MULTI-PHASE EXTRACTION AND PRODUCT RECOVERY
Presentation Objectives

- Discuss important processes affecting success
- Describe product recovery technologies and applicability
- Describe applicability of multi-phase technologies
- Identify data needs for technology selection/design
- Recommend pilot testing approaches
- Provide design guidance
- Discuss operational strategies
- Compare closure strategies and tools to determine progress toward close-out
- Identify contracting approaches and patent issues
Important Processes: Product Recovery

- Floating product recovery options
- Oil/water mix
- Smearing over time
- Mobility
  - Product must be connected
  - Lower in fine material, at small apparent thickness
  - Affected by oil piezometric gradient
- Almost anything you do will strand product
  - Leave residual in soil, water
  - Waiting will also strand product
Light Non-Aqueous Phase Liquid (LNAPL) Distribution at the Pore Scale - Sand
Air-Based Remediation Technologies

LNAPL Distribution At The Pore Scale - Sandy Loam

Air  LNAPL  Water

Saturation

Elevation

Air  LNAPL  Water

0  1.0

Saturation

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Distribution of Product Over Time

FREE 75.0%
RESIDUAL 25.0%

FREE 35.0%
RECOV. 20.0%
RESIDUAL 45.0%
FREE 10.0%
RECOV. 30.0%
RESIDUAL 60.0%

TIME

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Estimating Oil Volume

- Baildown test - coarse material only
  - Remove oil
  - Monitor oil/air, oil/water contacts
  - Oil thickness in well when oil/water level begins to drop is free-oil thickness
- Summation of fuel saturation over area
Product Recovery - Skimming

• Concept: recover product only
  – Floating pumps
  – Hydrophobic membrane
• Advantages: low cost
• Disadvantages: poor recovery
Skimmer Systems

Well

Air / Oil Level

Oil / Water Level

product
Dual Extraction & Total Fluids Extraction

• Dual extraction
  – Concept: pump water and product separately from same well
  – Advantage: improved recovery, separation
  – Disadvantages:
    • Cost to treat water
    • Larger wells required
    • More stranding of product in cone of depression

• Single pump (total fluids) extraction
  – Simultaneously remove both water, oil w/single pump
  – Lower water table, ease of operation
  – Emulsification of product and water
Dual Extraction

“Smeared” Residual Oil

Possible Trapped Product

Air / Oil Level

Oil / Water Level

Product

water

Air-Based Remediation Technologies
Multi-Phase Extraction (MPE)

MPE is the combined extraction of gas and liquid from the subsurface, in one of two forms:

• Dual-phase extraction (DPE): separate conduits/pumps convey gas and liquid from the extraction well
• Two-phase extraction (TPE): same conduit/pump conveys gas and liquid from the extraction well. Also known as “slurping”
Schematic of DPE System (Low or High Vacuum) (After EPA 1997)

NOTE: The extraction well may also be screened above the saturated zone for treatment of the vadose zone.

Air-Based Remediation Technologies
Schematic of TPE System
(After EPA 1997)

NOTE: The extraction well may also be screened above the saturated zone for treatment of the vadose zone.
MPE Applicability

- Vocs and biodegradable semi-volatile organic compounds (SVOCs) in the unsaturated zone and/or zones that can be dewatered
- Sites with recoverable non-aqueous phase liquid (NAPL)
- Medium-permeability soil ($10^{-3}$ to $10^{-5}$ cm/sec)
- Groundwater yield < 20 L per minute per well
MPE Application Strategies

MPE generally chosen for following reasons:

- To enhance the extraction of soil gas to accomplish SVE or bioventing;
- To enhance the recovery of NAPL (i.e., accomplish free product recovery), also known as bioslurping; and/or
- To increase production of ground water from a low-yield aquifer (vacuum dewatering)
Common Limitations Of MPE

• Non-uniform and/or narrow zone of influence
• Inadequate air-contaminant contact
• Causes
  – Subsurface heterogeneity
  – Mass transfer limitation
• Excessive recovery of groundwater (driving up treatment costs)
• Emulsions
Moisture Profiles, Clay-Rich Soils
(Radian International 1997; Baker and Groher 1998)

a) OU18 ± typical relative reduction in moisture content is < 4%.
b) NECOU ± minimal changes in moisture content evident.
Implications For Technology Effectiveness

- At sites with high permeability soil ($>10^{-3}$ cm/s), TPE wells will tend to be flooded with water, with very little or intermittent airflow, resulting in limited effectiveness.
- At low permeability sites ($<10^{-5}$ cm/s), high emergence pressure will limit MPE effectiveness, except within preferential pathways.
- MPE is best suited for moderate permeability sites.
Hypothetical Scenarios That Can Prevail During MPE. (After Baker and Groher 1998)
Dense Non-Aqueous Phase Liquid (DNAPL) Recovery

Concepts

- Understand stratigraphy, look for low spots
- Construct well appropriately
  - Screen low
  - Sump
- Pumps - single, dual phase
- Limitations - similar to floating product
DNAPL “Skimmer” Systems

Well

Air / Water Level

DNAPL / Water Level

Top of Clay, Etc.
Design Data Needs
Multi-Phase Extraction

- Water table depth, fluctuations, gradient
- Stratigraphy
- Distribution and nature of contaminants
  - Product saturation
  - Solubility / vapor pressure
  - Location relative to flow
  - Biodegradability
- Hydraulic conductivity
- Ground water geochemistry
- SVE properties, bacteriological nature

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Pilot Testing for MPE

• Purpose:
  – Verify enhanced recovery of immiscible product is possible
  – Verify can aerate soil above new water table
  – Determine vacuum propagation
  – Determine hydraulic properties of saturated zone

• Approach
  – Single well typical, construct as expected for full-scale
  – Temporary air/liquid recovery and treatment equipment
  – Monitoring points around the extraction well
Pilot Test Monitoring

- Above-ground vacuum and fluid flow
- VOC removal, NAPL recovery
- Vacuum influence (unsaturated zone)
- Drawdown and upwelling, hydraulic conductivity
- Monitoring saturation (e.g., Neutron probes)
- Comparisons with air-emergence pressures
Process Flow Diagram Of TPE Pilot Study Equipment (Radian International 1997)
Subsurface Design

- Well placement
  - Cover 3-D extent with adequate capture in saturated and unsaturated zones
  - Criteria:
    - Achieve adequate gradient to cause modest movement of product toward wells, if product recovery is goal
    - Apply adequate vacuum to aerate cone of depression or improve water recovery
    - Consider lateral variation in permeabilities
  - Modeling very helpful, some useful nomographs in USACE engineer manual on MPE
Subsurface Design, Continued

• Airflow design
  – Similar to SVE if goal is to aerate newly dewatered soil
  – Flow generated at adequate vacuum to dewater pores or enhance liquid movement

• Water recovery design
  – Flow at desired drawdown, accounting for applied vacuum (pilot data critical)

• Product recovery
  – Depends on specific location, pilot testing, baildown testing important
Time to 80% Reduction in Product Thickness for Different Soils, 3 m Well Spacing

Vacuum (mm of Hg)

Time (days)

(a) Radius = 3 m

Air-Based Remediation Technologies
Time to 80% Reduction in Product Thickness for Different Soils, 6.1 m Well Spacing
Subsurface Design

• Well design
  – Drill method: do not use drilling mud if possible, difficult to develop near water table
  – Take careful logs of materials encountered, take samples
  – Diameter: typical 10-cm or larger (at high flows)
  – Materials: typically PVC, need stainless if aggressive NAPL, need special wellhead for applying vacuum
  – Screen: continuous wrap, size slot based on formation,
  – Filter pack: design as for water wells
  – Development important, but take care to preserve product saturation at water table
Subsurface Design, Continued

• Monitoring systems
  – Parameters: pressure/air flow, ground water and soil gas concentrations
  – Permanent probes
    • Both saturated/unsaturated zones
    • Choose representative locations based on geology, contaminants
    • Neutron probe/TDR access holes
  – Flow control valves, pressure gauge at each well
  – Flow measurement device for each wellhead
    • Difficulty in measuring combined flow
Component Design, Continued

• Piping:
  – Similar to SVE, water lines. May need dual wall pipe
  – Can use flexible tubing
  – Need to handle product if applicable
  – Calculate balanced flow for individual piping legs
  – Increased piping losses due to moving liquids and vapor
Component Design

- Blowers/pumps/separators
  - Blower type: often high vacuum, liquid ring, rotary vane or rotary lobe
  - Identify necessary vacuum, have flexibility
  - Liquid pumps: consider cavitation due to vacuum
  - Separation of liquids from vapors, emulsification
  - Safety issues, especially with fuel recovery
MPE System Construction, Start-Up

- Install and test wells to verify conditions before treatment system finished, to allow modification
- Collect baseline data
- Verify construction adequacy (wells, piping, above-ground equipment)
  - Start-up Checklist in EM 1110-1-4010 on MPE
- Start ground water extraction, verify liquid pump controls, if separate liquid pumps
- Start vapor extraction equipment with dilution valves open, gradually close dilution valves
- Verify treatment equipment meeting emission requirements
- Collect subsurface response
Air-Based Remediation Technologies
Air-Based Remediation Technologies
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Air-Based Remediation Technologies
Operations

- Balancing system (fluid flows)
- Adjust to changes in water table
  - Change pump depth (skimming, dual extraction, DPE)
  - Adjust drop tube depth (TPE)
  - Adjust applied vacuum and air flow (DPE, TPE)
- Maximize mass recovery (NAPL, vapor, dissolved, bio)
- Additional wells may be needed
  - Extraction wells
  - Passive or active air injection wells
- Well Maintenance (biofouling, solids in well)
Operations, Continued

- Maintain equipment
  - Blowers, pumps, thermal oxidizers
  - Safety, particularly with jet fuel, rotating equipment, hot piping at thermal oxidizer
- Dispose of recovered product
  - Reuse options, energy recovery
- Emulsion issues
- See EM 1110-1-4010 checklists and tables, including:
  - Suggested operational performance checklist
  - Field troubleshooting guide
  - Operational strategy guide
MPE SYSTEM O&M MONITORING

• System monitoring
  – Pressure (P), temperature (T), flow (Q) at various points
  – Extraction wells (P), monitoring wells (P), blower (P, T, Q), flow measurement points (P, T), effluent (T, Q)

• Contaminant monitoring
  – Contaminant concentrations in ground water and effluents, at blower inlet / outlet, each MPE extraction well, and vadose zone monitoring point
  – Thickness and composition change of NAPL
  – Carbon adsorption units
    • Measure concentrations between carbon contactors,
    • Measure humidity
MPE System O&M Monitoring, Continued

• Biological parameters monitoring
  – Respiratory parameters – O₂, CO₂, CH₄
  – Nutrients, pH, ORP, microbial plate counts

• Soil moisture change, ground water elevation, blower amperage, noise level
Optimization Data Evaluation Decision Matrix

Evaluation Process available in EM1110-1-4010
Patent Issues

- Xerox US patent for TPE
  - May be expired
- Other patents? Should verify
MPE Site Closure

- Verification sampling
  - Soil sampling
  - Soil gas sampling
    - Monitoring points (especially in areas of stagnation)
    - Extraction wells
    - Influent monitoring (inadequate basis if sole means of monitoring progress)
    - Require adequate purging
    - Offgassing from ground water
  - Rebound test
Multi-phase & Product Recovery

References

- EM 1110-1-4010 Multi-Phase Extraction
- EPA/600/R-96/031 Engineering Design of Free Product Recovery Systems
- EPA/600/R-96/042 In-Situ SVE-Based Systems for Free Product Recovery & Residual Hydrocarbon Removal
- EPA Clu-in Web Site on Multi-Phase Extraction http://www.clu-in.org/techfocus/default.focus/sec/Multi-Phase_Extraction/cat/Guidance/
- DPE and TPE are both Presumptive Remedies for VOCs in soil and groundwater (4/97): See:
  http://www.epa.gov/oerrpage/superfund/health/conmedia/gwdocs/voc/index.htm or
- US Air Force Bioslurping Page (many references)
Multi-Phase Extraction Case Study
Holloman AFB, New Mexico USA

- Engine Testing Facility, leaking piping from storage tank
- Contaminant: Jet Fuel, up to 2 m floating product in wells, estimated 3,800,000 L fuel
- Hydrogeology:
  - Unsaturated, homogeneous silty sand (hydraulic conductivity \([K]\) 0.002 cm/sec)
  - Water table 2-6 m depth
  - Soils near water table layers of sand, silt, clay \((K = 3.5 \times 10^{-5} \text{ cm/sec})\)
  - Deeper soils: sandy silt, silty sand \((K = 0.0003 \text{ cm/sec})\)
- Goal – remove immiscible product only
MPE Case Study - Holloman AFB, New Mexico USA, Continued

- Technology applied (full scale remediation)
  - Multi-phase extraction (TPE, 1995-1998), followed by vacuum-enhanced skimming
  - 133 extraction wells, 40-60 wells operated at once
  - Bail-down testing of wells
  - Liquid-ring vacuum pumps
  - Air-liquid, oil-water separation
  - Thermal oxidation for vapors
    - High energy content of extracted vapors
    - Supplemented by burning recovered product
  - Groundwater treatment – original limitation
MPE Case Study, Continued

Wells and Geology

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MPE Case Study, Continued

Mass Removal

Figure 2-18. Plots of Vapor Mass Fluxes for BTEX and TPH, 1997–2001
MPE Case Study, Product Recovery

Figure 2-20. Plot of Free Product Yield by Quarters, January 1997 to July 2001

Air-Based Remediation Technologies
MPE Case Study, Continued

Change in Composition Over Time

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<th>Relative Concentration (percent)</th>
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Figure 2-9. Plots of Carbon Group Concentrations in Vapor-Phase Samples of 1993 and 2001
MPE Case Study - Holloman AFB, New Mexico USA, Continued

- Results
  - Over 6 years, recovered only approximately 15% of the product
  - Modeled future recovery
    - Possible to get 70% and achieve goal
    - Long time to attain goal, though
    - MPE necessary to attain goal, skimming not adequate
  - Remediation continues
Air-Based Remediation Technologies

Summary

• Need to understand distribution of contaminant and moisture
• Product recovery/MPE has specific applicability based on project goals and aquifer properties
• Limitations include:
  – Inadequate contaminant recovery or contact
  – Excessive ground water recovery or emulsions
• MPE EM provides concepts and tools for MPE application