



## Project Summary

# Cleaning Excavated Soil Using Extraction Agents: A State-of-the-Art Review

R. Raghavan, E. Coles, D. Dietz

In response to the RCRA Hazardous and Solid Waste Amendments of 1984 prohibiting the continued land disposal of untreated hazardous wastes, the U.S. Environmental Protection Agency (EPA) has instituted a research and development program for new technologies to treat RCRA and Superfund wastes. As part of this research program, technologies applicable to cleaning excavated soils were reviewed.

This report reviews the state-of-the-art of soil cleaning technologies and their applicability to Superfund sites in the United States. The review includes Superfund site soil and contamination characteristics; as well as soil washing technologies, their principles of operation, and process parameters. The technical feasibility of using soil washing technologies at Superfund sites in the United States is assessed.

Contaminants are classified as volatile, hydrophilic, or hydrophobic organics; PCBs; heavy metals; or radioactive material. Soils are classified as either sand, silt, clay, or waste fill.

Three generic types of extractive treatments are identified for cleaning

excavated soils: water washing augmented with a basic or surfactant agent to remove organics, and water washing with an acidic or chelating agent to remove organics and heavy metals; organics-solvent washing to remove hydrophobic organics and PCBs; and air or steam stripping to remove volatile organics.

Although extraction of organics and toxic metal contaminants from excavated sandy/silty soil that is low in clay and humus content has been successfully demonstrated at several pilot-plant test facilities, extraction from clay and humus soil fractions is more complicated and requires additional pilot-scale testing before application at Superfund sites.

*This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).*

### Introduction

Under the Comprehensive Environmental Response, Compensation, and

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Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), cleanup activities at hazardous waste sites must reduce the toxicity, mobility, and volume of hazardous substances. The 1984 Hazardous and Solid Wastes Amendment (HSWA) to the Resource Conservation and Recovery Act (RCRA) was created in large part in response to citizen concerns that existing methods of hazardous waste disposal, particularly land disposal, were not safe.

The land ban provisions of the 1984 RCRA amendments have given considerable impetus to developing more economical and effective means of treating hazardous waste. EPA is now sponsoring research on new treatment technologies to destroy, detoxify, or incinerate hazardous waste; on ways to recover and reuse hazardous waste; and on methods to decrease the volume of hazardous waste requiring treatment or disposal. On-site treatment technologies that remove contaminants or decrease contaminant levels may achieve better hazard control than containment techniques. In addition, as landfill disposal becomes more expensive and as hazardous waste transportation is more stringently regulated, on-site waste treatment technologies will become more desirable--if they are technically demonstrated, environmentally safe, and economical. One of the research areas initiated by the EPA is use of extraction agents for washing excavated contaminated soil. Washing excavated soil holds promise for being applicable to all contaminants.

### ***Soil Washing for Safe On-site Redeposit***

Soil washing employing extraction agents consists of soil excavation, above-ground treatment, isolation and removal or destruction of the contaminant, and redeposit of the cleaned soil. Each of the above-ground treatment techniques for separating the contaminant from the soil uses an extraction agent--a liquid, gas, chemical additive, or combination of agents--that mobilizes the contaminant, which is chemically or physically attached to the soil particles.

This report reviews the technologies that may be applicable for cleaning excavated soil. Physical separation and extraction technologies are examined and evaluated for their applicability to soil washing.

Specifically, this report:

1. surveys the contaminants (by type and concentration) and soil (by type and quantity) at the various National Priority List (NPL) sites to define the most frequently occurring problems at these sites,
2. reviews the extractive treatment technologies that have potential for cleaning the contaminants from soils, and
3. recommends areas for future research.

### ***Patterns of Contamination at NPL Sites***

The choice of soil washing method will depend on the type of contaminant and type of soil at the site. Therefore, NPL site information files were surveyed to determine the contaminants and soil types prevalent at these sites.

To determine the patterns of contamination at NPL sites, contaminants are categorized into major groups from a soil washing perspective, based on the following soil washing parameters:

- water solubility
- vapor pressure
- octanol/water partition coefficient
- density

These parameters are used to create contaminant categories:

- hydrophilic organic compounds (volatile and nonvolatile)
- hydrophobic organic compounds
- volatile organic compounds
- heavy metals
- PCBs
- radioactive material
- other organics

Soil is classified according to its major particle size fraction as sand, silt, or clay. Since the soil and contaminants together determine the effectiveness of a particular soil washing method, the contaminant and soil types are categorized under one of 32 soil-contaminant type pairs. Derived from soil and contaminant data at 82 NPL sites in

USEPA's Region II (consisting of New York, New Jersey, Puerto Rico, and the Virgin Islands) these soil-contaminant type pairs are listed together with their frequency of occurrence. Three pairs occur at significantly greater frequency than do the remaining 29 pairs. These are hydrophobic volatile compounds, hydrophobic nonvolatile compounds, and heavy metals--all of them in sites with sandy soil.

### **Procedure**

Three major extraction techniques are used to clean soil: water washing with extractants, solvent extraction, and air stripping.

Water washing with extractive agents is applicable for cleaning nonvolatile hydrophilic and hydrophobic organics and heavy metals from soil. The solvent extraction processes show potential for cleaning nonvolatile hydrophilic and hydrophobic organics from soil. Air stripping processes are limited to cleaning soil of volatile organics.

Most of the soil cleaning processes involve mixing the extractant with soil, followed by solid/liquid separation where the cleaned soil is separated from the extractant fluid. The extractant is then cleaned of the contaminant and recycled as required.

### **Water Washing**

In water washing with extractive agents, the washing solutions can be basic aqueous solutions (caustic, lime, slaked lime, or industrial alkali-based washing compounds); acidic aqueous solutions (sulfuric, hydrochloric, nitric, phosphoric, or carbonic acids); or solutions with surfactant or chelating agents. Use of hydrogen peroxide, sodium hypochlorite, and other oxidizing agents, which chemically change the contaminants, often facilitates the washing process. A strong (highly ionized) basic or surfactant solution can be used for some organics extraction, and strong (highly ionized) acidic or chelating agent solutions can be used for metals extraction.

In cleaning soil by aqueous extraction, large objects are removed by screening and then cleaned separately. The soil is then mixed thoroughly with water and

extraction agents to remove the contaminants from the soil. This is followed by solid/liquid separation where the coarse fraction of the soil is separated. The extraction agent with contaminant and smaller soil particles (clay and fine silt) undergoes further solid/liquid separation where fine soil fractions are separated as much as possible. The extraction agent is cleaned and recycled. The separated soil fraction undergoes post-treatment where it is cleaned of any residual extraction fluid.

### **Solvent Extraction**

Solvent extraction using organic solvents may be used to clean soil contaminated with high concentrations of nonvolatile hydrophobic organics. Hydrophilic organics can be removed by solvent extraction but are most effectively removed by water washing, as discussed previously. The choice of a suitable solvent depends primarily on chemical structure of the contaminant, solvent extractive capacity, soil type, and equilibrium characteristics. In addition to these, the solvent should be stable and must have favorable density, viscosity, and interfacial tension properties. There should be a sufficient difference between the boiling points of the contaminated solute and the solvent to facilitate post-treatment separation.

Leaching and immersion extraction are the two general extraction techniques. In its most typical form, leaching is a batch extraction operation in which the screened soil is deposited in a screened-bottom tank inside retaining walls, and solvent is sprayed over it. The solvent leaches the contaminant from the soil.

For low-solubility contaminants, fine soils like clay and silt or soils with a very low residual contaminant content, the leaching process is unacceptable because of slow mass transfer rates. For these cases, the solid is dispersed into the liquid in an immersion extraction. In its simplest form, an immersion extractor is an agitated tank filled with the solvent, in which the soil is suspended and thoroughly mixed. When the extraction equilibrium has been reached, the agitation is stopped and the solids allowed to settle.

The most easily treated soil is a coarse sand that retains, after free gravity drainage, approximately 2 to 3 wt% solvent. For finer-grained soils, centrifugation or thermal desorption may be necessary to obtain low solvent residuals.

Soil/solvent separation must be effected to recycle solvent. For coarse easy draining soil, solvent is separated by gravity drain. For hard-to-settle soil the operation requires centrifugation or filtration. Residual solvent is normally removed from separated soils by either solvent displacement or gas, steam, or vapor stripping.

Contaminants are generally removed from the solvent by distillation, assuming a difference in boiling point for the solvent and contaminated material; otherwise an extractive technique may first be needed. Small amounts of contaminant may be recycled with the solvent and may be present in a subsequent soil extraction.

### **Air Stripping**

Air stripping is normally used to remove volatile organic compounds (VOCs) from soil. To strip VOCs from soil, the VOCs must be vaporized. The stripping may be done at ambient temperatures, or heat may be used to increase the rate of vaporization. Air and steam are the most commonly used stripping gases. Adsorption or combustion removes VOCs from a circulating air stream. When steam is used as the stripping medium, the steam can be removed by condensation, and a relatively concentrated vapor of VOC remains for disposal.

In general, any system that is employed to dry solids can also strip VOCs from soil. These systems consist of: a gas/solids stripping device; a stripping gas circulating device; and a means to remove, recover, or destroy the VOCs in the stripping gas.

## **Results and Discussion**

### **Water Washing**

To date, several aqueous extraction systems for cleaning excavated contaminated soil have been demonstrated on a pilot scale; some of these soil pretreatment/extraction methods are listed in Table 1.

### **Solvent Extraction**

Large quantities of solids (ores, sugar beets, etc.) have been extracted using continuous countercurrent extractors such as Dravo's Rotocel (rotary-type) Endless-Belt Extractor,\* Lurgi's Frame Belt Extractor, the DeSmet Belt Extractor, and the BMA Diffusion Tower. Some of these solvent extraction processes used for treating soil are listed in Table 2.

### **Air Stripping**

When treating soils that adhere and form large particles (i.e., are fine-grained and tend to agglomerate), a Holo-flite screw, rotary kiln/dryer, or Hereschoff furnace may be used for stripping.

When processing granular free-flowing sandy soils, which disperse easily, fluid bed combustors of the circulating or bubbling types are applicable. Table 3 describes this equipment and states process operating conditions.

## **Conclusions and Recommendations**

The following conclusions have emerged from this literature review of theoretical, bench-scale, and pilot-scale investigations of state-of-the-art technologies for the extraction of contaminants from soil.

- Pilot-scale tests conducted by TNO, Heijmans, HWZ Bodemsanering, BSN, and Ecotechniek show that sand or silt can be washed.
- Above-ground extraction of organics and heavy metals from sandy soil containing very low levels of clay is feasible.
- Above-ground extraction of organics and heavy metals from clay soil fractions has not been demonstrated on a pilot scale.
- Separation of the extractant from the soil and regeneration of the extractant have not been successfully demonstrated for clay soils.
- Contaminant extraction experience does provide enough information to support a decision on the technical feasibility of applying soil washing at NPL sites.

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\*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

**Table 1.** Aqueous Phase Extraction Processes

Aqueous Extraction Process	Capacity tons/hr	Year Operation Commenced	Comments
Netherland's bromide removal from sand (Netherlands Organization for Applied Research)	Pilot scale	1982	Organic bromide compounds removed from sandy soil containing less than 10% clay and humus. Extraction agent was caustic solution (pH > 11). Extractant-to-soil ratio: 2:1.
Heijmans Milieutechniek extractive cleaning of heavy metals and cyanide from soils	10-15	1985	Process has potential for cleaning soil contaminated with cyanides, heavy metals, and water-immiscible and low-density hydrocarbons.
HWZ Bodemsanering extractive cleaning of cyanide-contaminated sandy soils	20	1984	The extracting agent used is a detergent.
Ecotechniek thermal washing of sandy soil contaminated with crude oil	20	1982	Sands containing 200,000 ppm of oil were cleaned to approx. 20,000 ppm.
Bodemsanering Netherlands (BSN) high-pressure washing of sandy soil contaminated with oil	20	1983	This plant is transportable.
Klockner Umwelttechnik high-pressure water jet for cleaning contaminated sandy soils	15-40	1987	This process is a modified version of the BSN process and is effective for cleaning soils with fines (< 63 $\mu$ m) not exceeding 20%. Water pressure 5,075 psi.
Harbauer soil cleaning system	40	1987	This wet extraction process uses hydraulically produced oscillation/vibration to achieve initial separation of soil particles and contaminants. Soil recovery is approximately 95% of input volume.
EWB-Alsen-Breitenburg cleaning of sandy soil contaminated with oil	Pilot scale- 8 to 10 m <sup>3</sup> /hr	Not Available	Custom reagents added to water. Water-to-soil ratio is 1:1; cleaning efficiency is 95%.
Lee's Farm lead extraction from soils	Pilot scale- 30	1985 (for short duration)	Crushed soil (lead contaminated) was washed with a 30% EDTA aqueous solution using an inclined-screw washing unit. Tests were used to specify equipment that can handle clays.
USEPA's extraction of spilled hazardous materials from excavated soil	Pilot scale- 6	1984 (limited operation)	Process using EDTA removed 97% of the lead in soil containing 47,000 ppm. The plant is mobile.

**Table 2.** Solvent Extraction Processes

Solvent Extraction Process	Capacity (scale)	Year Operation Commenced	Comments
Soilex	Pilot Scale	1984	A kerosene-water solvent removes PCBs from soil. The PCB leaching percentage is 84%. Kerosene is recovered, decontaminated, and recycled. Kerosene residuals in soil have been about 25% of the kerosene charged.
CF Systems Corporation Cambridge, MA	Commercial scale, 1,000 barrels/day	1988	Propane at or near its critical point is used to dissolve organic contaminants present in a sludge-water slurry. Typically, 99% of the organics are extracted from the sludge. Propane is separated from the organics by flashing, and then is recompressed, cooled, and recycled to the extractor.
Basic Extraction Sludge Treatment (BEST)	Prototype commercial scale, 100 tons/day design	1986	Triethylamine (TEA) extracts oil from oily sludges. TEA is soluble in water below 65°F, insoluble above 65°F. Hazardous oil is recovered, not destroyed. Operation of this multi-step process is highly sophisticated.

**Table 3.** Equipment for Air Stripping VOCs from Soil

Volatile Organic Stripping Equipment Name	Equipment Description	Process Operating Conditions
Holo-Flite™ Screw	A jacketed trough houses a double-screw mechanism. Heat transfer medium enters the hollow screw shafts and flights (indirect heating). Air contacts soil directly. Removal efficiency 99%.	Soil discharge temp. = 50° to 150°C. Soil residence time = 30 to 90 min. Air inlet temp. = ambient to 90°C. Circulating oil temp. = 100° to 300°C.
Rotary Kiln/Dryer	Rotating Drum. VOCs can be evaporated using direct or indirect heating.	Temperature in the kiln controlled at 100° to 400°C if the character of the soil is to be maintained (or to avoid fouling the walls)
Hereschoff Furnace	Soil fed to the center of the top tray is moved by rotating flights to the outer edge, falls to second tray, moves to center on second tray, falls to third tray, etc.; gas moves counter-current to the soil. ID fan required.	Temperatures to 500°C are attainable.
Circulating Bed Combustor	Hot gas flows countercurrent to soil and entrains the soil. Entrained soil is separated from hot flue gases in a cyclone and recirculated to the bed. A solids draw-off is provided.	Requires free-flowing soil feed.
Bubbling Bed Combustor	Gas is blown from a distributor at bottom of bed. Bed is maintained below fluidization.	Residence time controlled by bed height or soil feedrate.

- More applied pilot-scale testing must be conducted to support any statement on the environmental and economic practicability of extraction technologies.
  - Experience with contaminant removal via water washing at the bench, pilot, and prototype scales supports application of the technology for cleaning sandy and silty soils. Economic competitiveness of soil washing compared to other remedial technologies such as incineration or fixation is indicated. Further study is needed to establish fixed and operating costs for aqueous extraction of soil contaminants.
- A program is needed that would include the following components:
- Characterization of soil at NPL sites from a soil washing perspective. This would include particle size distribution, mineralogical observations, physical and chemical analyses, etc.
  - Bench-scale testing to establish the required processing configurations and operating conditions for the various wastewater treatment and regeneration subsystem options.
  - Preliminary process design, sizing, and costing of a modular transportable pilot-plant system to determine process economics for comparison with incineration and other remedial technologies.

- Design, construction, and operation of a modular transportable pilot-scale unit to demonstrate its applicability at selected NPL sites.
- Research and development efforts toward broadening the application to washing of high-clay soils, if economically justified.

*R. Raghavan, E. Coles, and D. Dietz are with Foster Wheeler Enviresponse, Inc., Livingston, NJ 07039.*

***Darlene Williams is the EPA Project Officer (see below).***

*The complete report, entitled "Cleaning Excavated Soil Using Extraction Agents: A State-of-the-Art Review," (Order No. PB 89-212 7571AS; Cost: \$15.95, subject to change) will be available only from:*

*National Technical Information Service  
5285 Port Royal Road  
Springfield, VA 22161  
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*The EPA Project Officer can be contacted at:*

*Releases Control Branch  
Risk Reduction Engineering Laboratory  
U.S. Environmental Protection Agency  
Edison, NJ 08837*