

Title: Remediation of Soils Contaminated by Leaking Underground Storage Tanks by Vapor Extraction and *in situ* Bioremediation

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Background: Vapor extraction is widely used to remediate unsaturated subsurface soils contaminated by volatile hydrocarbon mixtures. While primarily a physical remediation technique, soil vapor extraction is thought to enhance hydrocarbon biodegradation *in situ*; the premises being that aerobic hydrocarbon biodegradation is O₂-limited in subsurface environments, and that biodegradation may be improved by replenishing O₂ supplies through ventilation. Field data show that hydrocarbon-contaminated vadose zone soils are commonly O₂ depleted. However, the effects of ventilation on microbial populations *vis-à-vis* enhancing *in situ* biodegradation in these environments are ill-defined.

Objectives: The project's goals were to assess 1) the level of site remediation achieved by biodegradation during vapor extraction and 2) how any stimulatory effect of vapor extraction on *in situ* microbial activity might be capitalized in follow-up bioremediation efforts.

Methods: Short- and long-term effects of a soil vapor extraction system (VES) on a subsurface environment and *in situ* biodegradation of gasoline were evaluated in a field study. The research site was the location of a leaking underground gasoline storage tank in northwestern Wisconsin. The contaminant was largely confined to the vadose zone soils, with a plume approximately 12.2 m long and 7.6 m wide at a depth of 3 m to 5.5 m (ca. 900 Mg of contaminated soil). Multilevel monitoring clusters, including piezometers, thermocouples, and soil moisture sensors, were installed across the site to measure "local" vadose zone conditions. Subsurface temperature, moisture, solid and gas-phase contaminant levels, nutrient levels, and microbial population densities were monitored during and after VES operation for 462 d. Microbial activity was assessed by measuring changes in the O₂ and CO₂ levels in subsurface air [e.g., *in situ* respirometry (ISR) tests]. A VES consisting of two vapor recovery wells was operated at an air extraction rate of $1.6 \times 10^{-2} \text{ m}^3 \text{ s}^{-1}$ (pump pressure = -2.51 MPa) for 180 d, at which time vapor extraction efficiencies had decreased significantly and the pump was shutoff. Subsurface re-equilibration was then monitored for 164 d. The VES was operated again from d 409 to 442 following the re-accumulation of gasoline vapors.

Results and Discussion:

Prior to VES operation, O₂ and CO₂ levels in the plume differed substantially from those in background soil: O₂ concentrations as low as 2% and CO₂ levels as high as 14% were indicative of ongoing biodegradation. In an ISR test conducted on 6 days after VES startup, O₂ consumption rates ranged from 6.2 to 1.4% d⁻¹. But, as VES operation proceeded, microbial activity levels dropped steadily: after 62 d of VES operation O₂ consumption rates averaged only 0.2% d⁻¹. This activity decrease was primarily related to substrate (gasoline) extraction by the VES; changes in soil temperature and moisture were of secondary importance. Following VES shutdown on

d 180, approximately 70 d elapsed before renewed microbial activity was detectable. During the subsequent 164 d, this renewed activity paralleled re-accumulation of subsurface gasoline vapors and increasing soil temperatures, but averaged only 0.05% O₂ depletion d⁻¹. Following VES operation from d 409 to 442, average O₂ consumption rates had increased to 0.11% O₂ d⁻¹. The fact that gasoline vapor extraction during the second VES operation did not "inhibit" microbial activity, as appeared to be the case during the first VES operation period, suggested that the long-term response of microbial populations to VES operation was not controlled by gasoline vapor levels alone. Soil analyses indicated that low activity levels were probably not a reflection of limiting nutrient levels or small populations of hydrocarbon-degrading bacteria. The total amounts of gasoline removed by the VES and aerobic biodegradation were estimated at 400 and 139 kg, respectively.

**Conclusions/
Implications:**

VES operation was effective for soil remediation by enhancing gasoline volatilization. However, the approach was ineffective for enhancing *in situ* biodegradation, at least in the short-term, due to high levels of substrate removal. Based on these results, a two-phase model is proposed to account for the effects of VES operation on microbial activity. Phase 1 occurs immediately following initiation of VES operation, and is characterized by declining microbial activity levels in response to VES-induced substrate reduction. In Phase 2, a slow increase in microbial activity occurs over a relatively long period. This "re-equilibration" of population activity may reflect interactions between re-accumulation of gasoline vapors, temperature fluctuations, and possible changes in population metabolic functions.

Recommendations: In terms of *in situ* bioremediation, this study suggests that microbial activity can be maintained by ensuring low threshold soil O₂ levels (e.g., 2 to 5%) and minimizing the amount of gasoline extracted. This is essentially the basis of modified VES operations termed "bioventing". While field demonstrations have shown that bioventing can be applied to maintain biodegradation, much is still unknown regarding vapor movement in these systems and metabolic responses of microbial populations to ventilation-induced changes in complex fuel mixtures. Advances in these areas could produce better approaches to optimize biodegradation and quantify *in situ* bioremediation. With regards to the latter, assessment of *in situ* biodegradation currently relies heavily on the O₂/CO₂ analysis done in ISR tests. Solid-phase measurements are needed to validate or refine biodegradation estimates based on gas analysis.

Related Publications : Hickey, W.J., 1995. Soil ventilation effects on microbial populations in gasoline-contaminated subsurface soils. J. Environ. Qual. 24:000-000 (in-press)

Hickey, W.J., 1995. Rapid field methods for *in situ* respirometry studies J. Environ. Qual. 24:000-000 (in press)

Key words: soil vapor extraction, bioventing, *in situ* bioremediation, hydrocarbons

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Final Report: A final report containing more detailed information on this project is available for loan from Wisconsin's Water Library, University of Wisconsin - Madison, 1975 Willow Drive, Madison, Wisconsin 53706 (608) 262-3069.