



# Superfund Engineering Issue

## Treatment of Lead-Contaminated Soils

### Index

- Introduction
- Soil Characterization
- Treatment Technologies for Lead-Contaminated Soils
  - Extraction
  - Solidification/Stabilization
  - Vitrification
  - Electrokinetics
  - Flash Reactor Process
- Technology Contacts
- References

### Introduction

This bulletin summarizes the contents of a seminar on treatment of lead-contaminated soils presented on August 28, 1990, to Region V Superfund and RCRA personnel by members of EPA's Engineering and Treatment Technology Support Center located in the Risk Reduction Engineering Laboratory (RREL) in Cincinnati, Ohio. This bulletin is intended to summarize the information presented during the seminar and it should not be viewed as a definitive treatise on lead treatment technologies.

The seminar was sponsored through EPA's Technical Support Project (TSP). The Office of Solid Waste and Emergency Response (OSWER) and the Office of Research and Development (ORD) established the Superfund Technical Support Project in 1987 to provide technical assistance to Regional Remedial Project Managers (RPMs) and On-Scene Coordinators (OSCs). The TSP consists of a network of Regional Forums, four specialized Technical Support Centers (TSCs) located in ORD laboratories, and one TSC at OSWER's Environmental Response Team.

Technical presentations were made by David Smith and Paul de Percin of EPA's RREL in Cincinnati, Ohio; Michael Royer of RREL in Edison, New Jersey; and Radha Krishnan, P.E., of PEI Associates, Inc., in Cincinnati, Ohio. The seminar was coordinated by Louis Blume and Steve Ostrodka of EPA Region V.

Lead is one of the most common contaminants at Superfund sites across the Nation. Region V alone has over 100 sites on the National Priorities List (NPL) where lead contamination is found. The magnitude of the problem increases when emergency response sites and RCRA corrective action sites are taken into account. Lead is a common contaminant at sites where past industrial activities include battery breaking and recycling, oil refining, paint manufacture, metal molding and casting, ceramic manufacturing, and primary and secondary smelting. Several technologies have been implemented for treating lead-contaminated soils. Research and evaluation of other treatment technologies is ongoing.

The seminar summarized in this bulletin was developed to provide RPMs and OSCs with an overview of the state of the art for treatment of lead-contaminated soils. More detail on specific technologies can be obtained from the referenced reports and from consultation with technology contacts.

The seminar was organized to address site characterization issues and actual treatment technologies. The treatment technologies were divided into two categories: "demonstrated" and "emerging." Extraction processes (e.g., soil washing and acid leaching) and solidification/stabilization techniques have been evaluated where lead was a contaminant of concern. The emerging technologies discussed were in situ vitrification, electrokinetics, and flash smelting.



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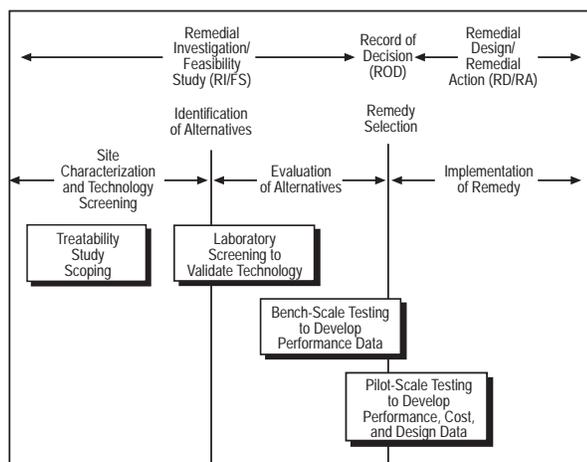
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The remainder of this bulletin summarizes information concerning data needs for site and soil characterization and the applicability of the discussed treatment technologies.

## Soil Characterization

Determining the appropriate treatment techniques to be used to clean up a particular soil requires knowledge of the chemical and physical nature of the contaminated soil. Potential treatment technologies must be identified early in the phased remedial investigation/feasibility study (RI/FS) process as shown in Figure 1. This is to ensure the data required to evaluate a technology's applicability to a site is collected during the remedial investigation or as part of a treatability study.



**Figure 1. The role of treatability studies in the RI/FS and RD/RA process (USEPA 1989a)**

Table 1 provides a list of soil characterization parameters related to treatment technologies that may aid the RPM/OSC in developing sampling and analysis plans and treatability studies.

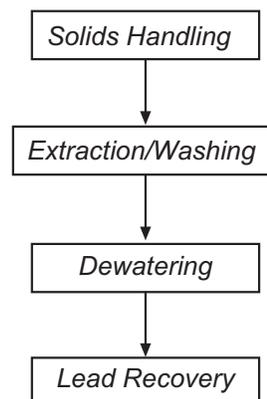
## Treatment Technologies for Lead-Contaminated Soils

### Extraction

**FUNCTION:** Extraction refers to several processes that separate the contaminants from soil particles. Often the goal of the process is to reduce the volume of contaminated soil that ultimately must be treated or disposed or to transfer the contaminants from the soil medium to an aqueous medium where they can be more easily treated.

**PROCESS:** There are two general extraction processes interest: soil washing and acid leaching. Soil washing used a washing solution (e.g., water, surfactant, chelating agent) and mechanical agitation to extract the contaminant from the soil particles. Figure 2 is a generalized process diagram for soil washing. In

general, the contaminated soil is excavated before treatment. The washing agent is chosen depending on the contaminant type and particle size distribution of the soil.



**Figure 2. General block diagram of soil washing process**

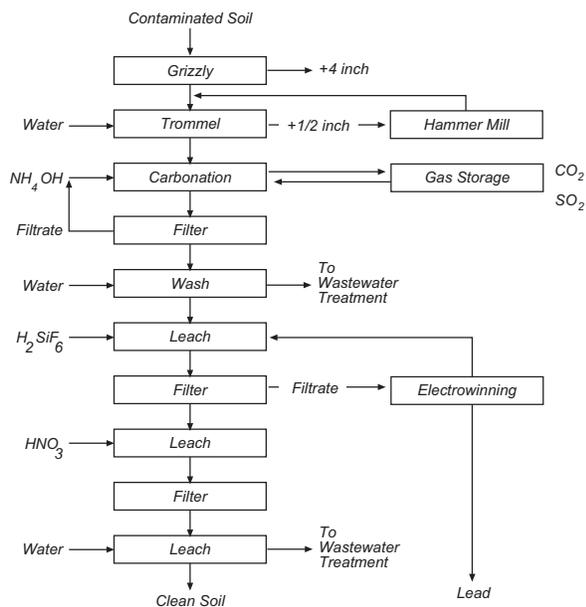
The acid leaching process (under development by the Bureau of Mines specifically for lead-contaminated soil and battery casings) converts lead sulfate and lead dioxide to lead carbonate, which is soluble in fluosilicic acid. Lead is recovered from the leaching solution by electrowinning and the acid is recycled back to the leaching process. Further leaching with nitric acid may increase lead movement. Figure 3 is a process flow diagram of the Bureau of Mines' process.

**APPLICATION:** Soil washing experiments have shown that a significant fraction of the contaminants are attached to the fines (silt, humus, and clay) and that the coarse material can be cleaned by physically separating and concentrating the fines. Addition of a chelate solution (e.g., EDTA) has been shown to be effective in improving metal removal efficiencies. Surfactant solutions have shown high organic removal (compared with water wash) for the fines particles. Water appears to be more effective in mobilizing organics than metals, probably because some organic compounds are slightly hydrophilic.

A number of bench-scale studies were conducted to evaluate soil washing for treating lead-contaminated soils (USEPA 1989b). The purpose of these screening treatability studies, which were conducted under a give set of operating conditions, was to determine if soil washing can reduce the levels of lead contamination in the soil and to examine the partitioning of lead relative to soil particle size. The results of these tests, expressed as percent reduction of total lead, are presented in Table 2. The data indicate that limited removal of lead occurs, particularly in the course and medium fractions. The concentration of TCLP-leachable lead also was significantly reduced, as shown in Table 3. Additional bench-scale studies are required to determine the optimum operating parameters and to verify that site-specific cleanup goals can be achieved. Further data on these tests are contained in the referenced reports.

The acid leaching procedure using fluosilicic acid is specifically applicable to lead-contaminated soils and battery casings. This leaching process was developed with the purpose





**Figure 3. Block diagram of Bureau of Mine's fluosilicic acid system to leach and electrowin lead from contaminated soils.**

of reclaiming lead for secondary smelting. It has not been widely tested for general application at Superfund sites; however, the technology has been tested on several lead-contaminated soils. Table 4 summarizes the bench-scale test results.

**LIMITATIONS:**

SOIL WASHING

- Effectiveness of treatment is highly dependent on particle size.
- Fine particles have high adsorption capacity for contaminants and can be difficult to remove from washing fluid.
- Aqueous waste stream and fines fraction require subsequent treatment.
- Materials handling issues are critical to treatment effectiveness.
- Wash solution must be tailored for the site.
- Difficulty and costs in recovering chelating agents.

**Table 2. Results of Bench-Scale Evaluations of Soil Washing**

Site/Waste	UNTREATED SOIL			%LEAD REDUCTION IN TREATED SOIL			
	Predominant Lead Species	Avg. Tot. Lead, mg/kg	EP Tox. mg/L	Wash Solns. Tested	>2	250µm to 2mm	<250µm (fines)
Old Man's Township	PbCO <sub>3</sub>	48,000	300	Water	NR	53.5	4.38
				EDTA (1)	NR	48.9	14.1
C&R Battery	Pb <sub>3</sub> (CO <sub>3</sub> ) <sub>2</sub> (OH) <sub>2</sub>	68,400	418	Water	26.7	23.7	27.6
				EDTA (1)	NR	16.2	64.7
Schuylkill	PbCO <sub>3</sub>	4,700	55.5	Water	81.0	54.0	37.3
				EDTA (1)	98.1	50.2	15.0
Gould Soil	PbSO <sub>4</sub>	27,600	148	Water	NR	53.6	NR
				EDTA (1)	67.5	68.6	44.7
Gould Casings	PbSO <sub>4</sub> PbO <sub>2</sub>	209,000	1,830	Water	82.9	-	34.1
				EDTA (1)	79.7	-	44.3
J&L Fabricating	Pb <sub>4</sub> SO <sub>4</sub> (CO <sub>3</sub> ) <sub>2</sub> (OH) <sub>2</sub>	4,194	N/A	Water	NR	51.8	NR
				EDTA (2)	NR	67.3	NR
				EDTA (3)	NR	35.2	NR
				EDTA (4)	74.2	63.9	NR
				EDTA (5)	NR	69.5	NR
SARM III	PbSO <sub>4</sub> PbO <sub>2</sub>	12,776	N/A	Water	99.4	97.9	N/A
				EDTA (1)	99.5	98.9	N/A

NR = no reduction

N/A = not available

(1) 3:1 molar ratio for EDTA to total chelatable metals, pH = 7-8

(2) 0.0160M, pH = 7-8

(3) 0.0148M, pH = 7-8

(4) 0.0210M, pH = 7-8

(5) 0.0210M, pH = 11-12

Source: USEPA 1989b

**Table 3. TCLP Lead for Bench-Scale Soil Washing Studies**

Site Name	Wash Solution	Untreated Soil, mg/L	>2mm, mg/L	% Reduction	250 $\mu$ m to 2 mm, mg/L	% Reduction	<250 $\mu$ m mg/L	% Reduction
Gould Soil	Water	657	96.0	85.4	273	58.4	700	NR
	EDTA	657	177	73.1	241	63.3	323	50.8
J&L Fabricating	Water	225	83.6	62.8	51.1	77.3	163	27.6
	EDTA(a)	225	130	42.2	37.2	83.5	38.4	82.9
	EDTA(b)	225	153	32.0	48.1	78.6	79.9	64.5
Pesses Chemical Co.	Water	0.297	0.864	NR	<0.103	>65.3	0.0670	NR
	EDTA(a)	0.297	<0.062	>79.1	0.305	NR	0.297	NR
	EDTA(b)	0.297	<0.062	>79.1	0.730	NR	0.465	NR

(a) pH = 7-8

(b) pH = 11-12

NR = no reduction

Source: USEPA 1989b

**Table 4. Results of the Bureau of Mines' Treatability Tests on Lead-Contaminated Soils**

Site/Waste	UNTREATED		TREATED MATERIAL		
	Predominant Lead Species	Average Total Lead, ppm	Leach Method	Total Lead, ppm	EP tox, mg/L
United Scrap Lead °Soil	Pb, PbSO <sub>4</sub> PbO <sub>2</sub>	8,000-18,000	HNO <sub>3</sub>	200	<1
United Scrap Lead °Soil	Pb(2%), PbSO <sub>4</sub> PbO <sub>2</sub>	8,000-18,000	H <sub>2</sub> SiF <sub>6</sub> /HNO <sub>3</sub>	203	<1
Arcanum °Soil	Pb(6.6%) PbSO <sub>4</sub>	71,000	H <sub>2</sub> SiF <sub>6</sub> /HNO <sub>3</sub>	330	0.26
Arcanum °Soil	Pb(6.6%), PbSO <sub>4</sub>	71,000	HNO <sub>3</sub>	<250	<1
C&R Battery °Soil	Pb, PbSO <sub>4</sub> PbCO <sub>3</sub> , PbO <sub>2</sub>	17,000	HNO <sub>3</sub>	29	<0.1

Source: Schmidt 1990

### ACID LEACHING

- Acid handling requires special handling procedures and construction materials.
- Residual waste streams require subsequent treatment.
- Process has not been widely tested at Superfund sites.
- Lead sulfate sludge requires further treatment before disposal.

### RESIDUALS:

**SOIL WASHING** - The aqueous waste stream (wash solution) will require treatment for contaminant removal. The resulting fines will likely need to be treated (e.g., using solidification/stabilization) before disposal.

**ACID LEACHING** - Several aqueous waste streams are generated during this process that require treatment. The treated soil must be analyzed to determine the options for either additional treatment or disposal. Lead can be reclaimed from this process.

### Solidification/Stabilization

**FUNCTION:** Solidification/stabilization (S/S) reduces the hazardous potential of contaminated sites by converting the contaminants into their least soluble, mobile, or toxic form, thus minimizing their potential migration offsite. The process has been well developed for above-ground application. The unique aspect of in situ application is the means of mixing S/S agents within the soil. Many mixing agents are not effective in immobilizing organic contaminants. However, recent studies indicate that modified clays, silicates, and some organic binders can be used to immobilize organic contaminants.

**PROCESS:** The S/S process, often referred to as fixation or immobilization, involves mixing the contaminated soil with an appropriate ratio of binder/stabilizer and water. Binding and hardening material ties up the free water in the matrix. Reactions with hydroxides and carbonates form insoluble metal compounds. Potential binders include pozzolan-portland cement, lime-fly ash, thermoplastic binders (asphalt), and sorbents such as activated carbon, clays, zeolites, and anhydrous sodium silicate.

For the in situ process, the binding agents (e.g., cement, lime, kiln dust, fly ash, silicates, clay, and zeolites or combinations thereof) used for contaminated wastes are mixed with the contaminated material by the surface area, injection, or auger method. In situ S/S has been applied at contaminated sites.

Solidification/stabilization has been widely tested and implemented at Superfund sites and is considered a reliable treatment technology for many metal-contaminated soils and sludges. Generally, immobilization by the solidification/stabilization technique has lower costs than other treatment options.

**APPLICATION:** Solidification/stabilization is highly suited for soils, sludges, or slurries contaminated with metals. The treatment is applicable to slurries after the solids content of the matrix has been adjusted. It is a required treatment for several metal-containing hazardous wastes prior to land filling.

Many of the additives are not effective in immobilizing organic contaminants. Modified clays, however, are currently being studied for application in the S/S of organic contaminants. Recent tests with some silicate binders and some organic binders have shown success in immobilizing and perhaps treating some semivolatile and heavier organic contaminants.

Solidification/stabilization has been demonstrated through the SITE program by several vendors. HAZCON, Inc., uses a proprietary binder with cement to immobilize organic and

inorganic contaminants in soils by binding them in a concrete-like mass. Table 5 and 6 summarize the results of treatment of lead-contaminated soils using the HAZCON process. Soliditech, Inc., also uses a proprietary reagent and additives with fly ash, kiln dust, or cement to immobilize metals and organics. Table 7 shows some results of the Soliditech process on lead, arsenic, and zinc.

The most significant challenge in applying solidification/stabilization treatment in situ for contaminated soils is achieving complete and uniform mixing of the solidifying/stabilizing agent with the soils. In situ surface area mixing of solidifying/stabilizing agents with contaminated sludges in a lagoon is typically accomplished by use of a backhoe, clamshell, or dragline. Other in situ mixing techniques are the injection system, the auger/cassion system, and the auger system. These application techniques are generally limited to depths of less than 100 feet.

**LIMITATIONS:**

- The volume of treated material will increase with addition of reagent.
- Organics are usually not effectively treated using standard binding/stabilizing agents. If organics are of concern, special proprietary binding agents will be necessary.
- Delivering reagents to the subsurface and achieving uniform mixing and treatment in situ may be difficult.
- Volatilization and emission of volatile organic compounds may occur during mixing procedures and emissions control may be warranted.

**Table 5. Lead Analysis of Untreated and Treated Soils—Hazcon S/S Process**

Location Code	Untreated, ppm by Wt.	Treated, ppm (28-day Results)
DSA	3,230	830
LAN	9,250	2,800
FSA	22,600	10,300
LFA	13,670	1,860
PKA	7,930	3,280
LAS	14,830	3,200

Source: USEPA 1989c.

**Table 6. Concentration of Metals in TCLP Leachates—Hazcon S/S Process, mg/L**

Location Code	Untreated Soil	7-Day Cores	28-Day Cores
DSA	1.5	0.015	0.007
LAN	31.8	<0.002	0.005
FSA	17.9	0.07	0.400
LFA	27.7	0.04	0.050
PKA	22.4	0.01	0.011
LAS	52.6	0.14	0.051

Source: USEPA 1989c.

**Table 7. Chemical Properties of Untreated and Treated Wastes—Soliditech, Inc. S/S Process**

Chemical Parameter (a)	Untreated Waste	Treated Waste(b)	OFFSITE AREA ONE	
			Leachate from Untreated Waste(c)	Leachate from Treated Waste(c)
Arsenic	94	92	0.19	ND
Lead	650	480	0.55	0.012
Zinc	120	95	0.63	ND

(a) Analyte concentration units for the untreated and treated waste are mg/kg. Analyte concentration units for the leachate from untreated and treated waste are mg/L.

(b) Treated wastes were sampled after a 28-day curing period.

(c) Leachate values refer to results from TCLP test.

ND = not detected

Adapted from: USEPA 1989d.

- The permeability of the treated area is significantly reduced. Revegetation may require placement of a soil cover of sufficient depth. However, properties of stabilized material can be engineered to produce an excellent sub-base or slab for subsequent industrial use at the site.
- Runoff controls may be required.

**RESIDUALS:**

- The solidified/stabilized product is the principal residual.
- Vapors or gaseous emissions may be released in some cases, requiring capture and subsequent treatment.

**Vitrification**

**FUNCTION:** Contaminated soils are converted into chemically inert and stable glass and crystalline materials by a thermal treatment process.

**PROCESS:** Large electrodes are inserted into soils containing significant levels of silicates. The electrodes are usually arranged in 30-foot squares. Graphite on the soil surface connects the electrodes and graphite. A high current of electricity passes through the electrodes and graphite. The heat causes a melt that gradually works downward through the soil. Volatile compounds are collected at the surface by a negative pressure hood for treatment. After the process is terminated and the ground has been cooled, the fused waste material will be dispersed in a chemically inert and crystalline form that has very low leachability rates. Figure 4 is a schematic diagram of the process.

This technology is currently slated for demonstration as part of the SITE program. It has been chosen as a remedy at several site cleanups such as Northwest Transformer in Washington and Crystal Chemical in Houston, Texas. Bench-scale testing has been conducted for the New Bedford Harbor site in Massachusetts and the Jacksonville, Arkansas, Water Treatment Plant site. The Department of Energy (DOE) has evaluated in situ vitrification at several locations in its Hanford, Washington, facility.

**APPLICATION:** Vitrification was originally tested as a means of immobilizing low-level radioactive metals. The process destroys nitrates and partially decomposes sulfate compounds in the wastes. Fluoride and chlorine compounds are dissolved into the glass materials up to their limits of solubility. Wastes containing heavy metals, PCBs, process sludges, and plating wastes are amenable to treatment by the vitrification process because they will either fuse or vaporize. Contaminant organics and some metals are volatilized and escape from the soil surface and may be collected by a vacuum system. Inorganics and some organics are trapped in the melt that, as it cools, becomes a form of obsidian or very strong glass. The treatment rate is 3 to 5 tons/hour.

Vitrification may also be useful for forming barrier walls (e.g., similar to slurry walls), however, this concept has not been proven.

**LIMITATIONS:**

- The process is energy intensive and often requires temperatures up to 2500°F for fusion and melting of the waste-silicate matrix.
- Special equipment and trained personnel are required.
- Water in the soils affects operational time and increases the total costs of the process.
- The technology has the potential to cause some contaminants to volatilize and migrate to the outside boundaries of the treatment area instead of to the surface for collection.
- A substantial amount of time may be needed for cool-down of the melt.
- The technology has not been demonstrated at depths over 20 feet.
- The boundary between successive melts may require special attention to assure that an impermeable bond is formed.

**RESIDUALS:**

- Resulting vitrified mass is effectively inert and impermeable.
- Soil cover material is needed to allow for vegetative growth and support.

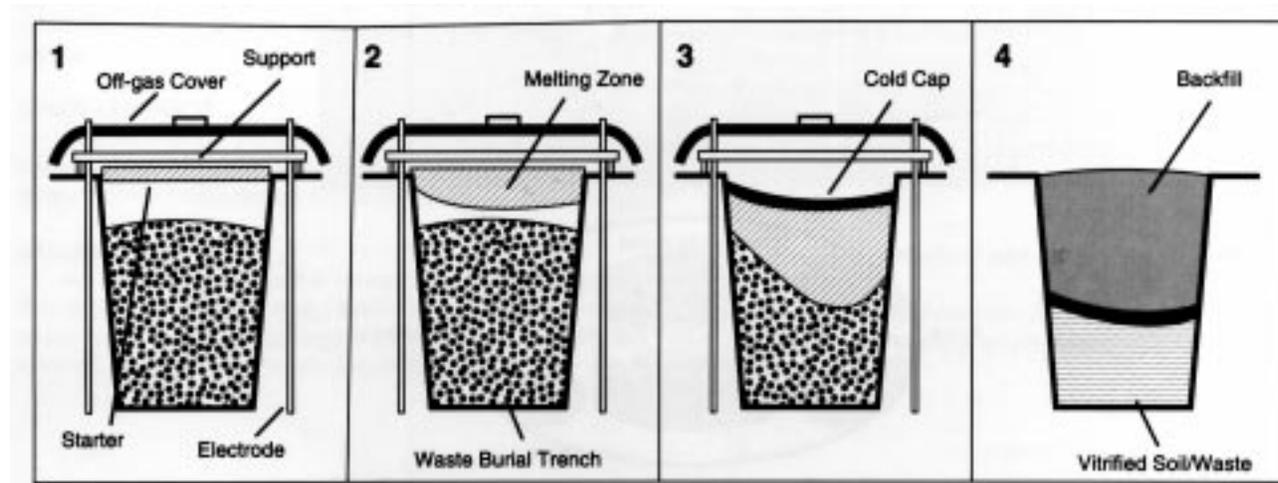


Figure 4. The in situ vitrification operating sequence (USEPA 1990a)

## Electrokinetics

**FUNCTION:** Electrokinetic technology can remove heavy metals and other contaminants from the soil and groundwater when the soil is electrically charged with direct current. The movement of ions, particles, and water are transported under the influence of an electrical field.

**PROCESS:** An electrokinetic phenomenon occurs when liquid migrates through a charged porous medium under the influence of a charged electrical field. The charged medium is usually some kind of clay, sand, or other mineral particle that characteristically carries a negative surface charge. The electrical field is applied through anodes. Cations bound in the soil will migrate toward the negatively charged cathode. Concentration gradients in the soil solution are established between the cathode and anode. The concentration gradients cause diffusion from areas of low concentration to areas of high concentration (see Figure 5). The spacing of wells containing the cathode and anode depends on site-specific factors. Both the cathode and anode housing have separate circulation systems filled with different chemical solutions. The contaminants are captured in these solutions and brought to a purification system.

This technology has been field demonstrated in the United States and Europe.

**APPLICATION:** Ionic metal species that are subject to ionic reaction and migrate in the soil system appear to be the types of contaminants that can be effectively treated. Also, a nearly static groundwater regime and saturated, moderately permeable soils at a shallow depth are favorable conditions for applying this technology.

### LIMITATIONS:

- This technology is confined to sites contaminated with metals.
- Electrical power requirements could be excessive, thus the technology might not be cost effective.

- Further treatments would be required for sites contaminated with organics or other waste types.
- Precipitation of salt and secondary minerals could decrease the effectiveness of this technology.
- The technology may raise the soil pH to levels that result in the mobilization of metallic contaminants. The high pH levels could also inhibit or destroy microbial populations present within the soil.
- Chlorine gas may be formed from the reduction of chlorine ions in the vicinity of the anode.

### RESIDUALS:

- Nonmetallic contaminants would not be affected and would remain in the soil matrix.
- Precipitated salts and secondary minerals need to be removed from the collection points to increase the effectiveness of the technology.
- Metallic contaminants would need to be removed from the collection points and treated at the surface.

## Flame Reactor Process

**FUNCTION:** The flame reactor process (patented by Horsehead Resource Development Co., Inc.) is a flash smelting system that treats residues and wastes containing metals.

**PROCESS:** The reactor processes wastes with a very hot (greater than 2000°C) reducing gas produced from the combustion of solid or gaseous hydrocarbon fuels in oxygen-enriched air. In a compact low-capital cost reactor, the feed materials react rapidly allowing a high waste throughput. The end products are a nonleachable slag (a glasslike solid when cooled) and a recyclable, heavy metal-enriched oxide. The volume reduction achieved (of waste to slag) depends on the chemical and physical properties of the waste. Figure 6 shows a process flow schematic for the Horsehead Development Co. flame reactor.

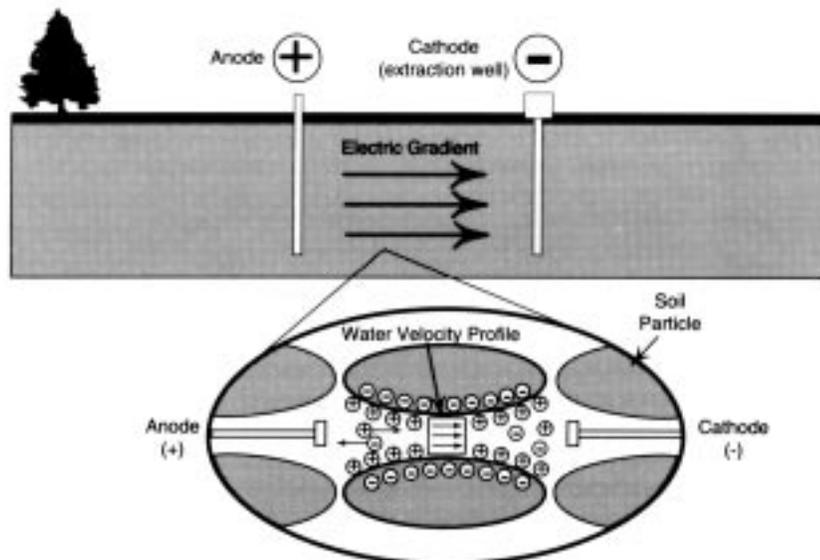
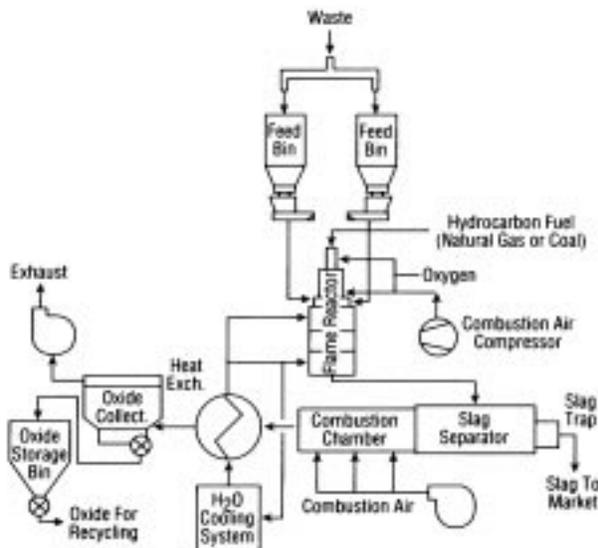


Figure 5. Diagram of a typical electrokinetic operation (USEPA 1990a)



**Figure 6. Horsehead Resource Development Company flame reactor process flow schematic (USEPA 1989d)**

The flame reactor technology can be applied to granular solids, soil, flue dusts, slags, and sludges containing heavy metals. The volatile metals are fumed and captured in a product dust collection system, and the nonvolatile metals are encapsulated in the slag. At the elevated temperature of the flame reactor technology, organic compounds should be destroyed. In general, the process requires that wet agglomerated wastes be dry enough (up to 15% total moisture) to be gravity-fed and fine enough (less than 200 mesh) to react rapidly. Larger particles (up to 20 mesh) can be processed, however, a decrease in the efficiency of metals recovery usually results.

**APPLICATION:** Electric arc furnace dust, lead blast furnace slag, iron residues, zinc plant leach residues and purification residues, and brass mill dusts and fumes have been successfully tested. Metal-bearing wastes previously treated contained zinc (up to 40%), lead (up to 10%), cadmium (up to 3%), and chromium (up to 3%), as well as copper, cobalt, nickel, and arsenic.

**LIMITATIONS:**

This technology is currently being demonstrated as part of the Superfund Innovative Technology Evaluation (SITE) program. It has not been widely tested for use at Superfund site cleanups.

**RESIDUALS:**

An iron-rich aggregate is formed from the molten slag. The metal contaminants (e.g., lead) are recovered as a crude, heavy metal oxide, which may be marketable. Air pollution controls are required to handle the off-gas.

**Technology Contacts**

The following individuals can be contacted with technical questions concerning the treatment technologies:

**Extraction:**

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