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Application Note #2

BIO-VEPS Recovery Of LNAPLs at Holloman AFB, New Mexico

The attached technical paper was presented at the National Defense Industrial Associates 25th Environmental Symposium & Exhibition on March 29, 1999 in Denver, Colorado. This paper represents a very good example of the benefits of combining two well known technologies, Free Product Skimmers and Vacuum in the same well to increase LNAPL recovery. The Free Product Recovery Pumps mentioned in this paper were Xitech ADJ1000 Smart Skimmers. If you would like more information about this application or our products please call Xitech or visit our Web Site at www.xitechinc.com.

BIO-VEPS recovery of LNAPLs is an alternative to BIO-SLURPING. BIO-VEPS stands for Vacuum Enhanced Product Skimming With Biological Action. There are 2 good reasons to choose BIO-VEPS over BIO-Slurping. The first reason is that the BIO-VEPS technology is less expensive to purchase and operate. BIO-VEPS eliminates all above ground treatment system technology, and uses only low inches of water vacuum to enhance LNAPL recovery, thus eliminating the need for expensive liquid ring vacuum pumps. The second reason is that the Law has recently been changed to consider natural attenuation on most LNAPL sites after the liquid LNAPL is removed. This means that recovery of groundwater is no longer necessary on most sites. BIO-VEPS has retained all of the good attributes of BIO-Slurping like In situ mass destruction of LNAPLs via Bio enhancement, large range of recovery of liquid LNAPLs to the recovery wells, and recovery of light vapor LNAPLs. A BIO-VEPS system is very easy to operate and maintain. Xitech has developed the ADJ1000(4”) and ADJ200(2”) Smart Skimmers for BIO-VEPS applications. These skimmers can recover liquid LNAPLs from wells operating under 160 inches of water vacuum. Teaming up our Smart Skimmers with an above ground low vacuum system is the most cost effective method for recovering LNAPLs today.

OPTIMIZING FREE-PRODUCT (LNAPL) RECOVERIES USING INNOVATIVE BALANCING OF VER & SKIMMER TECHNOLOGIES

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ABSTRACT: A 3-month pilot study was performed to determine if down-hole hydrocarbon pumps, equipped with hydrophobic filters, can be used as an adjunct to vacuum-enhanced recovery (VER) systems for the efficient recovery of light non-aqueous phase liquid (LNAPL) hydrocarbons. Since on site groundwater is classified as non-potable, remediation beyond the removal of any LNAPL thickness is not necessary. The study goal was to achieve a higher rate of LNAPL removal without an increase in costs (i.e., additional water treatment), to insure the greatest volume of LNAPL recovery from the subsurface per dollar spent. Application of various stepped vacuums and pumping intervals resulted in average LNAPL recharge rate increases by an approximate factor of five (5X). Increased product recoveries from 1.5 gallons (gal)/day/well in Phase I of the study to greater than 10 gal/day/well in Phase II were recorded. The dynamic wellfield management techniques tested increased pre-study LNAPL product recovery by 41 percent when compared to similar time intervals for the previous 12-month operational period of high-vacuum dual-phase extraction (HVDPE) operation alone.

INTRODUCTION

Vacuum-enhanced technologies have been demonstrated to successfully remediate hydrocarbon-impacted soil in low permeability formations. Combining technologies and realizing combined benefits, which are greater than additive without each technology's limitations (synergistic effect), are essential to moving sites toward closure sooner. In the pilot study performed, an existing HVDPE system was combined with down-hole free-product skimmer pumps.

A significant feature of VER is the induced airflow, which in turn induces LNAPL flow toward the extraction well. The pressure gradient created in the air phase results in a driving force on the LNAPL that is greater than that which can be induced by pumping the LNAPL with no induced airflow (gravity). Also of importance is the fact that airflow created by the vacuum enhances the LNAPL content surrounding the extraction well. This accumulation around the well ensures that the permeability controlling the conductivity of LNAPL is maximized. For these reasons, in addition to mass removal via soil vapor extraction, VER has the potential for removing more LNAPL and at greater rates than do other source removal mechanisms. However, the increased vacuums required to bring the recovered LNAPL to the surface from greater depths brings with it significant volumes of groundwater. Groundwater extracted during VER must be handled, treated, and discharged, which increases costs in necessary equipment and long-term operations.

Alternatively, skimmer systems withdraw little to no groundwater. The selected skimmer has a polyethylene LNAPL collection filter, a self-adjusting depth range capable of compensating for 2.5 feet (ft) of rising/falling groundwater effects, and weighted to float at the groundwater/LNAPL interface. The skimmer filter is hydrophobic and has a programmable timer, which periodically applies air pressure to the collection chamber to push accumulated

LNAPL to the surface. In general, the resulting limited pressure head (actual free-product-saturated formation thickness) provides minimal LNAPL drive toward the extraction well. This passive movement typically yields relatively low hydrocarbon recovery rates.

Objective. Determining the effect of using skimmer pumps as an adjunct to VER of LNAPL was the objective of the pilot study. The study evaluated the efficacy and feasibility of combining two existing technologies in an effort to increase LNAPL recovery, while minimizing groundwater removal, thus decreasing equipment and long-term operational costs.

Site Description. In 1991, approximately 2,000 gal of JP-8 jet fuel leaked from underground lines leading from an above ground storage tank at the T-38 Test Cell (IC) on Holloman Air Force Base (HAFB). The base is located in southern New Mexico, 7 miles west of the city of Alamogordo. In subsequent investigations 450,000 to 485,000 gal of JP-8 LNAPL, ranging from a sheen to a maximum apparent thickness of 7.5 ft, were detected over an 11-acre area.

Groundwater occurs at 6 to 20 ft below ground surface depending on topography surrounding the TC. Hydraulic conductivities, based on slug tests, range from 7.9×10^{-5} to 2.9×10^{-4} centimeters/second. Porosities averaged 33 percent. However, effective porosities are interpreted to be significantly less than 33 percent in most cases. The gypsiferous nature of the site soil has resulted in a groundwater total dissolved solids (TDS) content in excess of 10,000 milligrams/liter in most of the basin. Groundwater beneath HAFB is classified as non-potable under the New Mexico Water Quality Control Commission Regulations. Therefore, it does not require remediation beyond the removal of any LNAPL contamination that might exist.

Shallow soil beneath the TC extending to approximately 15 ft consists of intercalated layers of alluvial sediment. Upper soil is typically tan to light brown, fine-grained, silty sand/sandy silt or silty clay/clayey silt. Underlying this layer to approximately 30 ft is reddish-brown silty clay/clayey silt with interbedded fine-grained silt and sand. Discontinuous caliche layers are also present across the site. Moisture contents of vadose zone soil ranges from 2 to 11 percent, increasing with depth. The heterogeneic character of HAFB soil, combined with the high percentage of fine-grained silt present throughout the shallow soil, results in low permeabilities. These characteristics limit the migration of the LNAPL plume, but also hinder hydrocarbon recoveries.

OPERATIONAL HISTORY

A Corrective Measures Study was performed in 1994 to establish cleanup objectives and identify and screen potential remediation alternatives. The established corrective action objects (CAO) mirrored the HAFB negotiated basewide soil remediation standards of 1000 milligrams/kilogram (mg/kg) total petroleum hydrocarbons (TPH) and 25 mg/kg benzene with the New Mexico Environment Department. At the conclusion of the CMS, HVDPE was selected as the best remedial alternative.

Interim Remediation System. A rapid response action was initiated to alleviate potential explosive vapors in the central one-acre of the LNAPL plume. Under contract to the US Army Corps of Engineers (USACE), Omaha District, a HVDPE system was designed and constructed. The system consisted of 11 extraction wells, a 5,000 standard cubic feet per minute (SCFM) thermal oxidizer unit (TOU), a 60 gal per minute water treatment system, an 8,000 gal storage tank and an 80 ft X 80 ft infiltration gallery for groundwater reinjection. A 30-hour pilot study was performed prior to construction to collect design information for the interim system. Wells were constructed of 4-inch (in.) diameter schedule-40 polyvinyl chloride (PVC) pipe and screen that were installed in a 10-in. diameter borehole. Drop tubes, located inside the well casings, were made of 2-in. diameter schedule-40 PVC pipe which allowed system operators to adjust the vacuum point elevation based on water table fluctuations and product thickness variations. The system was designed to operate at a vacuum of 16 to 20+ in. of mercury (Hg), providing 25 SCFM flow rates at individual wells, and utilizing a closed-loop oil-sealed vacuum blower.

Foster Wheeler Environmental Corporation (FWENC), was awarded a Total Environmental Restoration Contract (TERC) by the USAGE in 1994 and was selected to conduct all restoration activities on HAFB, one of three Air Combat Command (ACC) anchor bases. The TERC was developed to facilitate ACC's Accelerated Cleanup Program. As such, FWENC and its subcontractor team took over the operation and maintenance of the interim system in March 1995. The interim system was operated until November 1995 when construction of the full-scale HVDPE system was initiated.

Full Scale Remediation System. In June 1996, construction of the full-scale system. was completed and the system was brought on line. An additional 122 extraction wells were installed and two additional vacuum skids and vapor/liquid separators were utilized. The extraction well network, totaling 133 extraction wells, was divided into 6 sections (A through F) each comprised of 21 to 23 wells. The preexisting air and water treatment facilities were adequate for the full-scale system. Valves that allow for the operation of any combination of the six sections were strategically placed in the extraction network piping. This valving was critical to the manipulation of the LNAPL plume and allowed system operators the flexibility to adjust the number of vacuum skids utilized, vary which sections were on line, and adjust drop tube positions/elevations relative to the groundwater/free-product interface.

Previous System Configuration & Performance. System optimization efforts resulted in the use of 34-in. diameter drop tubes raised at varying distances above the groundwater/free-product interface and each vacuum skid pulling from two sections. The benefits of such a system configuration were immediately apparent and included: (1) a manageable volume of water was being extracted while the product-fraction of the total liquid extracted increased substantially, (2) a more uniformly concentrated vapor flow reduced the occurrences of high-temperature TOU shutdowns, and (3) longer periods between maintenance activities were achieved with the reduced impact of the high TDS groundwater affecting the system.

To Date, the T-38 Remediation System has removed over 225,000 gal of JP-8. Between August 1997 and May 1998, the majority (approximately 86 percent) of the mass of hydrocarbons removed were in the vapor phase. The fraction of free-phase product removed posed the concept of a cost-effective increase in source removal utilizing other technologies as an adjunct to the existing system.

SCOPE OF PILOT STUDY

Two tests were performed to assess proposed modifications to increase system performance while reducing operation and maintenance costs. Phase I involved baseline data collection and the application of down-hole hydrophobic skimmer pumps to remove the free (mobile) phase product. Phase II included VER and the concurrent use of the hydrophobic pumps.

Phase I: Baseline Data Collection. Pilot study preparation (equipment procurement, system configuration, etc.) and collection of baseline field data including fluid-level measurements (depth to groundwater and LNAPL thickness) and baildown tests were performed in the first 4 weeks. Ten existing 4-in. recovery wells were selected for the study: five wells with the greatest observed LNAPL thickness (D-Section, best recovery potential) and five wells with the smallest observed LNAPL thickness (B-Section). Baildown tests were performed and static (no vacuum enhancement) LNAPL recovery rates were recorded.

Phase Vacuum Step Tests and Optimization. Incremental (low to high) vacuum pressures were applied to the test wells and LNAPL recovery rates were recorded for the remaining 8 weeks of the study period (system was not operated over the weekend). Recovered free product was collected in a 55-gal drum at each well head and was measured daily. Based on site soil and previous operational knowledge, vacuum steps were 10, 20, and 30 inches of water column (IWC). Various skimmer-pump cycle times (both interval and duration) were tested in an effort to observe the effect on LNAPL recovery.

DISCUSSION OF RESULTS

During the 3-month study period, the skimmers removed an approximate total of 7,812 pounds (lbs), or 1,260 gal of free phase LNAPL, from the subsurface and only 31 gal of water. Hydrocarbon mass removed in the aqueous (dissolved) phase was estimated based on the minimal groundwater extracted and the average concentration of total hydrocarbons detected in the monthly regulatory samples. The vapor extraction portion of the study removed approximately 9,000 lbs, or 1,452 gal, based on laboratory analytical results.

Overall, the investigation removed approximately 16,819 lbs of total hydrocarbons, or 2,713 gal, based on a laboratory tested specific gravity of 0.83 for the recovered fuel, almost half in the free phase. Table 1 summarizes the hydrocarbon recovery data.

Table 1. Summary of Hydrocarbon Recovery Data

Hydrocarbon Phase	Volume Removed (gal)	Mass Removed (lbs)	Percent of Mass Removed
Liquid (Free Phase)	1,260	7,812	46.5
Aqueous	1.2	7.4	<0.1
Gaseous	1,452	9,000	53.5
Total	2,713	16,819	100.0

Increased Recovery Rates. As illustrated in Figure 1, product recovery rates increased following vacuum application, increasing the initial recovery rates from 1.5 gal/well/day to greater than 10 gal/well/day. Approximate recharge rate increase factors ranged from 2.5 for the poorest recovery well to 10 for the greatest recovery well, averaging 5.6.

The first vacuum step was performed at 10 IWC. Vacuum-enhanced hydrocarbon recoveries increased by a factor of five (5X) and the free product was recovered with no groundwater. Properly positioned skimmer pumps (adjusted for product thickness groundwater depression) reduced the required maintenance necessary for efficient operations. At 20 IWC vacuum, additional maintenance activities were required. Recoveries were not only less than at 10 IWC, but emulsification of the LNAPL caused water to be entrained in the recovered fuel and increased required filter replacements. Similarly at 30 IWC vacuum, although recovery rates

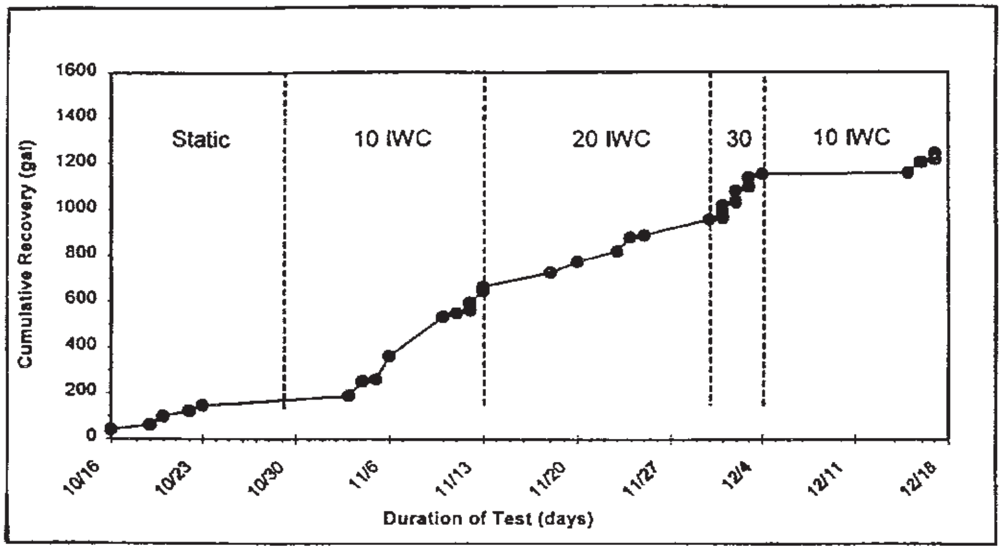

Figure 1. Free Product Recovery versus Time Throughout Pilot Study.

were temporarily higher, maintenance was required more frequently and recoveries greater than one or two well volumes were not sustainable. Product saturation in the soil surrounding each well was successfully reduced, however, long-term recovery diminished to volumes less than recoveries obtained at 10 IWC. Figure 2 illustrates the step tests and hydrocarbon recovery rates at well D-10.

Given the low permeability of the site soil, groundwater up-welling at both of the higher applied vacuums reduced the accessible LNAPL saturated formation thickness. This is of particular interest in thin product-bearing formations; since the limiting factor for product yield is that drawdown cannot exceed the saturated thickness of the product-saturated zone (assuming no induced gradient). So a balance must be obtained in that the highest achievable gradient is desired, with the least amount of induced up-welling reducing the product-bearing formation, and limiting recovery to the well.

For verification and repeatability, the final vacuum step of the study was repeated at 10 IWC. Repeating the step test provides a more accurate basis for comparing sustainable LNAPL recovery rates with other removal technologies. Similar to the first step test at 10 IWC, identical recoveries were observed in the last step.

Pump interval and duration were varied to find the effect on recovery. Pump intervals were initiated at 1.5 hours and durations of more than 10 minutes. Well recoveries however were not great enough to sustain these durations; therefore durations were decreased as recoveries were increasing ultimately using a 30-second duration at an interval of every 30 minutes. This combination of interval and duration, applying 10 IWC vacuum, was found to be the most productive in terms of the greatest LNAPL recovery rate.

Engineering Comparison. Historical HVDPE free-product recovery rates were reviewed and compared to pilot study recoveries. Results indicated the combined methodology recovered 41 percent more free-product. HVDPE, on a larger scale, concurrently achieved progress toward both CAOs, though not as efficiently or as cost effectively as the demonstrated combined methodology. The increase in source-removal rates (decrease in LNAPL thickness), with minimal increase in costs, was substantial.

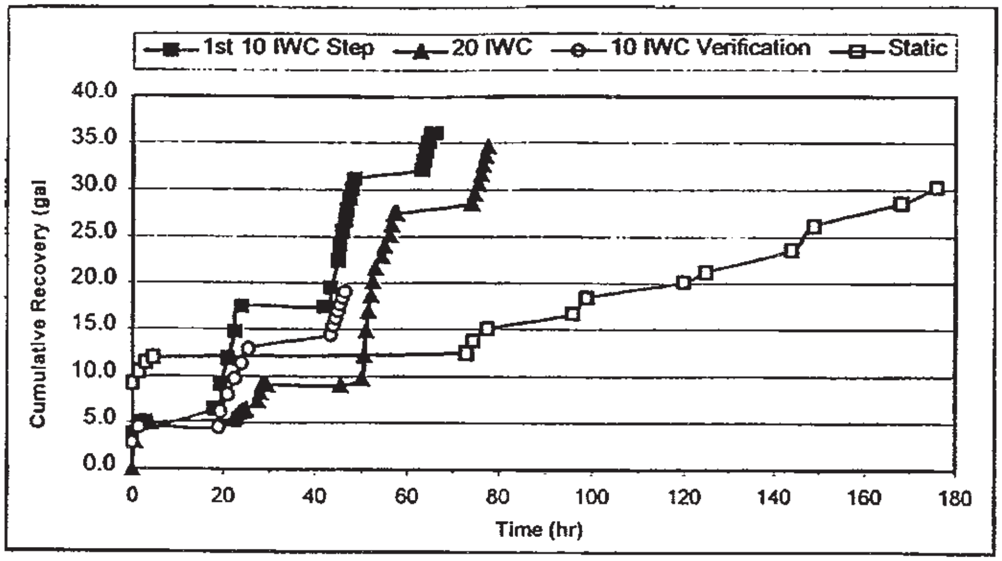

Figure 2. VER Relative to Static Recovery.

The demonstrated combined methodology proved a great adjunct to the existing system, satisfying the goal of the cost-effective collection of free-product with little to no groundwater. Additionally, the VER/Skimmer pump system can be rotated to greater free-product thickness sections/areas, increasing system flexibility. Concurrent realization of both remedial objectives will save costs, opposed to vadose zone remediation completed prior to LNAPL thickness removal due to higher mass-transfer rates in the vapor phase during HVDPE. This sequential approach is inefficient and will result in prolonging the remedial timeframe, increasing long-term costs.

CONCLUSION

Increased mass-removal rates decrease total removal costs. The investigation results demonstrated the combined extraction methodology ensured effective source removal, which will ultimately decrease long-term operation and maintenance costs. Dynamic combination of today's existing technologies, and realizing the combined benefits without each technology's limitations, is essential to moving sites toward closure sooner.

Concerns/Limitations. The following concerns/limitations warrant mentioning:

- Application of higher vacuums would be expected to produce proportionately higher yields of free product. However, groundwater up-welling (in lower permeability soil) decreases the accessible product-bearing saturated formation and, therefore, limits recovery to the well.
- Hydrophobic filters used in this study were density selective. Higher vacuums also resulted in limiting recoveries as a result of water entrainment, as the free product emulsified to the eventual point of being pumped with water.
- The increased mass-removal rates and the effectiveness of the combined technology are directly dependent on site characteristics (geologic, hydrogeologic, and contaminant characteristics, etc).
- Vacuumed-enhanced increased removal , rates in higher conductivity soil must be weighed against reduced control of free-phase plume migration.