Technology Overview Report

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Bioslurping

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FOREWORD

About GWRTAC

The Ground-Water Remediation Technologies Analysis Center (GWRTAC) is a national environmental technology transfer center that provides information on the use of innovative technologies to clean up contaminated groundwater.

Established in 1995, GWRTAC is operated by the National Environmental Technology Applications Center (NETAC) in association with the University of Pittsburgh's Environmental Engineering Program through a Cooperative Agreement with the U.S. Environmental Protection Agency's (EPA) Technology Innovation Office (TIO). NETAC is an operating unit of the Center for Hazardous Materials Research and focuses on accelerating the development and commercial use of new environmental technologies.

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About "O" Series Reports

This report is one of the GWRTAC "O" Series of reports developed by GWRTAC to provide a general overview and introduction to a groundwater-related remediation technology. These overview reports are intended to provide a basic orientation to the technology. They contain information gathered from a range of currently available sources, including project documents, reports, periodicals, Internet searches, and personal communication with involved parties. No attempts are made to independently confirm or peer review the resources used.

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Revision Note

This report has been modified on 2/24/98. Table 2 on page 6 was changed by switching columns 3 [Skimmer] and 4 [Bioslurping]. Also, Kaneohe, HI, was misspelled as Kanehoe. Thanks to all readers who have reported this mistake.

ABSTRACT

This technology summary report provides a brief overview of an environmental remediation technology, including an introduction to its general principles, reported applicability and utilization, and cited advantages/disadvantages. This report is provided for informational purposes only and is not intended as a state-of-the-art peer reviewed analysis of this technology. Information used in the preparation of this report was gathered from periodicals, through Internet searches, and in some cases, from personal communications with involved parties. No attempt was made to confirm the veracity of interpretations and/or representations made in any information resource used. In addition, listing of any technology, corporation, company, person, or facility does not constitute endorsement, approval, or recommendation by the National Environmental Technology Applications Center (NETAC).

Bioslurping involves the simultaneous application of vacuum enhanced extraction/recovery, vapor extraction, and bioventing to address LNAPL contamination. Vacuum extraction/recovery is used to remove free product along with some groundwater, vapor extraction is used to remove high volatility vapors from the vadose zone, and bioventing is used to enhance aerobic biodegradation in the vadose zone and capillary fringe.

The bioslurping system is made up of a well into which an adjustable length "slurp tube" is installed. The slurp tube, connected to a vacuum pump, is lowered into the LNAPL layer, and pumping begins to remove free product along with some groundwater (vacuum enhanced extraction/recovery). The vacuum-induced negative pressure zone in the well promotes LNAPL flow toward the well and also draws LNAPL trapped in small pore spaces above the water table. When the LNAPL level declines slightly in response to pumping, the slurp tube begins to draw in and extract vapors (vapors extraction). This removal of vapors promotes air movement through the unsaturated zone, increasing oxygen content and enhancing aerobic bioremediation (bioventing). When mounding due to the introduced vacuum causes a slight rise in the water table, the slurp cycles back to removing LNAPL and groundwater. This cycling minimizes water table fluctuations, reducing "smearing" associated with other recovery techniques.

Liquid (product and groundwater) removed through the slurp tube is sent to an oil/water separator, and vapors are sent to a liquid vapor separator. Aboveground water and vapor treatment systems may also be included, if required. However, in some cases, system design modifications have allowed discharge of groundwater and vapor extracted via bioslurping without treatment. Results of field tests of bioslurping systems have shown that LNAPL and vapor recovery are directly correlated with the degree of vacuum. A comparison of bioslurping to conventional methods of LNAPL recovery reported that bioslurping achieved the greater recovery rates than either skimming or dual-pump methods.

Reported advantages of bioslurping, as compared to other LNAPL recovery/treatment techniques, include lower project costs (because less groundwater is extracted and because vapor and groundwater may not require treatment) and a reduction in aquifer "smearing." Disadvantages cited as associated with bioslurping include potential "biofouling" of well screens due to active aeration and lack of treatment of residual LNAPL contamination in saturated soils.

This document was prepared for distribution by the Ground-water Remediation Technologies Analysis Center (GWRTAC). GWRTAC is being operated by NETAC, under a Cooperative Agreement with the United States Environmental Protection Agency's (EPA) Technology Innovation Office (TIO).

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1.0 INTRODUCTION

Bioslurping is an *in situ* remediation technology, adapted from vacuum dewatering techniques used in construction projects, that is being developed and tested for the cleanup of light non-aqueous phase liquid (LNAPL) contamination (7, 8). Bioslurping simultaneously employs ***vacuum-enhanced extraction/recovery*** to remove free-phase LNAPLs from the water table and capillary fringe, ***vapor extraction*** to remove high volatility vapors from the vadose zone, and ***bioventing*** to stimulate biodegradation of less volatile hydrocarbons in unsaturated and capillary zones (5, 9). By removing free product and addressing residual contamination in the same step, bioslurping can increase efficiency and lower costs and treatment times when compared to phased hydrocarbon remediation techniques (7).

The ***main components*** of a bioslurping system, designed to extract groundwater, free product, and soil gas in the same process stream, include:

- Recovery ("slurper") well(s) with "slurp tube";
- Vacuum pump capable of extracting liquids and vapors (usually a liquid ring pump);
- Liquid/vapor and oil/water separation units;
- Water and vapor treatment units, if required.

An unslotted "spear" or "slurp tube" of adjustable length is installed within the screened interval of the recovery well, extending into the LNAPL layer. Free product, groundwater, and soil gas are extracted through this tube via vacuum pumping. Creation of a ***negative pressure gradient (vacuum)*** within the well enhances removal of floating LNAPL and residual product trapped in small pores above the water table. The bioslurping system ***cycles between removing liquid*** (product and groundwater) ***and vapors*** through the slurp tube, maintaining a relatively consistent water table elevation during treatment. In addition, the extraction of vapors through the slurp tube promotes aeration of the unsaturated zone, increasing the oxygen content and therefore the rate of aerobic biodegradation (3, 4, 5).

Adjustment of bioslurping system design parameters may, in some cases, allow discharge of recovered groundwater and/or vapors without aboveground treatment (6). In addition, the amount of groundwater removed during remediation may be less than with other techniques due to vacuum-enhanced recovery of free product and minimal water table drawdown. When the free product recovery phase of treatment is completed, the bioslurper system can be converted into a standard bioventing system to complete remediation activities (9).

2.0 APPLICABILITY

2.1 CONTAMINANTS

Bioslurping was designed and is being tested to address contamination by petroleum products with a floating LNAPL layer.

2.2 SITE CONDITIONS

Use of bioslurping has occurred mostly at sites with fine to medium grained overburden materials, but has also been used successfully at sites with medium to coarse grained materials and in fractured rock (5).

3.0 METHODOLOGY

3.1 SYSTEM COMPONENTS

The ***recovery/extraction wells*** used in a bioslurping system are constructed similar to conventional monitoring wells and are screened above and below the level of the draw pipe of slurp tube and at least across the capillary fringe. The ***unslotted open-ended slurp tube***, which is manually adjustable within the well, is installed and sealed in the well at a depth within the LNAPL layer. The slurp tube is connected to a ***vacuum pump***, generally a liquid ring pump, capable of extracting liquids and vapors. Piping to ***air-liquid and oil-water separators,*** to a ***product collection system***, and to ***air and water treatment and/or discharge systems*** (if required) are also connected through the slurp tube (4, 5, 6, 8, 9).

3.2 SYSTEM OPERATION

When pumping begins in a bioslurping well, free product along with some groundwater is extracted. If product flow rate is sufficiently high into the well and if the water table if within approximately 25 feet of the surface, product flows up the tube as a solid column. Otherwise, it can be lifted as slugs or film, or "slurped" upward via entrainment (8). The recovered liquid is directed to an oil-water separator, the product is collected for recycling, and the groundwater is collected for treatment, if required, and discharged. When the flow rate toward the well becomes insufficient to deliver liquid to the slurp tube (liquid level falls below end of tube), vapor from the area surrounding the screened interval is extracted, creating a low to medium vacuum (3 to 20 inches of mercury). The extracted vapor is directed to an air-liquid separator and then to an air treatment system, if required, prior to discharge. The removal of vapors through the slurp tube induces air flow in the subsurface toward the extraction well. The resulting increased oxygen concentrations enhance aerobic biodegradation in the vadose zone and capillary fringe as in bioventing (8, 9).

After some period of vapor removal, the liquid level rises, in response to the vacuum-induced pressure gradient, to the level of the slurp tube, and product and groundwater are again extracted through the tube. This cycling between the removal of groundwater/free product and soil gas forms the basis of the bioslurping technology. The volume of groundwater removed through bioslurping can be minimized by adjusting the depth of the slurp tube, and volume of vapor can be controlled through adjustment of vacuum pumping rates and resulting extraction rates (5, 9).

The negative pressure gradient in the bioslurping well created by the induced vacuum provides a greater "driving force" for free-floating LNAPLs to flow into the well than pumping with no vacuum (4, 6). As a result of this pressure gradient, LNAPL accumulates around the well, ensuring maximum permeability of LNAPL due to continuous saturation in the recovery zone. (6). In addition to an increase in recovery efficiency of free product, the introduction of a vacuum on unsaturated soils may also allow removal of product trapped in small pores within the capillary fringe (4).

Bioslurping pulls LNAPL mainly in a horizontal direction, the plane with the highest expected hydraulic conductivity, resulting in increased efficiency compared to other dual pumping systems that create a cone of depression and use a vertical hydraulic gradient for LNAPL removal (4). Because groundwater drawdown is not required for operation of a bioslurping system, the problem of "smearing" of contaminants, often encountered with other recovery techniques, is eliminated (3, 6.). Smearing can increase the vertical extent of contamination in an aquifer by introducing contaminants into saturated soils as LNAPL travels deeper into the aquifer on the lowered water table (5, 8).

3.3 SITE CHARACTERIZATION AND MONITORING

Some important ***site characteristics*** that must be investigated prior to design of a bioslurping system include:

- LNAPL analysis for BTEX and boiling-point distribution of hydrocarbons;
- Particle-size distribution, bulk density, porosity, moisture content, BTEX, and TPH content of site soils;
- Baildown tests to determine LNAPL recovery rate;
- Soil gas permeability test to determine radius of influence of extraction well (conducted during bioslurping test);
- *In situ* respiration test to determine biodegradation rates (6).

Important factors in monitoring bioslurping system performance include:

- Volume and composition of liquids and vapors extracted;
- Composition of liquids and vapors remaining in soil at different levels;
- Vacuum levels in slurper wells and in surrounding soil;
- Groundwater levels in and around remediation area (5).

4.0 TECHNOLOGY PERFORMANCE

4.1 NAVAL AIR STATION (NAS) FALLON, NV

This pilot-scale project at NAS Fallon includes 48 bioslurping wells. For the first year of bioslurping operations at this site, the system ran for approximately 39 weeks. During this time, total free product recovered averaged 24 gallons per day. Hydrocarbons removed in the liquid phase averaged approximately 170 pounds per day. Groundwater was extracted at a rate of approximately 0.46 gallons per minute, with dissolved hydrocarbon removed at a rate of 0.58 pounds per day. Soil gas was extracted at a rate of 40.25 standard cubic feet per minute, averaging 4.66 pounds per day during the first year of operations. Table 1 presents data from first year operations at NAS Fallon (9).

TABLE 1. HYDROCARBON RECOVERY DATA--NAS FALLON

Hydrocarbon Phase	Mass Removed (in lbs.)	Percent of Mass Removed
Liquid (free phase)	45,859	97.0
Aquesous	157	0.3
Gaseous	1,256	2.7
Total:	47,272	100.0

During a two-year operational period at NAS Fallon, the bioslurping system achieved an average LNAPL recovery rate of 45 gallons (170 L) per day. Vapor discharge, using a liquid ring pump, was approximately 5 pounds (2.3 kg) per day for the low volatility fuels present at NAS Fallon. Data collected during this project indicated that ***LNAPL and vapor recovery are directly correlated with degree of vacuum placed on the system*** and that ***vapor discharge rates are likely dependent on "depth to water table and degree of fuel weathering.*** Based on the results of *in situ* respirometry at the site, biodegradation did not appear to be a major factor in removal of fuel from the subsurface (4, 9)

4.2 AIR FORCE BIOSLURPER INITIATIVE

The Air Force Bioslurper Initiative, funded and managed by the U. S Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division, involves the assessment of bioslurping technology at 23 Air Force sites. At these sites, bioslurping was compared to conventional skimming and dual-pump recovery techniques for LNAPL remediation. Results from all sites indicated that ***LNAPL recovery was greater with bioslurping than with either of the other techniques*** evaluated. Bioslurping fuel recovery rates at some sites were an order of magnitude greater than rates using skimming or dual-pump methods. At one site, bioslurping, while producing relatively low recovery rates, was the only method that successfully recovered free product. Table 2 summarizes results from 4 of the sites evaluated as part of the Air Force Initiative (6).

TABLE 2. FUEL RECOVERY FROM SELECTED AIR FORCE BIOSLURPER INITIATIVE SITES

Fuel recovered (in gallons [liters] per day)				
Site	**Skimmer (Test 1)**	**Skimmer (Test 2)**	**Bioslurping**	**Dual-Pumping (Drawdown)**
Andrews	7.8 [29.5]	0.73 [2.76]	79 [299]	NA
Bolling	17 [64]	8.2 [31]	60 [227]	31 [117]
Kaneohe	0 [0]	0.055 [0.2]	2.4 [9]	0 [0]
Wright Patterson	4.0 [15]	NA [NA]	4.6 [17]	2.5 [9.5]

4.3 UST SPILL/FRACTURED BASALT SITE

A bioslurping system at the site of a gasoline and diesel UST spill into fractured basalt has removed 3,900 L of LNAPL during one year of system operation. Liquid product recovery ranged from 0.78 to 3.51 L per hour, with an average recovery rate of 1.4 L per hour. Recovery rates were highest "immediately after system startup and during periods of low water table (dry weather conditions)" The costs for design and installation of the bioslurping system at this site were approximately $80,000, and operating expenses were approximately $40,000 per year (3).

5.0 TECHNOLOGY ADVANTAGES

- The reduction in the ratio of groundwater extracted to LNAPL recovered, as compared to other LNAPL remediation systems, can result in lower project costs due to minimization of storage, treatment, and disposal costs;
- Keeping soil gas extraction rates to a minimum may also reduce project costs by maintaining vapor concentrations below regulatory limits, allowing direct discharge without treatment;
- Since concentration of LNAPLs are usually higher in the vapor phase than in the aqueous phase, groundwater extracted during bioslurping may also meet regulatory limits for direct discharge to sanitary sewers (1, 4, 6);
- Fluctuations in the elevation of the water table, and associated smearing, are minimized since product moves horizontally toward bioslurping wells. (5, 8);
- Recovery of residual hydrocarbons in the vadose zone ("held in small pores by negative pore pressure") is enhanced by the partial vacuum induced during bioslurping (5);
- Bioslurping systems can be designed to limit plume migration through hydraulic control (6);
- If desired as part of remedial activities, bioslurping well design can be modified to expose contamination below water table (dewatering);
- Bioslurping systems can easily be converted for standard bioventing activities following free product removal and groundwater remediation activities (9);
- Many components of bioslurping system are located underground, allowing greater site access during remediation (3).

6.0 TECHNOLOGY LIMITATIONS

- Liquid ring pumps (and other high-velocity pump systems) tend to form emulsions, especially when diesel is part of recovered fluids;
- "Biofouling" of well screens is possible due to active aeration of bioslurping wells (1)
- Bioslurping does not treat residual contamination in saturated soils (7).

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