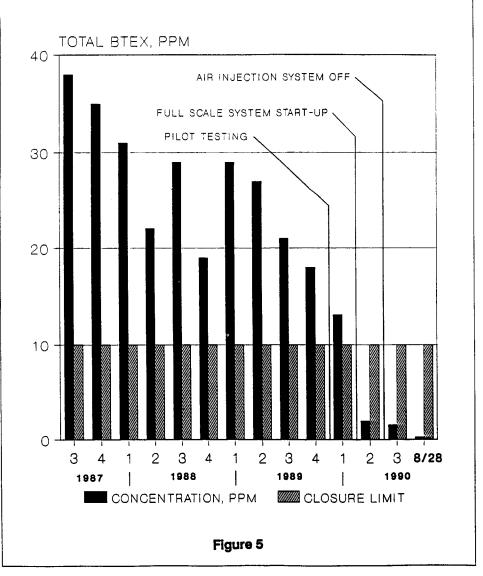
Based on the parameters evaluated during the pilot test, a full scale air sparging system was designed and The full scale system consisted installed at the site. seven shallow air injection wells and six deep injection wells enveloping the area of concern. Figure 4 presents the remediation area layout. The deep air injection wells were screened from 25 feet to 27 feet below grade in the fine Two, 2.5Hp Ingersoll-Rand Model T102520P1 sand material. provide oil-less compressors were utilized to hydrocarbon free air supply to the injection wells. shallow air injection wells were operated on a three hours on, nine hours off schedule, at an air pressure of 1 to 2 psi and 3 to 6 cfm air flow rates. The deep injection wells were operated on a six hours on, six hours off schedule, at an air pressure of 6 to 8 psi and 2 to 6 cfm air flow rates.

RESULTS

The operation of the full scale air sparging system consisted of a sixty day run time within the period from March 21, 1990 through July 14, 1990. During that period, approximately five to ten pounds of gasoline range hydrocarbons have been removed from the ground water and soils within the remediation area. The mass of hydrocarbons removed agreed reasonably well with an engineering estimate of the mass of contaminants in the saturated zone based on the soils analysis (four to seven pounds). The periodic determination of the composition of the SVES discharge by gas chromatography demonstrated that the dominant remediation process occurring at the site was the physical/chemical stripping process and not biodegradation.

Ground water samples were collected and analyzed utilizing EPA Method 602 prior to, during, and after the operation of the full scale air sparging system. The results of the ground water analysis are presented in graphical form in Figure 5. From Figure 5 it can be seen that following 2 to 3 weeks of operation the levels of BTEX in the groundwater had declined to well below the DEM closure criteria within the area of concern. One to two weeks prior to groundwater sampling the system was shut-off to allow the subsurface environment to come to equilibrium. BTEX concentrations in ground water samples obtained from MW-3 have been measured as low as the hundreds of ppb level. Dissolved oxygen levels within the area of concern rose from an average level of 1.4 milligrams per liter (mg/1) to

TOTAL BTEX CONCENTRATION AT MW-3 SAMPLING PRIOR TO/AFTER AIR INJECTION



approximately 6 to 8 mg/l reflecting the aeration of the ground water within the zone of influence of the air sparging system. At this site the oxygenation of the ground water did not have an adverse effect on the chemistry of the aquifer system (change in pH or redox potential), however the potential geochemical and biological changes that may occur as a result of the sparging process should be evaluated during the design of this type remediation system. As determined by pressure measurements in the vadose zone the air sparging system as designed displayed an effective radius of influence that enveloped the area of concern.

CONCLUSIONS

An air sparging system was designed, installed and operated at a gasoline spill site in Rhode Island. Formerly the site had undergone five years of remediation utilizing a combined system of groundwater pump and treat, free product recovery and soil vapor extraction. While the soil vapor extraction system was effective in remediating the vadose zone soils, gasoline contamination remained on the soils below the water table level and the Rhode Island DEM closure criteria of 10,000 ppb total BTEX at MW-3 was not achieved.

Following 60 days of operation of the air sparging system approximately 5-10 pounds of gasoline range hydrocarbons were stripped from the ground water and water saturated soils. Within 2 to 3 weeks of operation the closure criteria was achieved at MW-3. Except for an anomalous rise in total BTEX levels at MW-3 in October of 1990 the closure criteria has been maintained at the site. The site continues to be on a quarterly ground water monitoring program.

The results of the case study demonstrate the potential for air sparging to be utilized as a complimentary technology to vapor extraction to attain a cost effective, turnkey solution for remediation of volatile organic chemical spill sites. Care should be taken in the site evaluation in order to predict potential inhibitory chemical reactions that may occur in the aquifer as a result of the sparging process.

From this case study and the available literature it is apparent that air sparging system design is based on empirical pilot testing, VAPEX are presently involved in a joint venture with a leading university research center in laboratory and field studies in order to better understand the major parameters governing the sparging process and in the development of a multi-phase fluid flow model to be utilized as an engineering design tool in the application of the technology.

BIOGRAPHICAL SKETCH

Michael Marley is a Principal and Technical Director at VAPEX. Mr. Marley has a Bachelor's degree from Queens University (Belfast, Northern Ireland) and a Master's degree from the University of Connecticut, both in Civil Engineering. He is presently completing work on his Ph.D. dissertation at the University of Connecticut on the development and application of air flow models in the design of soil and ground water remediation systems. Mr. Marley has over 12 years of field experience, has lectured nationally on the design and implementation of soil vapor extraction systems and complimentary technologies, and has authored more than 20 technical articles.

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