SEAR Wastewater Treatment: Contaminant Removal and Material Recovery

U.S. Environmental Protection Agency
National Risk Management Research Laboratory
Cincinnati, Ohio
Outline

• Motivation for Treatment
• Contaminant Removal Options
• Surfactant Recovery Options
• Co-Solvent Recovery Options
• Case Study
  – ESTCP Demonstration at MCB Camp Lejeune
• Conclusions
In Situ Soil Flushing/Flooding

Flushed Solution Injection Well  |  Solvent Disposal Site  |  Extraction Well

DNAPL

Clay Aquitard
Example Properties of Extracted SEAR Fluid

- Surfactant = 0 to 6 wt%
- Alcohol = 0 to 6 wt%
- Contaminant = 0 to 10,000 mg/L
- pH = 4 to 8
- Ca^{2+} and/or Na^{+} = 0 to 250 mg/L
- Fe^{2+} = 0 to 20 mg/L
- Extraction rate > injection rate
Motivations for Treatment

• Disposal Constraints at Site
  – BOD/COD
  – Hazardous compounds
  – Nuisance foam

• Desire/Requirement to Reuse Surfactant and/or Co-Solvents
  – Material savings
  – Cost savings
Basic Wastewater Treatment Without Surfactant Recovery

Surfactant
Alcohol
Salt

Mix Tank

Air Stripper

BioTreatment

POTW

Off-Gas Treatment

DNAPL

Clay Aquitard

Air

SEAR Wastewater Treatment
Wastewater Treatment With Surfactant Recovery

- POTW
- BioTreatment
- Air Stripper
- Mix Tank
- Surfactant Recovery
- Contaminant Removal
- No Off-Gas Treatment
- Air Stripper
- Permeate
- DNAPL
- Surfactant, Water
- DNAPL
- Clay Aquitard
Material Recovery Example: Assumptions

- Surfactant Cost = $5/lb-active
- Surfactant Injection Concentration = 4.0 wt%
- Surfactant Recovery Cost = $4 per 1,000 gallons
- Contaminant Removal Cost = $29 per 1,000 gal
- Surfactant Injection Rate = 4 gpm
- Extraction Rate = 10 gpm
- Single-Pass Recovery of Surfactant = 85%
- Single-Pass Surfactant Soil Losses = 10%
Surfactant Recovery Economics

- **Mix Tank**
- **Surfactant Recovery**
- **Contaminant Removal**
- **DNAPL**
- **Clay Aquitard**
- **Water**
- **NAPL**

Surfactant Recovery Economics involves the use of surfactants in the Mix Tank to facilitate the removal of contaminants. The surfactants are recovered and used to enhance the remediation process.
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contaminant Removal Expenses ($/1000 gal)</td>
<td>29.00</td>
</tr>
<tr>
<td>Disposal Costs for Surfactant Solution ($/gal)</td>
<td>0.50</td>
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<tr>
<td>Surfactant Cost ($/lb active)</td>
<td>5.00</td>
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<tr>
<td>Surfactant Recovery Expenses ($/1000 gal)</td>
<td>4.00</td>
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<tr>
<td>Recovery of Surf. (% of feed to UF)</td>
<td>85</td>
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<tr>
<td>Single Pass Soil Loss of Surf. (as % of surf. fed)</td>
<td>10</td>
</tr>
<tr>
<td>Surfactant Injection Concentration (wt%)</td>
<td>4.00</td>
</tr>
<tr>
<td>Injection Flow Rate (gal/min)</td>
<td>4</td>
</tr>
<tr>
<td>Extraction Flow Rate (gal/min)</td>
<td>10</td>
</tr>
<tr>
<td>Density of Fluid (lb/gal)</td>
<td>8.33</td>
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<tr>
<td>Surf. Conc. in Extracted Fluid (wt%)</td>
<td>1.44</td>
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<tr>
<td>Feed Rate of Surfactant (lb/day)</td>
<td>1919.23</td>
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<tr>
<td>Surfactant Extraction Rate (lb/day)</td>
<td>1727.31</td>
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<tr>
<td>Surfactant Recovered (lb/day)</td>
<td>1468.21</td>
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<tr>
<td>Add. Surf. Needed for Reinjection (lb/day)</td>
<td>451.02</td>
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<tr>
<td>Recovery of Surf. (% of feed to UF)</td>
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<tr>
<td>Cost of Surfactant with recycle ($/day)</td>
<td>2255.10</td>
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<tr>
<td>Cost of Surfactant without recycle ($/day)</td>
<td>9596.16</td>
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<tr>
<td>Cost of Pervap ($/day)</td>
<td>417.60</td>
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<td>Cost of Ultrafiltration ($/day)</td>
<td>57.60</td>
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<tr>
<td>Total Cost with Recycle ($/day)</td>
<td>2730.30</td>
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<tr>
<td>Surf. Cost Without Recycle - no disposal ($/day)</td>
<td>9596.16</td>
</tr>
<tr>
<td>Cost Savings</td>
<td>71.5%</td>
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<tr>
<td>Annual Savings ($)</td>
<td>2.51E+06</td>
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<tr>
<td>Potential Disposal Costs for Surf. Solution ($/day)</td>
<td>7200.00</td>
</tr>
</tbody>
</table>

Material and Cost Savings Spreadsheet
Result #1: *Material* Savings

Surfactant Injected = 1,900 lb/day
Surfactant Recovered = 1,500 lb/day

77% Material Recovery
### Result #2: Cost Savings

- **Surfactant Cost without Recycling** = $9,600/day
- **Total Cost with Recycling** = $2,740/day
  - Fresh Surfactant = $2,260/day
  - Surfactant Recovery = $60/day
  - Contaminant Removal = $420/day

#### 72% Cost Savings

$2.5 million saved per year

**Disposal Cost Avoidance:** Up to $7,200/day
Complicating Factors

- Other streams to be treated
- Additional technologies to be operated
  - Logistics
  - Staff inexperience
  - More things to go wrong
Contaminant Removal Technologies

- Air Stripping
- Steam Stripping
- Pervaporation
- Vacuum Stripping
- Catalysis/Reaction
- Distillation

- Liquid/Liquid Extraction
- Adsorption or Absorption
- Precipitation (of surfactant)
Vapor-Liquid Stripping Processes: Air, Steam, Vacuum

- NAPL
- Water
- Surfactant
- Monomer
- Micelle
Surfactant Reduces Henry’s Law Constant

![Graph showing the reduction of Henry's Law Constant with increasing Isalchem 145 concentration for different compounds (TCA, TCE, Toluene, PCE).]
Air Stripping

• Contaminants
  – Volatile

• Advantages
  – Low cost
  – Deep experience base

• Disadvantages
  – Foaming
  – Off-gas treatment required
  – Poor alcohol removal
Steam Stripping

- **Contaminants**
  - Volatile and semivolatile

- **Advantages**
  - Mature technology
  - Applicable to range of contaminants

- **Disadvantages**
  - Foaming
  - More expensive
Liquid/Liquid Extraction

- **Contaminants**
  - Volatile, semivolatile, non-volatile

- **Advantages**
  - Applicable to range of contaminants
  - No foaming

- **Disadvantages**
  - Stability of interface
  - Emerging technology
  - More difficult regeneration
Adsorption/Absorption

• Contaminants
  – Volatile, semivolatile, non-volatile

• Advantages
  – Applicable to range of contaminants
  – No foaming

• Disadvantages
  – Stability of sorbent
  – Regeneration more complicated
Pervaporation

• Contaminants
  – Volatile

• Advantages
  – No foaming
  – Can be used for alcohol recovery
  – Fouling resistant (if designed properly)

• Disadvantages
  – Emerging technology
  – More expensive than air stripping
Pervaporation = Permeation + Evaporation

VOC Removal from Water

VOC-Selective Membrane (Non-Porous)
Pervaporation System Components

- Liquid Feed
- Feed Pump
- Filter
- Flowmeter
- Heater
- Vacuum Pump
- Vent
- Membrane Module
- Condensers
- Permeate Vapor
- Permeate Condensate Reservoirs
- Residual Liquid
- Chiller Unit
Surfactant Recovery Technologies

- Micellar-Enhanced Ultrafiltration (MEUF)
- Nanofiltration (NF)
- Foam Fractionation
- Precipitation
- Batch Drying
Micellar-Enhanced Ultrafiltration (MEUF)

Feed

Permeate

Ultrafiltration Membrane

- NAPL
- Water
- Surfactant Monomer
- Micelle
Micellar-Enhanced Ultrafiltration (MEUF)

- **Recovers**
  - Surfactant micelles
- **Advantages**
  - Low cost
  - High % recovery for low CMC surfactant
  - Commercially available
- **Disadvantages**
  - Surfactant in permeate *(further treatment and material loss)*
  - Micelle recovery may concentrate contaminants and cations
Nanofiltration (NF)
Nanofiltration (NF)

• Recovers
  – Monomers and micelles

• Advantages
  – High % recovery of even monomers
  – Commercially available

• Disadvantages
  – Low membrane flux
  – Higher pressures required
  – Moderate to high cost
Foam Fractionation

• Recovers
  – Surfactant monomer

• Advantages
  – Low cost
  – Can recover monomer

• Disadvantages
  – Not for bulk removal
  – Best for monomer recovery
Hybrid Surfactant Recovery Process

Water Surfactant Alcohol Salt

Injection Tank

Water Surfactant Alcohol Salt

MEUF

Foam Frax

Water Surfactant Alcohol Salt

Injection Tank

Water Alcohol Salt

SEAR Wastewater Treatment
Alcohol Recovery Technologies

• Pervaporation
• Distillation
• Steam Stripping
ESTCP Field Demonstration

- MCB Camp Lejeune
  - Soil contaminated with dry-cleaning solvent (PCE)
- Objective: To remove PCE from soil using SEAR process and to recycle/reuse the surfactant
ESTCP Field Demonstration

Mix Tank

Pervaporation

MEUF

Pervaporation

Surfactant, Water

Surfactant, Alcohol

Surfactant

Water, Alcohol

Alcohol

Water

PCE

Clay Aquitard
MCB Camp Lejeune Demonstration Participants

- U.S. Navy
- U.S. EPA
- Duke Engineering & Services
- University of Oklahoma
- University of Texas at Austin
- Baker Environmental
- IT Group (OHM, IT Corp.)
U.S. EPA’s MCB Camp Lejeune Pervaporation Unit
MCB Camp Lejeune Pervaporation Systems
MCB Camp Lejeune Extracted Fluid

- Flow = 1.0 gpm
- Surfactant = 0 to 1.2 wt%
- Isopropyl alcohol = 0 to 4.5 wt%
- PCE = 35 to 1,000 mg/L
- Other VOCs < 5 mg/L
- pH = 4.0 to 4.4
- $\text{Ca}^{2+} = 250 \text{ mg/L}$
- $\text{Fe}^{2+} = 15 \text{ mg/L}$
### Process Parameters for MCB Camp Lejeune Wastewater System

<table>
<thead>
<tr>
<th>Flow Rate (gpm)</th>
<th>Average Temperature (°C)</th>
<th>Surfactant Conc. (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>30.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.2</td>
<td>32.0</td>
<td>0.2</td>
</tr>
<tr>
<td>0.4</td>
<td>34.0</td>
<td>0.4</td>
</tr>
<tr>
<td>0.6</td>
<td>36.0</td>
<td>0.6</td>
</tr>
<tr>
<td>0.8</td>
<td>38.0</td>
<td>0.8</td>
</tr>
<tr>
<td>1.0</td>
<td>40.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The diagram shows the relationship between flow rate, average temperature, and surfactant concentration. The data points indicate a clear correlation between the parameters, with the surfactant concentration increasing with temperature and flow rate.
PCE Removal by MCB Camp Lejeune Pervaporation Field Unit (95% Removal Objective)
EPA Camp Lejeune Pervaporation Unit: Performance

• PCE Removal
  – Groundwater: 99.94 +/- 0.02 %
  – Surfactant Solution: 95.8 +/- 0.3 %
  – 160 kg (360 lb) PCE removed

• Varsol (Mineral Spirits) Removal
  – Groundwater: < MDL
  – Surfactant Solution: approx. 50%
MEUF Equipment at MCB Camp Lejeune
(University of Oklahoma)
MCB Camp Lejeune MEUF Samples
MCB Camp Lejeune MEUF Performance

- 76% surfactant recovery
- 3,800 lb surfactant recovered
- Adversely affected by alcohol
Reinjection Issues

- Reformulation of surfactant
  - Need to maintain desired properties of mixture

- Reinjection of some contaminant
  - No process will remove 100%

- Return of groundwater ions and reaction products to injection wells
  - For example, precipitation of iron caused by oxidation of Fe\(^{2+}\)
Competing Scale Issues

High Flow & Short Duration vs. Low Flow & Long Duration

• Low cost answer
  – Depends on lease terms/capital costs and operating expenses
  – Also depends on optimum ranges for the technologies
Conclusions

• Wastewater treatment must be considered when designing SEAR process

• Material savings, cost savings, and disposal cost avoidance may motivate treatment decisions

• Technologies are available to perform the necessary separations

• Added technical and logistical issues complicate implementation
Any Questions?