TWO-PHASE EXTRACTION
DESIGNING, PERFORMANCE EVALUATIONS AND VOCs STRIPPING

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ABSTRACT: This paper presents the results and lesson learned from several two-phase extraction tests and system operations data from the last three years. The paper provides an outline for the proprietary and non-proprietary two-phase extraction methods, designing and implementing effective pilot tests, performance monitoring, and design considerations for volatile hydrocarbons stripping and minimizing the friction losses. Two-phase extraction is an effective method for the remediation of soil and groundwater contaminated with volatile hydrocarbons. Two-phase extraction removes both groundwater and soil vapor in a common stream while enhancing biodegradation of the hydrocarbons in the vadose and the saturated zone. The method should be used after serious consideration for the water lifting mechanism of the vacuum, and the friction losses due to handling large volume of water. In most applications, a conventional vacuum blower system with a carefully designed knockout and piping system can perform as well as a liquid ring pump system. The success of two-phase extraction depends on the ability of the piping design to deliver maximum vacuum to the wellhead with minimal friction loss in the extraction pipe. One major challenge is to lift the water in the well from depths greater than 33 feet. There are several proprietary and non-proprietary methods available presenting their own challenges and benefits. Another major challenge is to measure the vapor flow at the individual wellhead when extracting from more than one well. A flow splitter was developed to overcome the difficulty of measuring flow of water and vapor separately. Two-phase extraction strips volatile compounds from the groundwater with stripping efficiency up to 99% for BTEX and/or MTBE observed during two full-scale system operations and over seven pilot tests.

INTRODUCTION

The purpose of this paper is to provide a brief overview of two-phase extraction methods for remediation of soil and groundwater contaminated with volatile organic compounds (VOCs).

Two-phase extraction is a method of vapor and water removal in a combined flow stream using a vacuum and a drop tube. Two-phase extraction is widely used for remediation of VOCs and can be applied as a good source reduction method to prepare any site for natural attenuation and risk-based site closure. Several records related to the use of two-phase extraction, multiphase extraction and dual phase extraction methods in the environmental cleanup area, can be found in literature going back to over a decade. This paper will briefly introduce few of these methods and applications that had significant impact on the use of two-phase and multiphase extraction methods.

One of the challenges of performing a two-phase or multiphase extraction is to overcome the limitations of the vacuum when extracting water from depths greater than 33 feet (10.06 m) below ground surface (BGS). The maximum available vacuum lift for water is 33.9 feet (10.33 m; 29.92-inches [76 cm] of mercury), which is the displacement of the Earth's atmospheric pressure. In order to obtain greater lift, the extraction pipe should have a mechanism to allow air inflow with the water at the same time. This can be accomplished by injecting air during extraction or allowing air to be extracted with the water by placing pipe intake at the air/water interface (water table). The applications of two-phase extraction can be summarized in two major categories: (1) non-proprietary methods (non-patented technologies) and (2) proprietary methods (patented technologies).

Non-Proprietary Methods:

Bioslurping. This method uses a drop tube set at the air/water interface to allow both air and water enter simultaneously into the drop tube when vacuum is applied to the distal end of the drop tube (Baker, 1996 and Trowbridge et al, 1991). This method is mostly used at the sites where LNAPL is present on top of the water table (multiphase extraction).

Dual Phase Extraction. This method uses two separate flow streams for vapor and water. Water is removed from the extraction wells using a submersible pump while extracting vapor from the vadose zone. The terms dual phase extraction and two-phase extraction have been used interchangeably in some literature. However, the dual phase extraction method is significantly different from the conventional two-phase extraction and may involve two completely separate above ground equipment and extensive piping (electrical or pneumatic conduit for each extraction well, separate extraction lines for vapor and water, etc).

Proprietary Methods:

The Morrow Method. A patented method that involves placing an air injection line that is open to atmosphere inside the drop tube (Morrow, 1991). This method is also known as *priming method* and *air assist* method. Air can be injected actively using a compressor, or passively as a response to applied vacuum to the drop tube to start two-phase flow. The drop tube draws vapor from the vadose zone, when the water level in the extraction well drops below the bottom intake of the drop tube.

The Xerox Method. A patented method that involves air injection into the drop tube using an air injection line(s) placed outside the drop tube (Mancini et al, 1994). The air injection line(s) connected to the drop tube via a manifold(s) on the side of the drop tube and to atmosphere through an injection pump (compressor or blower). The air can be injected at several points from the side and/or the bottom of the drop tube either actively, using a compressor, or passively as a response to the applied vacuum. When the water level in the extraction well drops below the bottom intake of the drop tube the vapor from the vadose zone is drawn into the drop tube.

The Bubblex[1] Method. A patented method that uses a drop tube with orifices to draw limited amount of air and vapor from the vadose zone with the water when

[1] Bubblex is a service mark of Tait Environmental Management, Inc., Santa Ana, California

vacuum is applied to the distal end of the drop tube (Pehlivan et al, 1999). This method draws vapor/air from the vadose zone at all times and uses this vapor/air to lift the water from depth greater than 33 feet as well as to strip VOCs from the extracted water.

Both proprietary and non-proprietary methods of two-phase extraction tried to overcome the limitation of vacuum extraction in lifting water from depth greater than 33 feet. In most cases the extraction and treatment unit used on the surface were identical with the exception of the drop tube used for extraction.

PILOT TEST AND SYSTEM DESIGN

Before using two-phase extraction, it is recommended that a pilot test be performed. A two-phase extraction test requires using a vapor extraction unit equipped with a high vacuum (liquid ring pump) blower, a water/air separating knockout tank, a carbon polishing unit for the water (or a storage tank), depending on the method selected, an air injection/priming system (a compressor or an air blower) and a drop tube system (with or without injection setup). Naturally, an effective pilot test should start with reviewing all the available assessment records, soil test results (physical and chemical properties) and any other feasibility testing results (aquifer test, vapor extraction test etc.). Prior to start of a pilot test, depth to groundwater in monitoring and extraction wells should be measured. Distances between all observation and extraction wells should be recorded. If more than one extraction well will be used for the pilot test, at least one of the wells should be placed near the source area and another one downgradient of the plume near the area where hydraulic control is desired. The extraction equipment, especially the air/water separation tank should be located at a low spot at the site to allow water flow under gravity from the wells to reduce the friction loss. Straight piping between the extraction wells and the system is preferred over a coiled hose. An effective pilot test should have the following monitoring/data collection program for the design of the system:

- The zone of influence of the vacuum and groundwater drawdown.
- Vapor and water flow rates.
- Recovery of VOCs from water and the vadose zone.
- Frequent measurements of vacuum at the system, at the extraction wellhead (drop tube) and at the well annulus (in the casing outside the extraction pipe).
- The analysis of extraction time versus water drawdown in observation wells (three wells minimum).
- The analysis of extraction time versus vacuum response in observation wells (three wells minimum).
- The analysis of extraction time versus vapor concentrations at the main extraction well or at the system.
- The analysis of extraction time versus water concentrations in the extraction stream (minimum three samples should be collected from the extracted water).
- Pre-test and post-test vapor readings from the extraction and select observation wells, including measurement of permanent gases (CO_2, CH_4, and O_2).

- Pre-test and post-test groundwater sample results from extraction and select observation wells. Collection of mid point groundwater samples from the extraction wells are also recommended for a test lasting over 4 hours.

PERFORMANCE MONITORING

The monitoring parameters listed under the Pilot Test section above should also be part of a performance evaluation monitoring when a two-phase system is operated. A performance evaluation monitoring should also include the cumulative removal data from the vapor phase, and aquatic phase with a comparative evaluation of the cost per pound removal to determine when the system is not cost effective to operate as configured. The removal rates of VOCs from individual wells should be monitored frequently to maximize the system operation. The well recoveries and biological activities in the extraction wells should be monitored frequently enough to recognize any bio-fouling in the wells.

CASE STUDIES – LESSONS LEARNED

This chapter is prepared to share experiences and lesson learned from over ten pilot tests, several full-scale two-phase and dual phase installations and operations. In each of these pilot tests and system operations I have learned valuable lessons in optimizing the system operation, maximizing the extraction of water and vapor and performance monitoring of the system operation. Following are the brief narratives and lesson learned from my personal experiences:

Vacuum Difference Between Extraction Pipe and Well Annulus. The difference between the vacuum readings in the extraction pipe at the wellhead and the vacuum readings in the well casing is related to the permeability of the vadose zone. We (my co-workers at Tait Environmental Management, Inc. and I) observed that the vacuum differences between the well casing and the drop tube varied in differing vadose zone soil types (change in permeability). Later we were able to test this concept in a display model as well. Our display model had 4-inch wells with a solid casing connected to a tank from the bottom openings below the water level of the tank. In order to simulate vadose zone permeability, we placed two extra openings to the well cap that was holding a clear PVC drop tube. A valve was placed on one of the extra opening, and a vacuum gauge on the other one. We applied 36 inches of water column (W.C.) vacuum to the drop tube and observed the vacuum in the well casing and the flow in the drop tube. When the valve setting was changed, the vacuum in the annulus was responding as a response to the increased or decreased air entry (connection to the atmosphere simulated the increase and decrease in vadose zone permeability). Since all the other parameters remained constant, we can reasonably predict that the vacuum differences between the extraction pipe and the well casing are related to changes in vadose zone permeability. As the vadose zone permeability (opening the valve) increased the vacuum difference between the drop tube and the well casing also increased. We have clearly observed this phenomenon in the field during all our pilot tests and system operations. For example in a sandy soil with approximately

5 feet of open(vadose zone) screen, 2 gallons per minute (gpm) of water flow, 40-50 CFM of vapor flow we have observed the extraction pipe (EP) vacuum to well annulus (WA) vacuum ratio to be 81/18 (~4.5/1) inches of W.C.. At the same site similarly constructed well in clayey sand and silt zone yielded 0.1 gpm water and 15-20 CFM vapor flow with an EP/WA vacuum ratio of 156/100 (~1.5/1).

Vapor and Water Flow Measurements. One of the most difficult measurements in two-phase extraction is the flow measurement. In order to measure both vapor and water flow accurately the liquid and vapor need to be separated. A flow splitter was developed to measure both vapor and water flow separately at each wellhead. The flow splitter is a looped piping that allows water flow to the lower section of the loop while routing the vapor flow to the upper section. With this apparatus we were able to establish air to water ratio for the VOCs stripping rates that we have observed in our pilot tests and performance monitoring data from the operating two-phase extraction systems (Pehlivan et al, 2000a).

Friction Loss Related to Moving Water With Vapor: When we were performing a ninety day test at a site in Southern California using a Baker Unit without the liquid ring pump, we observed that the water recovery (~ <1 gpm) from the wells were a lot less than the recoveries we observed during well development (~ 2gpm). We did some vacuum readings along the extraction pipe between the system and wellheads. We observed that the vacuum loss between the wellhead and knockout tank were over 60%. The majority of the vacuum loss was on the sloped pipe where it was rising to the knockout tank (approximately five feet of rise from the ground surface). We were using above ground piping at this site. We raised the piping, placed 5 foot of casing extension on each extraction well and provided a gentle slope in the extraction pipe toward the knockout tank. This modification nearly tripled amount of water recovery and increased the vacuum delivered to the wellhead.

Comparing the Pre-test and Post-test VOC Concentrations. During one test in Studio City, California, we have observed that the groundwater concentrations during extraction as collected from the extraction well declined in the well near the source zone and increased in the well on the perimeter of the plume. Similar observations in other tests were also noted. Although we can not conclusively predict that the change in pre-test and post test groundwater concentrations is always related to the proximity of the source, our observations in known cases made us to believe that there is a connection. Additionally, at a site where we were performing bi-weekly two-phase extraction in five wells, we observed that post test VOC concentrations in one of the well were consistently higher. We placed another well near this well observed that the VOC concentrations in groundwater was five times higher than the well that we observed increasing post-test VOC concentrations in our tests.

Consider Intermittent Operations. In one site we observed that after eight hours of extraction the VOC concentrations in the groundwater did not reached back to the near starting levels in over 5 days. In order to explain this observation, we re-evaluated the soil analytical results and the capillary pressure tests performed by a laboratory on the soil samples collected from the various soil zones at this site. We determined that the VOC contaminations were mostly in a zone with irreducible water saturation over 80%. We realized that our extraction efforts were removing the water from the 20% of the pore volume. The VOCs that was diffused into the 80% of the pore volume (irreducible water zone) would need to be diffused out of this space by replenishing the water in 20% of the pore space (effective pore space) in optimum frequencies. If we installed a system and operated continuously at this site, we would be flushing out a lot of clean water from the 20% of the pore space without impacting the irreducible water zone significantly. This would result in treatment of clean water, and unnecessary system operation costs. We realized that by operating weekly or bi-weekly we could accomplish the similar treatment efficiency with a system operating continuously.

Two-phase extraction strips VOCs. We have observed that up to 99% of the VOCs stripping is possible during two-phase extraction with a careful selection of design and operating parameters. The stripping efficiency is increased when the VOC concentrations in the vadose zone are lower, vapor flow is higher, water flow is lower, and depth to water is higher (Pehlivan et al, 2000a and 2000b).

SUMMARY

Two-phase extraction requires a good understanding of the subsurface geological and hydrogeological conditions while providing valuable information for such conditions. The observations and suggestions presented in this paper should not be accepted without first validating at a given site by a pilot test or operation and performance monitoring data. All the observations presented in the Case Study-Lessons Learned section were made by using the Bubblex Method. Using a different method may result in a different finding. I strongly suggest testing of our observations by other scientists working in this area. Additional studies related to the modeling of two-phase flow in the subsurface and stripping efficiency are recommended. Additionally, it is strongly suggested that before performing a two-phase extraction, a record search and a review of patents should be performed to avoid any legal ramifications.

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