EPA/540/R-94/513

ACID EXTRACTION TREATMENT SYSTEM FOR TREATMENT OF METAL CONTAMINATED SOILS

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Contract No:. CR-815792-01-0

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FOREWORD

The Superfund innovative Technology Evaluation (SITE) Program was authorized in the 1986 Superfund Amendments. The program is a joint effort between EPA's Office of Research and Development and Office of Solid Waste and Emergency Response. The purpose of the program is to assist the development of hazardous waste treatment technologies necessary to implement new cleanup standards which require greater reliance on permanent remedies. This is accomplished through technology demonstration designed to provide engineering and cost data on selected technologies.

The Risk Reduction Engineering Laboratory (RREL) is responsible for planning, implementing and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis for support of the policies, programs, and regulations of the EPA. This publication is one of the products of that research and provides a vital communication link between the research and the user community.

This project consisted of demonstration of the Center for Hazardous Materials Research's (CHMR) Acid Extraction Treatment System (AETS), which is a process for the treatment of soils contaminated with heavy metals. The project included the development of the process from laboratory-scale proof-of-concept testing through batch pilot-scale tests. AETS was tested using both surrogate soils and soils removed from current Superfund sites. These soils were contaminated with a variety of metals, including lead, cadmium, chromium, nickel, arsenic, copper, and zinc. The goals of the study were to develop and evaluate AETS.

E. Timothy Oppelt, Director
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ABSTRACT

Through a Cooperative Agreement with the U.S. Environmental Protection Agency's Risk Reduction Engineering Laboratory, the Center for Hazardous Materials Research (CHMR) developed the Acid Extraction Treatment System (AETS). The project was conducted with support from Interbeton bv and The Netherlands Organization for Applied Scientific Research (TNO), located in the Netherlands. AETS is intended to reduce the concentrations and/or leachability of heavy metals in contaminated soils to render the soils suitable to be returned to the site from which they originated. Additional applications may include treatment of contaminated sediments, sludge and other heavy metal-containing solids.

The objective of the project was to determine the effectiveness and commercial viability of the AETS process in reducing the concentrations and leachability of heavy metals in soils to acceptable levels. This report represents an account of the activities conducted during the project, the experiments performed, and the results.

Five soils were tested, including EPA Synthetic Soil Matrix (SSM), and soils from four Superfund sites (NL Industries in Pedricktown, NJ; King of Prussia site in Winslow Township, NJ; smelter site in Butte, Montana; and Palmerton Zinc site in Palmerton, PA). These soils contained elevated concentrations of arsenic, cadmium, chromium, copper, lead, nickel, and zinc.

The results of the study are summarized below:

- AETS is capable of treating a wide range of soils, containing a wide range of heavy metals to *reduce the TCLP below the RCRA limit and to reduce the total metals concentrations below the California-mandated total metals limitations.*

- In most cases, AETS is capable of treating the *entire* soil, with no separate stabilization and disposal for fines or clay particles, to the required TCLP and total limits. The only exception to this among the soils tested was the SSM, which may require separate stabilization and disposal of 20% of the soil because of lead. SSM was successfully treated for other metals, including arsenic, cadmium, chromium, copper, nickel and zinc. A modular system design will allow for the required flexibility to treat a range of soils.

- Costs for treatment, under expected process conditions, range between $100 and 180 per cubic yard of soil, depending on the site size, soil types and contaminant concentrations. Operating costs ranged between $50 and 80 per cubic yard.

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ACKNOWLEDGEMENTS

The Center for Hazardous Materials Research (CHMR) would like to acknowledge the cooperation received throughout the project from the U.S. Environmental Protection Agency, Office of Research and Development. In particular, we would like to thank Ms. Kim Lisa Kreiton, from the EPA’s Superfund Technology Demonstration Division who provided helpful guidance on the project. CHMR would like to acknowledge the following individuals from the research team who were responsible for important contributions to this project.

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The Netherlands Organization For Applied Scientific Research (TNO)

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Work on this project was funded through Cooperative Agreement Number CR-815792-01-0 established between the U.S. Environmental Protection Agency, Office of Research & Development, and the Center for Hazardous Material Research. The organizations which contributed to funding under this cooperative agreement include the EPA, CHMR, Interbeton and TNO. The members of the project research team appreciate the opportunity to participate in this important project to research and develop a new and innovative technology for the remediation and treatment of contaminated soils. Inquiries concerning this report, the project or the AETS technology may be addressed to:

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1.0 INTRODUCTION

Through a Cooperative Agreement with the U.S. Environmental Protection Agency's Risk Reduction Engineering Laboratory, the Center for Hazardous Materials Research (CHMR), developed the Acid Extraction Treatment System (AETS), which can be used to remove heavy metals from soils, solids, and sludge. The project was conducted with support from Interbeton bv and The Netherlands Organization for Applied Scientific Research (TNO), located in the Netherlands. CHMR, a not-for-profit subsidiary of the University of Pittsburgh Trust, is located in Pittsburgh, Pennsylvania.

This project represents an extension of existing "soil washing" techniques in the Netherlands, which have been directed primarily at the remediation of hazardous organic contamination. AETS is intended to treat soils contaminated with heavy metals. Additional applications may include treatment of contaminated sediments, sludge and other heavy metal-containing solids.

1.1 OBJECTIVE OF THE PROJECT

The objective of the project was to determine the effectiveness and commercial viability of the AETS process in reducing the concentrations and/or leachability of heavy metals in soils to acceptable levels as defined by Federal and state (particularly California) regulations. This was to be accomplished by a combination of laboratory-scale investigations during the first year (to prove the concept of acid extraction and establish process parameters) followed by design, construction and testing of a pilot-scale extraction unit during the second year. The process viability and economics were to be determined based on the results of the pilot-scale experiments.

1.2 PROCESS DESCRIPTION

A simplified block flow diagram of the AETS process is given in Figure 1. The first step in the AETS process is screening to remove coarse solids. These solids, typically greater than 4 mm in size, are relatively clean, requiring at most a simple rinse with water or detergent to remove smaller attached particles.

After coarse particle removal, the remaining soil is scrubbed in an attrition scrubber to break up agglomerates and cleanse surfaces. Then it is contacted with acid (HCl) in the extraction unit. The residence time in the unit will vary depending on the soil type, contaminants and contaminant concentrations, but generally ranges between 10 and 40 minutes. The soil/extractant mixture is continuously pumped out of the mixing tank, and the soil and extractant are separated using hydrocyclones. The solids are piped to the rinse system, while the extractant is treated using a proprietary technology which removes the metals and regenerates the acid. The soils are rinsed with water to remove entrained acid and metals. CHMR anticipates a final step, not currently performed, in which the soils will be mixed with lime and fertilizer to neutralize any residual acid and return the soil to natural conditions.

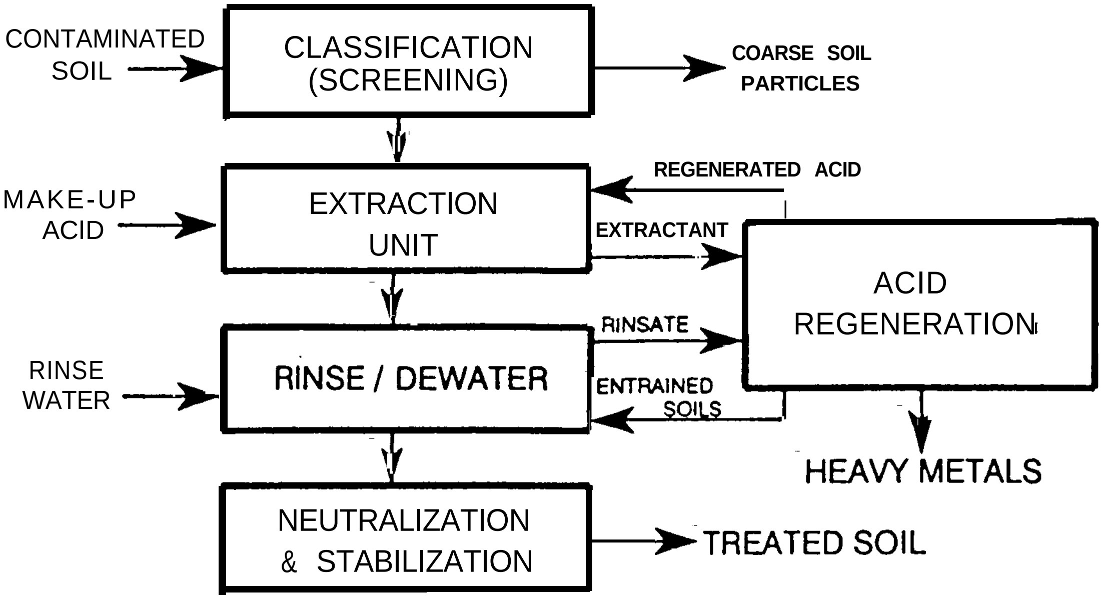


Figure 1 AETS Block Flow Diagram

1.3 PROJECT TEAM

The AETS research and development project is principally supported by an interdisciplinary project team of individuals from the following four organizations recognized internationally as leaders in the research, development and commercialization of environmental technologies.

The Center for Hazardous Materials Research (CHMR), a non-profit subsidiary of the University of Pittsburgh Trust, was formed in 1985 to assist industry and government develop practical solutions to the many problems associated with the use and disposal of hazardous materials and solid wastes. CHMR pursues its mission by conducting broadly based interdisciplinary applied research, technical assistance, education, and public policy programs on issues involving hazardous materials and waste in partnership with academic, industrial, and government organizations. CHMR is active in fostering international research and technology transfer, and has been providing research and development capabilities to businesses and industry, including assisting in the commercial development of new and innovative technologies.

The National Environmental Technology Applications Corporation (NETAC) is a unique public-private joint venture created in 1988 by the U.S. Environmental Protection Agency and the University of Pittsburgh Trust. Its purpose is to facilitate the commercialization of innovative environmental technologies that may positively impact the nation’s most pressing environmental problems. NETAC provides assistance in the transfer of new environmental technologies from government, university, and private sector laboratories to the marketplace through a flexible program of technology evaluations, applied research, bench and pilot-plant testing, and demonstration projects.

Both CHMR and NETAC operate out of the University of Pittsburgh's Applied Research Center (formerly Gulf Oil's R&D Center), which provides a combination of both technical expertise and superior applied research facilities.

The Netherlands Organization For Applied Scientific Research (TNO) is among the leading applied research institutions in the world. With a staff of 5,000, TNO researches, develops, and supplies state-of-the-art technology as well as innovative new technologies. TNO performed the initial work on AETS and played an important role in working with Dutch industry in the successful commercialization of a soil washing process for organic contaminants. TNO has licensed numerous technologies that are now commercially used throughout the world.

Interbeton bv is the international operating company of Hollandsche Beton Groep nv (HBG), founded in 1902. The HBG subsidiaries comprise nine operating companies: each with its own particular specialization. Since its establishment in 1958, Interbeton has gained broad international recognition, experience, and know-how; particularly in the field of general civil engineering and harbor construction. Recent Interbeton projects include the Dammam Port Development and King Khaled City Building project in Saudi Arabia; construction of the Hampton Road Tunnel in Virginia; completion of the Boston Harbor risers project; and construction of the Boston Harbor crossing tunnel. Interbeton is active and experienced in combining the know-how existing within HBG to research and develop new and innovative advanced equipment for civil construction; including the successful research, development, and commercialization of soil washing technology in the Netherlands.

1.4 SUMMARY OF LABORATORY SCALE EXPERIMENTS (FIRST YEAR)

The main goal of the first-year laboratory scale experiments was to determine the overall viability of the AETS process. CHMR also tried to identify potential problem areas which might occur in subsequent work. The following is a list of activities which were accomplished and the results of the laboratory scale experiments.

- The optimum pH to perform extractions was found to be between 1.5 and 3.0, based on experiments at different pH levels.

- Preliminary flow diagrams were developed and evaluated for the AETS process. These diagrams were used to design and build the pilot-scale extraction unit.

- The amount of acid used in the extraction is dependent on the type of soil being treated. Some soils, such as the Synthetic Soil Matrix (SSM), have very good buffering ability and therefore require more acid.

- The rinsing stage was found to be a critical step in the process design. The metals which are transferred from the soil to the extractant (acid) solution are removed during the rinsing. More efficient rinsing removes more of the metals.

1.4.1 Laboratory Scale Experimental Procedure

The following is a summary of the procedures for the laboratory scale experiments.

- The soil is mixed with enough water to give a 3:1 water to soil weight ratio, and then mechanically stirred so there is no accumulation in the container.

- A pH controller is used to bring the pH to the setpoint. The amount of acid used is recorded, and the extraction is continued for the desired amount of time.

- The mixer is shut off and the soil is allowed to settle.

- After the soil settles (approximately 30 minutes), the extractant is decanted. Deionized water is added to rinse the soil, and this is also removed after the soil settles again.

- Samples of the soil are removed for total metals and TCLP analysis. A second extraction may be run on the soil if desired.

1.4.2 Laboratory Scale Results

The bulk of the first-year experiments were performed on the Synthetic Analytical Reference Material (SARM) and the Synthetic Soil Matrix (SSM), both from the EPA, as well as soil from a Superfund site in Pennsylvania. Table 1 below shows the reduction of TCLP metals concentrations in the SARM soil during a typical two-step extraction at a pH of 2.

Table 1 SARM Laboratory Scale Extraction

	TCLP (mg/L)			Percent Reduction	
Metal	Untreated Sand	After One Extraction	After Two Extractions	One Extraction	Two Extractions
As	5.5	2	1.4	64%	75%
Cd	20	2.4	1.5	88%	93%
Cu	140	3.6	8.3	97%	94%
Ni	17	0.5	0.9	97%	95%
Pb	36	14	46	61%	N/A
Zn	650	9.6	18	99%	97%

Parametric experiments were used to determine the optimal pH, residence times and number of extraction steps. The best results were achieved using a one- or two-step process with 15 to 30 minute residence times, The following conclusions were drawn about the Acid Extraction Treatment System:

- The AETS process using hydrochloric acid is a viable means of reducing TCLP metals to levels below the RCRA limits for soils contaminated with As, Cd, Cu, Ni, Pb, and Zn.

- The process can reduce the soil's total metal concentrations by 60 to 99 percent.

- Although a single extraction step is sufficient in many cases, the system should be designed with sufficient flexibility to accommodate two steps.

The second year of the investigation was planned based on the results of the laboratory scale experiments.

2.0 SUMMARY OF SECOND YEAR ACTIVITIES

The following table is **a** brief chronological history of the events that took place during the second year of the AETS project.

EVENT	DATE
Beginning of second year.	4/91
Ideas for the preliminary system designs were being pulled together, as well as some minor equipment purchases, and the mass balance calculations were started.	6/91 - 8/91
Decisions were made to use a cyclone separation system rather than a screw-type conveyor system. More soils were needed and soils should be characterized for particle size distribution, total metals, and TCLP.	10/91
Preliminary system designs were drawn up. More soil was acquired from the EPA (SSM), and a Superfund site in Palmerton, PA. The SSM soil contained As, Cd, Cr, Cu, Ni, Pb, and Zn. The Palmerton soil is mainly contaminated with Cd, Cu, Pb, and Zn.	2/92
The tanks, mixers, piping, and 1-inch and 2-inch cyclones needed to construct the pilot-scale acid extraction system were purchased.	2/92-3/92
Soil from a Superfund site in Pedricktown, NJ was acquired. This soil was contaminated with high concentrations (>3%) of lead and lower concentrations of copper and zinc. The attrition scrubber, pH controller, and rubberized centrifugal pump were purchased.	4/92
The acid regeneration system was acquired.	5/92
The cyclones and acid regeneration system were installed and tested.	6/92
The attrition scrubber, up-flow filter, rubber pump, and pH controller were installed and tested.	7/92
Soil from a Superfund site in Butte, Montana was acquired. This soil is contaminated with copper and zinc. The initial experiments (AE-102 through AE-108) were performed using the pilot-scale system seen in Figure 2.	8/92

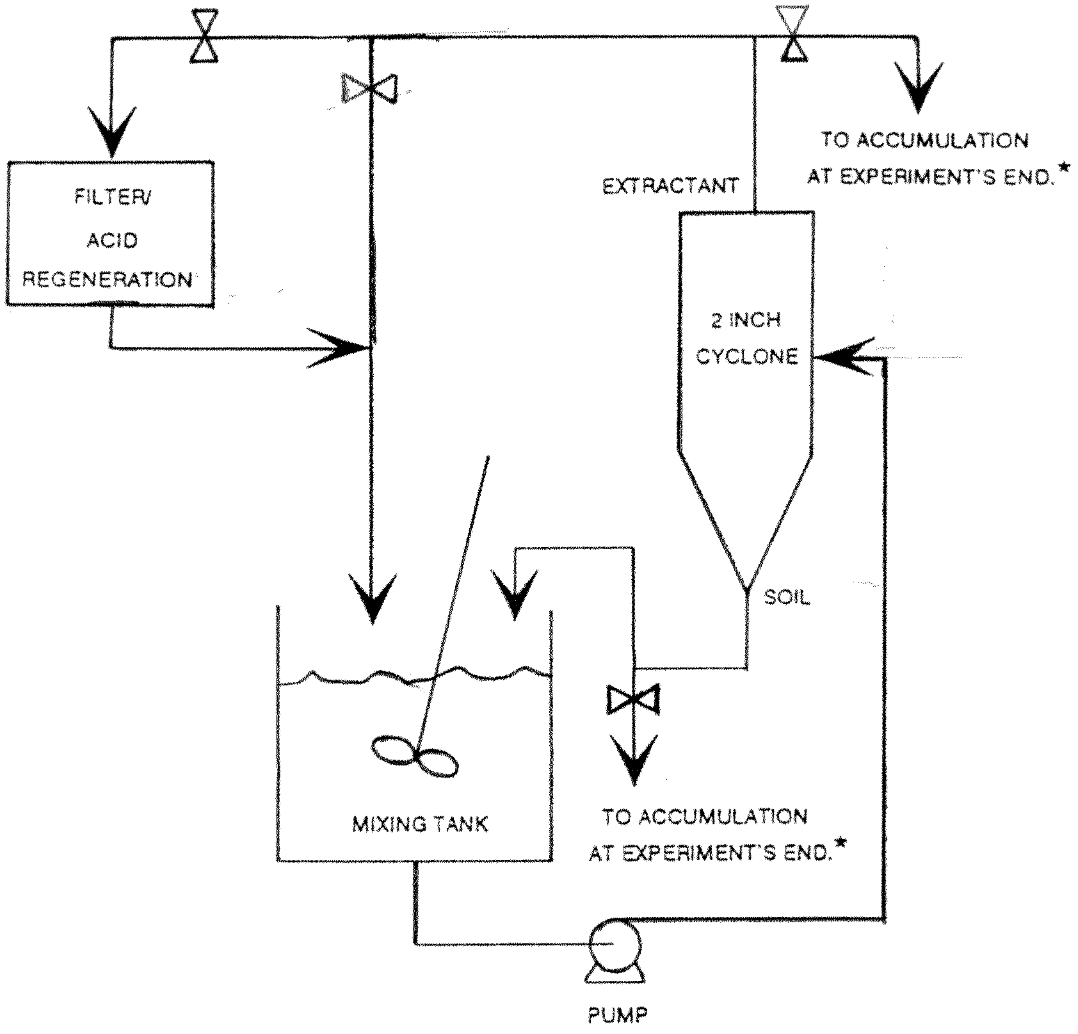
Soil from a site in King of Prussia, NJ was acquired. The main contaminants were copper, chromium and nickel. The rubberized pump was rendered unusable due to the abrasion of the soil.	10/92
A new slurry pump was ordered, installed, and tested. The new pump has an acid resistant impeller and inner coating, and can pump particles up to l-inch in diameter, which eliminates the abrasion problems.	10/92- 11/92
The second set of extractions, AE-112 to AE-117, was performed with only slight procedure changes from the first set, including the new slurry pump.	11/92
The entire process flow was changed to include a second pump and a second cyclone. The final set of extractions (AE-118 through AE-122) was run using this new configuration, which can be seen in Figures 3 through 5.	12/92
Follow-up experiments on the clay fractions of soils were performed. Agricultural tests were performed on treated soils.	1/93 - 2/93

2.1 SUMMARY OF EXPERIMENTAL PROCEDURES

The following experiments were performed on the pilot-scale acid extraction unit designed and built by CHMR. The experimental procedures are separated into three groups (the experiments are numbered in the text in the same format they were numbered in the laboratory):

- The first set of extractions, AE-102 through AE-108, which featured a static screening process for the initial soil classification.
- The second set of extractions, AE-112 through AE-117, which used soils were screened with an automatic shaker and a slurry pump.
- The third and final set of extractions, AE-118 through AE-122, which utilized a modified pilot-scale system.

The procedures used for the three sets of extractions are discussed in more detail in subsequent sections.



*THE SOIL IS ACCUMULATED TO BE RINSED, AND
THE EXTRACTANT IS ACCUMULATED FOR FINAL REGENERATION.

Figure 2 Extraction Flow Diagram

2.1.1 First Extraction Procedure

Initial Preparations

- Sieve soil to below 9 mesh after drying it overnight at 80°C.
- Test pumps, cyclones, valves and other parts of the AETS system to ensure that they are working properly before beginning the experiment.

Extraction Procedure

- Refer to Figure 2 for the process flow diagram.

- Put the soil in the attrition scrubber at a ratio of approximately 60 percent solids by weight and scrub for the allotted time.

- Rinse the scrubber with enough liquid (either fresh water or previously regenerated extractant) to get a ratio of 20 percent solids by weight in the extraction vessel.

- Begin the extraction by turning on: the mixer, pump to the 2-inch cyclone, and the pH controller.

- At the desired pH, the cyclone overflow is routed to the acid regeneration system, and then back to the extraction tank. The underflow is sent directly to the extraction tank. Continue the extraction for the desired time.

- At the end of the extraction, route the cyclone underflow to a 100 mesh screen for dewatering, and route the overflow to storage tanks for later regeneration.

- Regenerate the acid and rinse the soil in the manner specified.

- The filter size used was 1 micron.

- Repeat extraction procedure for the second extraction.

The equipment used for these extractions is listed in Appendix A.

2.1.2 Procedure Changes for Second Set of Extractions

- The extracted soil in the cyclone underflow is dewatered using a 200-mesh mechanical shaker, which allows for faster separation.

- Single step extractions are performed at a pH of 2.0 for 40 minutes, with soil samples being taken every 10 minutes, to determine the effects of residence time distribution. Timed soil samples are rinsed in a beaker to simulate tank rinsing.

- The extracted soil is rinsed using a few different methods, i.e. in the tank or on the shaker, depending upon the experiment.

- A 5 micron cartridge filter is used to separate clay from the extractant.

2.1.3 Procedure Changes for Final Extractions

- The plumbing was changed to add another pump and cyclone, and a settling tank to reduce the amount of clay sent to the filter and acid regeneration system.

- Extractions for this set are single step extractions at a pH of 2.0 for 20 minutes.

- The new process flow diagrams for the extraction and dewatering steps can be seen in Figures 3 and 4. The underflow from the l-inch cyclone shown in Figure 4 is put back on the 200-mesh screen to trap the fines in the sandy-soil fraction.

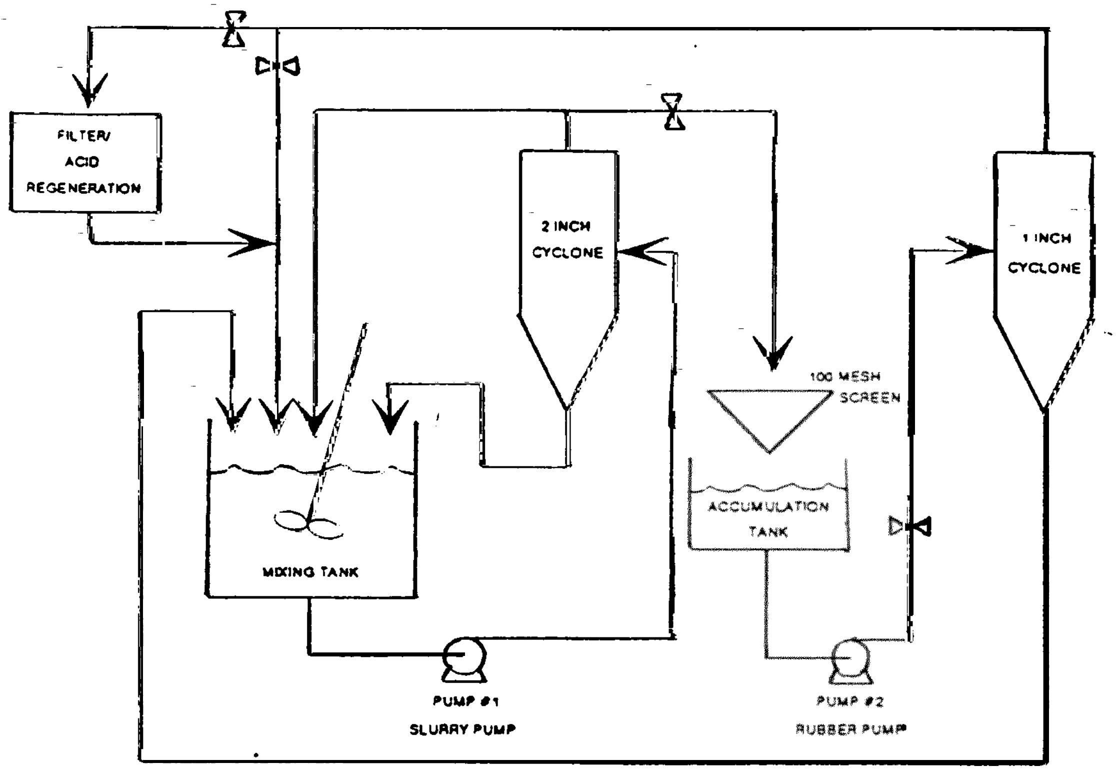
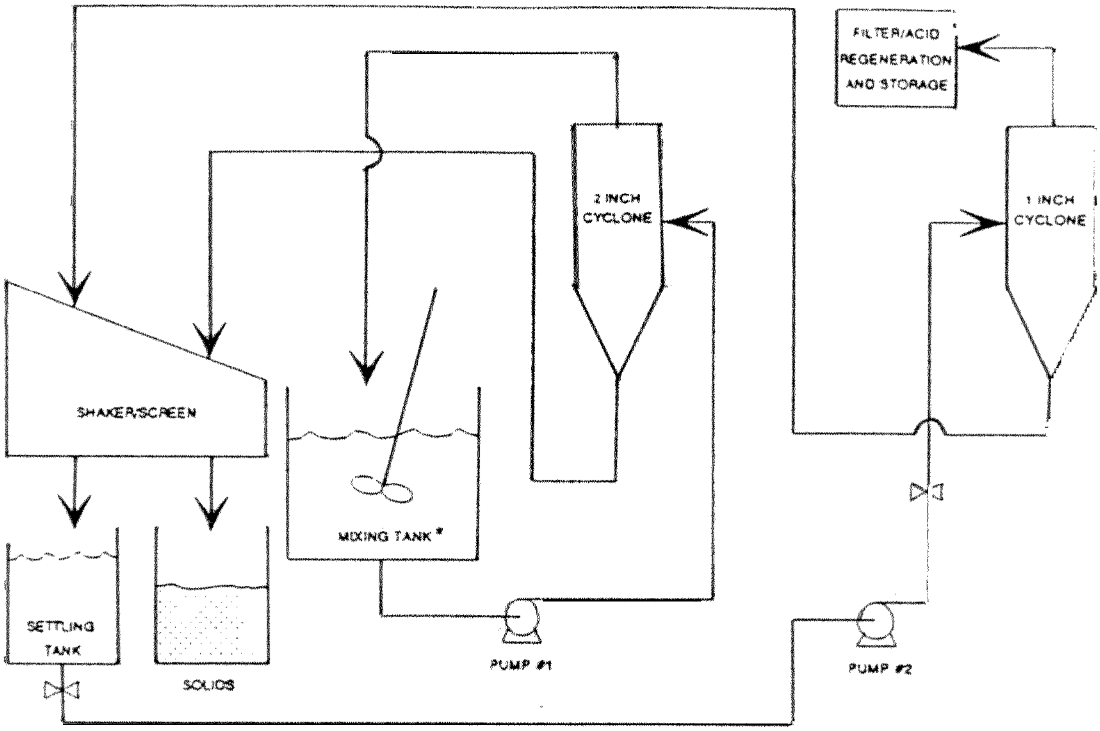


Figure 3 Revised AETS Flow Diagram

- A standard rinsing procedure was developed for the final set of extractions.
  - The soil is placed in the rinse tank with the appropriate amount of rinsate.
  - The soil is mixed for the desired amount of time and then drained onto the shaker, where the solids are separated, and the rinse is collected for regeneration.
  - The rinsate is regenerated prior to being reused in the next experiment, and the soil is the finished, clean, soil. See Figure 5 for the rinsing flow diagram.



*SYSTEM IS RUN UNTIL MIXING TANK IS EMPTY

Figure 4 Dewatering Flow Diagram

- The 1-inch cyclone underflow in Figure 5 is put on the shaker to “trap” the fines in the sandy-soil fraction. The overflow is used to rinse all of the soil out of the tank, due to the batch process being used.

2.1.4 Laboratory Analytical Procedures

The samples were analyzed according to the analytical procedures outlined in the Quality Assurance Project Plan (QAPP). These included the standard EPA method for TCLP extractions (SW-846 1311), and SW-846 6010 for total cadmium, chromium, copper, nickel, lead, and zinc analyses. Method SW-846 7061 was employed for arsenic analyses.

The Quality Assurance/Quality Control procedures employed are summarized in Appendix

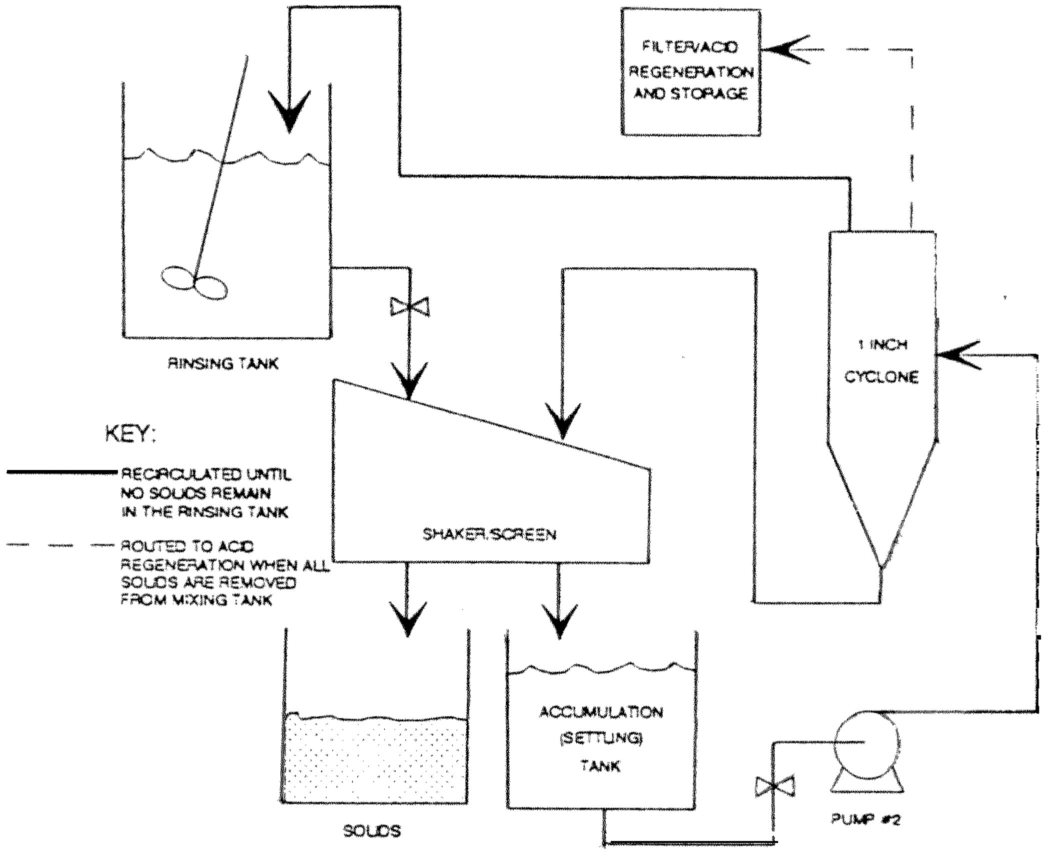


Figure 5 Rinsing Flow Diagram

2.2 SUMMARY OF PILOT-SCALE EXPERIMENTS

A total of 18 extractions were performed. The following table gives a description of the extractions, with a description of procedure adjustments made to each specific experiment.

EXPERIMENT	SOIL USED	CONDITIONS/COMMENTS
AE-102	Butte	No concurrent regeneration
AE-103	Butte	Pump malfunction/exper. stopped
AE-104	Butte	Regeneration during extraction; rinsing on screen
AE-105	Synthetic Soil Matrix	Fines (< 50 microns) removed prior to extraction
AE-106	Synthetic Soil Matrix	Fines removed prior to extraction

AE-107	Pedricktown	Soil rinsed on screen and in tank
AE-108	Palmerton	Extraction stopped due to pump malfunction; usable data obtained, though
AE-112	Butte	Single step extraction
AE-113	Butte	Samples taken over range of residence times to assess process
AE-114	Pedricktown	
AE-115	King of Prussia	
AE-116	King of Prussia	Extraction tank plumbing altered prior to extraction; new pump used
AE-117	King of Prussia	pH meter malfunctioned, no usable data obtained
AE-118	King of Prussia	Cyclone required adjustment
AE-119	Butte	Mass balance performed
AE- 120	Synthetic Soil Matrix	
AE-121	Synthetic Soil Matrix	10 micron filters used
AE-122	King of Prussia	

3.0 RESULTS AND DISCUSSION

In this section, the experiments are categorized based on the types of soil used. The experimental data, soil description, particle size distribution, and discussion will be presented for each type of soil. The following is a list of the soils used, and the number of successful extractions performed on each one with the pilot-scale system.

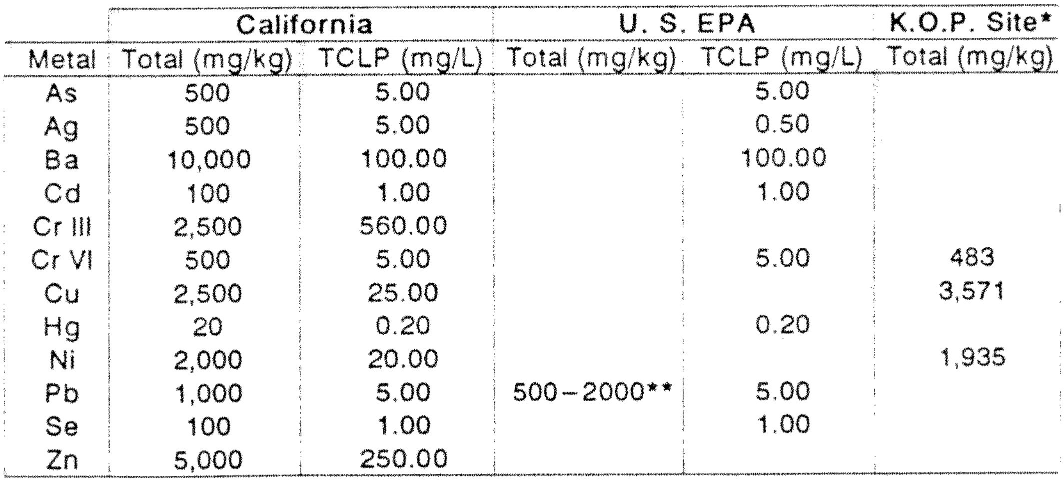
- Butte, Montana soil - 4 extractions
- King of Prussia, NJ soil - 4 extractions
- Synthetic Soil Matrix (SSM) - 4 extractions
- Pedricktown, NJ soil - 2 extractions
- Palmerton, PA soil - 1 extraction

The results from these extractions are discussed in subsequent sections.

3.1 TREATMENT GOALS

The treatment goals for metal-contaminated soils include two criteria -- Toxicity Characteristic Leaching Procedure (TCLP) and total metals.

Table 2 Total and TCLP Metal Treatment Requirements



	California		U. S. EPA		K.O.P. Site*
Metal	Total (mg/kg)	TCLP (mg/L)	Total (mg/kg)	TCLP (mg/L)	Total (mg/kg)
As	500	5.00		5.00	
Ag	500	5.00		0.50	
Ba	10,000	100.00		100.00	
Cd	100	1.00		1.00	
Cr III	2,500	560.00			
Cr VI	500	5.00		5.00	483
Cu	2,500	25.00			3,571
Hg	20	0.20		0.20	
Ni	2,000	20.00			1,935
Pb	1,000	5.00	500–2000**	5.00	
Se	100	1.00		1.00	
Zn	5,000	250.00			

*Treatment objectives for Heidemij Reststoffendiensten Soil Washing Demonstration.
**500 mg/kg in surface soil, 2000 mg/kg below the surface.

TCLP is a measure of the leachability of metals in soil. Salient TCLP maximum concentrations are set in RCRA for 7 metals. The limits are shown in the third column of Table 2. TCLP levels for additional metals have been set by the state of California. These, also are given in Table 2.

Total metals concentration limits are not set by Federal statute. They are often set by individual EPA Project Officers for specific sites. Sample total metals limits are given for the King of Prussia Superfund site. In addition, the EPA has set an action level of 500 mg/kg for lead in surface soils, and 2,000 mg/kg for lead in soils 2 feet or more below the surface. California has set total metals limits for a variety of metals. These limits are summarized in Table 2.

3.2 BUTTE, MONTANA SOIL

Site History

The Superfund site in Butte was placed on the National Priorities List (NPL) because of a potential dust hazard on the site. The soil is non-hazardous, because the main contaminants are copper and zinc, both of which are not considered by RCRA to be hazardous metals. The Butte soil was specifically chosen because it was non-hazardous, and any residuals produced during experiments would also be non-hazardous.

Soil Description

The screening results and particle size distribution are given in Table 3 and Figure 6. The figures show that 2 percent of the soil is smaller than 20 microns, and 6 percent is smaller than 60 microns. The initial soil had the texture of beach sand that had very little clay and large (>$^1/_8$") particles. The dried soil had a density of 1.25 g/cc, and the average total copper and zinc levels are 1250 mg/L and 116 mg/L, respectively.

Table 3 Butte, Montana, Screen Analysis

Mesh	Micron	Volume(ml)	% on
+5	4000	100 on	3.9
+9	2190	100 on	3.9
+20	841	250 on	9.8
+40	420	575 on	22.5
+60	250	750 on	29.4
+100	149	450 on	17.6
-100	N/A	325 thru	12.7

The soil is yellowish in color. Examination under a microscope revealed small turquoise and orange particles, some apparently attached to the surface of sand particles, and some scattered throughout the sand. There were no apparent size differences among the sand particles with or without metals on the surface.

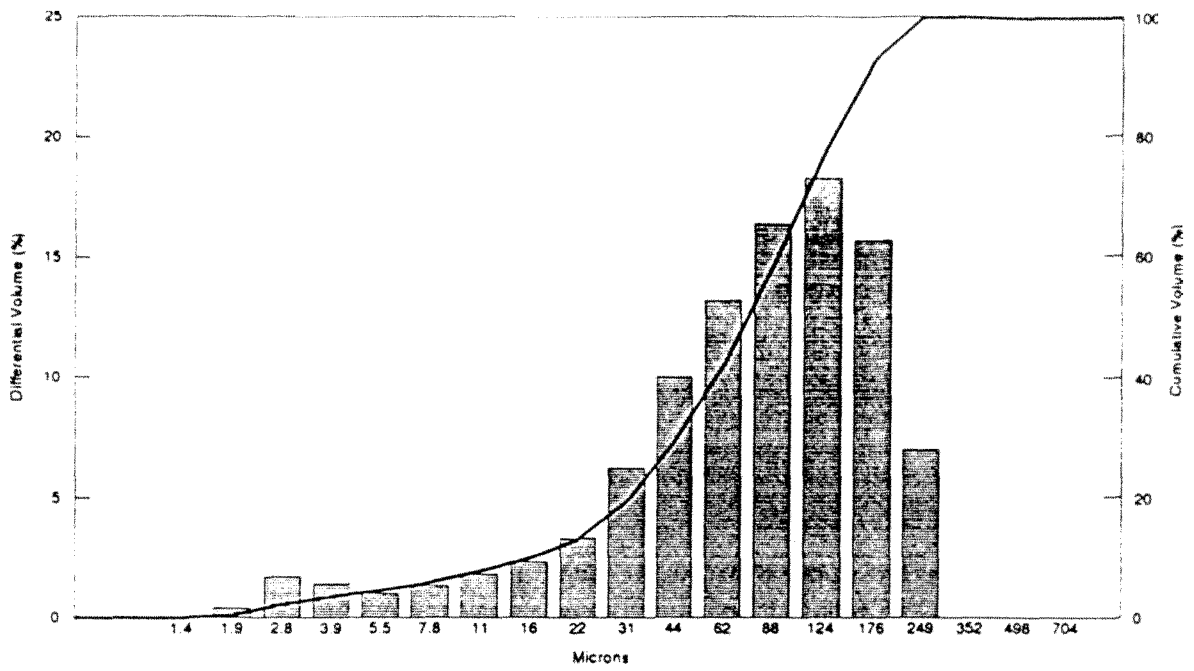


Figure 6 Butte Soil Particle Size Distribution

Discussion of Results

Seven experiments (AE-102, 103, 104, 112, 113 and 119) were attempted using the Butte soil. One experiment (AE-103) was cancelled due to a pump malfunction, and no data for AE-113 were obtained because the samples were destroyed during shipping. AE-102 and AE-104 were duplicate experiments run under identical conditions, with a two-step extractions and 20 minute residence times. AE-112 was a single stage extraction. This experiment was run to see how reproducible the removal levels were with new equipment. There were two main objectives for AE-119, the final Butte extraction. The first was to recover all of the soil to form a mass balance, and the second was to analyze the different soil fractions, i.e., the filter sludge, the sandy soil.

The data in Tables 4, 5, 6, and 7 show the results from experiments successfully conducted with the Butte soil. The tables show the TCLP concentrations for the untreated and treated soils (either after the first or second extractions), and the total metals concentrations in the untreated and treated soils. The soils were analyzed primarily for copper and zinc, with some analyses for lead and arsenic as well. The data show that the acid extraction system worked well for this particular soil. The initial TCLP and totals concentrations for the Butte soil were within the federal and California requirements.

Table 4 AE-102: Butte Soil, 1st Experiment

	TCLP (mg/L)			% Removal	
Metal	Untreated	1st Ext	2nd Ext	1st Ext	2nd Ext
Zn	2.6	N/A	0.0	N/A	100%
Cu	1.4	N/A	0.1	N/A	91%

	Total Metal (mg/kg)			% Removal	
Metal	Untreated	1st Ext	2nd Ext	1st Ext	2nd Ext
Zn	1350	499	285	63%	79%
Cu	114	31	201	73%	82%

Table 5 AE-104: Butte Soil, 3rd Experiment

	TCLP (mg/L)		% Removal
Metals	Untreated	2nd Ext	2nd Ext
Cu	1.7	0.05	97%
Zn	7.1	0.71	90%

	Total Metals (mg/kg)			% Removal	
Metal	Untreated	1st Ext	2nd Ext	1st Ext	2nd Ext
As	183	52	64	72%	65%
Pb	390		49		87%
Cu	127	26	21	80%	83%
Zn	1250	376	326	70%	74%

Table 6 AE-112: Butte Soil, 4th Experiment

	TCLP (mg/L)		
Metal	Initial	Final	% Removal
Cu	1.5	0.2	86%
Zn	2.7	1.2	56%

	Total Metals (mg/kg)		
Metal	**Initial**	**Final**	**% Removal**
Cu	**98.0**	**18.0**	**82%**
Zn	**1,170.0**	**195.0**	**83%**

Table 7 AE-119: Butte Soil, 6th Experiment

	Total Metals (mg/kg)		
Metal	Initial	Final	% Removal
Cu	125	27	78%
Pb	338	39	88%
Zn	1,230	118	90%

TCLP concentrations for copper and zinc were reduced between 55 and 100 percent of the initial levels. The total metals were reduced an average of 82 percent. In the cases where lead levels were analyzed, the system removed an average of 88 percent of the lead. The results indicated modest improvements in system efficiency using the better rinsing and dewatering procedures of the later experiments. The results demonstrated that AETS is capable of removing metals, even starting at relatively low concentrations.

Although the Butte soil contains a small amount of clay, no separate clay removal and disposal is anticipated to be necessary. Approximately 2 percent of the soil was retained on the filter prior to the acid regeneration system. This soil was analyzed for copper, lead and zinc and found to contain 380, 3500 and 980 mg/kg of each, respectively. The filter sludge could be mixed with the remaining soil. With the filter sludge mixed in, the composite result would have been a 75 to 90 percent reduction in metals concentration.

The significance of the Butte soil was its usefulness in determining experimental parameters using a non-hazardous soil, and a demonstration that metals can be removed efficiently even starting in a relatively low concentration range.

3.3 KING OF PRUSSIA, NJ SOIL

Site Historv

The King of Prussia Superfund site is located in Winslow Township, New Jersey. The facility on the site was used to neutralize acid streams from another facility located adjacent to the site. The contaminants of interest in this soil are chromium, copper, and nickel. The material is not RCRA hazardous. The site is listed on the Superfund NPL because of the high levels of chromium. In addition, the soil at the site was recently used to demonstrate another soil washing system (which works primarily by particle size separation). By incorporating the soil into AETS testing program, direct comparisons between the two systems are possible.

Soil Description

The screening results and particle size distribution are given in Table 8 and Figure 7. Seven percent of the soil is smaller than 20 microns, and 11 percent is smaller than

100 microns. This soil was light tan in color, with visible yellow clays and some large particles. The dried soil has a density of 1.34 g/cc.

Table 8 King of Prussia, NJ, Screen Analysis

Mesh	Micron	Weight (g)	% on (thru)
+20	841	295 on	59
+40	420	81 on	16
-40	N/A	127 thru	(25)

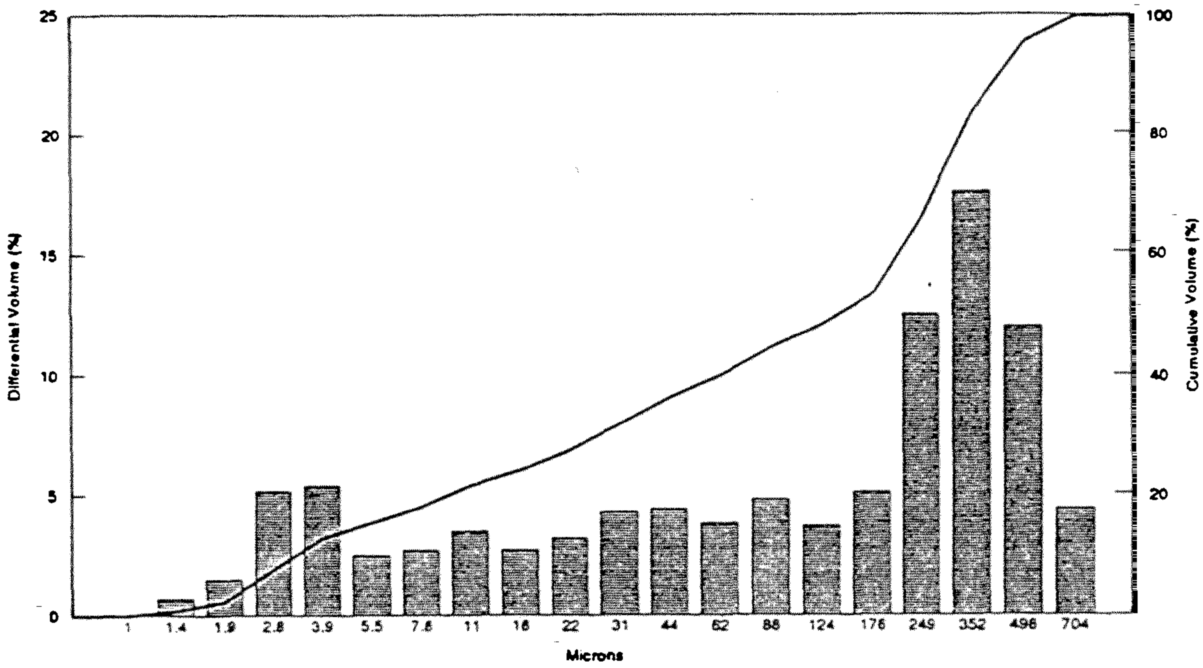


Figure 7 King of Prussia Particle Size Distribution

Microscopic examination revealed black, turquoise, and orange-red particles. The bulk of the soil is orange-red. The black and turquoise particles may be pieces of contamination.

Discussion of Results

Tables 9, 10, 11, and 12 summarize the results from experiments performed using this soil. These tables show the initial and final metals concentrations in the soils. Experiments AE-115 and AE-116 were intended to study the effects of residence time distribution. Soil samples were taken every ten minutes and rinsed by simulating tank

Table 9 AE-115: King of Prussia Soil, 1st Experiment

Metal Removal Efficiency from the Soil

	Total Metals (mg/kg)		
Metal	Initial	Final	% Removal
Cr	1020	37	96%
Cu	1240	17	99%
Ni	335	4	99%

Timed soil samples

	Total Metals (mg/kg)		
Soil	Cr (mg/kg)	Cu (mg/kg)	Ni (mg/kg)
10 minute	135.0	33.1	12.1
20 minute	78.7	18.1	5.1
30 minute	51.9	13.3	3.2
40 minute	73.7	21 .0	4.9

Table 10 AE-116: King of Prussia Soil, 2nd Experiment

Metal Removal Efficiency from the Soil

	Total Metals (mg/kg)		
Metal	Initial soil	Final soil	% Removal
Cr	1240	89	93%
Cu	1660	18	99%
Ni	518	6.3	99%

Timed soil samples

	Total Metals (mg/kg)		
Soil	Cr	Cu	Ni
10 minute	224	47	16
20 minute	183	40	15
30 minute	130	30	8

Table 11 AE-118: King of Prussia Soil, 3rd Experiment

Removal Efficiency from Soil

	Total Metals (mg/kg)		
Metal	Initial*	Final	% Removal
Cr	205	45	78%
Cu	293	47	84%
Ni	50	11	79%

* These results are inconsistent with other samples.

Table 12 AE-122: King of Prussia Soil, 4th Experiment

Metal Removal Efficiencies from the Soil

	TCLP (mg/L)		
Metal	Initial	Final	% Removal
Cr	0.2	0.1	59%
Cu	7.1	0.2	97%
Ni	27.6	1.2	96%

	Total Metals (mg/kg)		
Metal	Initial	Final	% Removal
Cr	1390	324	77%
Cu	2030	93	95%
Ni	514	12	98%

Other Soil Samples

		TCLP in mg/L; metals in mg/kg		
Sample & Description		Cr	Cu	Ni
122-S-07	Rinsed settled soil	4780	707	97
	Rinsed settled soil TCLP	0.8	0.4	0.1
122-S-08	Rinsed filter sludge	3390	760	100
	Rinsed filter sludge TCLP	0.3	1.1	2.8

rinse conditions in a beaker. Results of analyses of these samples are also presented in Tables 9 through 12. TCLP analyses were not performed because TCLP was not a concern with the site. The residence time data show significant decreases in total metals concentration between 10 and 20 minutes, with the metals concentrations still decreasing, but flattening after 20 minutes.

Differences between the 40-minute “timed” data and the final soils when 40-minute extractions were used may be accounted for by differences in the rinse methods used. The bulk of the soil was better rinsed than the small samples removed throughout the extractions.

AE-115 and AE-116 were identical experiments. The concentrations in AE-116 are slightly higher, and this is because the soil in AE-116 was rinsed with regenerated rinsate from AE-115. All of the metals may not have been removed from this rinsate.

AE-118 was the first extraction using the new process flow in Figures 3 through 5. AE-118 was performed under conditions similar to AE-115 and AE-116, except a 20-minute residence time was used. The initial soil analytical results ‘appear to be in error, since they were about 80 percent lower than other experiments using the same soils. The results from AE-118 indicate that copper and nickel removal was approximately the same for either 20 or 40 minute residence times. However, chromium was removed more efficiently when longer extractions were performed.

The objectives for AE-122 were to develop a soil balance and analyze the different fractions of the soil, in order to determine if all fractions of the soil could be recombined to produce a final soil which met the treatment criteria given in Table 2. The results are summarized in Table 13. The coarse solids, which are the bulk of the soil (80 percent or more), were well within all prescribed treatment standards. The fines fraction showed good removal efficiency for Cu and Ni, and was within the limits for these metals. The fines were not within the treatment limit for Cr. It appears that only about half the chromium was actually removed from the soil.

Table 13 Overall King of Prussia Results with Comparison to Heidimij Results

			AETS Results			
Metal	Treatment Standard (mg/kg)	Heidimij Result (mg/kg)	Avg Conc. Final Sand (mg/kg)	Avg Conc. in Fines (mg/kg)	Composite Result (mg/kg)	Overall Removal Efficiency
Cr	463	170	123	2705	639	47%
Cu	3571	350	44	646	164	90%
Ni	1935	70	8	100	26	94%

Based on average concentrations computed over all extractions performed, if the fines were mixed back in with the soil, the resulting composite would not meet the site treatment standard of 483 mg/kg chromium. However, the composite values represented a combination of 20 and 40 minute extraction results. Based on data exclusively from AE-115 and AE-116, which were performed with longer residence times, 40-minute extractions would remove additional chromium, producing a composite with 470 mg/kg chromium, which is within the treatment standard.

Overall, the King of Prussia soil -- maintained as a whole -- appears to be treatable with the Acid Extraction treatment System, using a 40-minute residence time.

3.4 SYNTHETIC SOIL MATRIX

Soil History

The Synthetic Soil Matrix (SSM) was developed by the EPA specifically for use in research and development of emerging or innovative technologies. It is a mixture of clay, sand, silt, gravel, and topsoil that is blended together to form the soil matrix. Organic and inorganic contaminants are added based on typical hazardous materials at Superfund sites. These experiments used SSM soil which contained high levels of metals and no organic contaminants. The metals in the SSM were arsenic, cadmium, chromium, copper, lead, nickel, and zinc.

Soil Description

The screening results and particle size distribution are given in Table 14 and Figure 8, respectively. Approximately 30 percent of the soil is under 50 microns. This soil has a significant amount of clay, and few large particles. The density of the soil was found to range between 1.29 and 1.34 g/cc.

Table 14 Synthetic Soil Matrix Screen Analysis

Mesh	Micron	Weight % on
+9	2190	4
+20	841	16
+40	420	15
+100	170	8
-100	N/A	57

According to its specifications, 40% of the SSM soil is below 75 microns. 12% is below 5 microns.

Microscopic analysis of the soil revealed only a few small particles of metals. The bulk of the particles are medium brown in color, with a few black flecks throughout. In addition, orange and turquoise colored particles were visible. Some of the sand particles appeared to be coated with the turquoise metals.

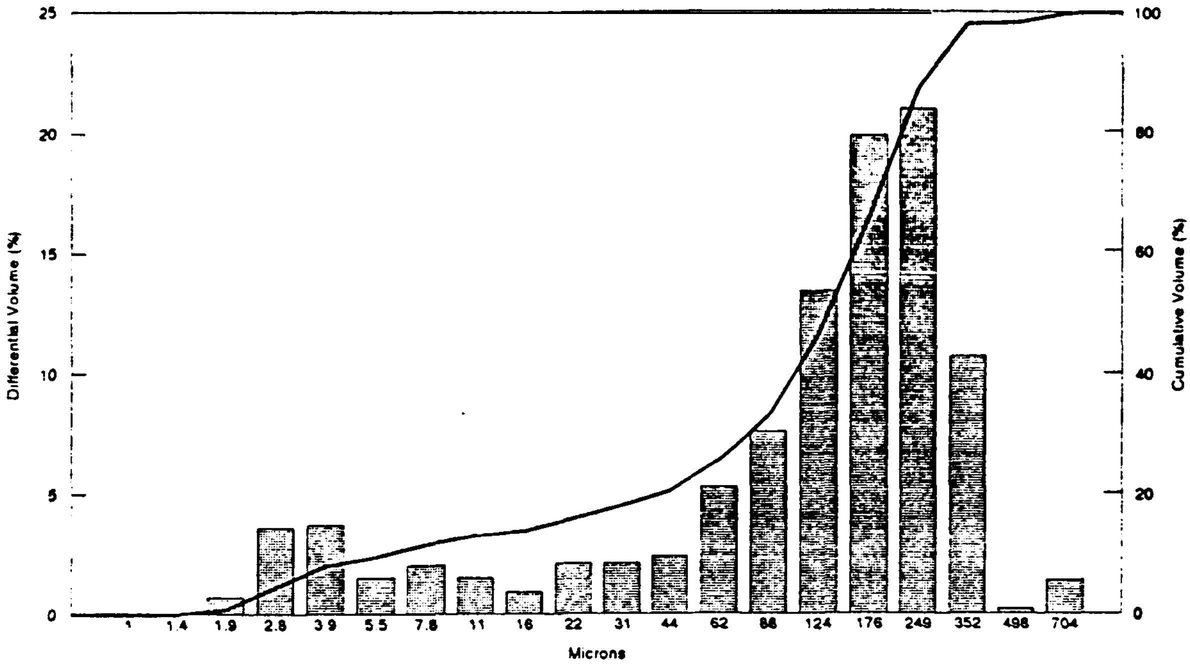


Figure 8 Synthetic Soil Matrix Particle Size Distribution

Discussion of Results

Four extractions were performed on Synthetic Soil Matrix. The results are presented in Tables 15, 16, 17, and 18, which give the untreated and treated soil TCLP and total metals values, as well as the reduction/removal efficiencies for the process. Table 18 also shows the analytical results from other process samples taken. Total metal removal efficiencies typically ranged between 80 and 90 percent for cadmium, copper, chromium, nickel, lead, and zinc. The arsenic removals only averaged 43 percent for total metals, however. This is consistent with the results of the first-year pH studies which showed that the best arsenic removal occurs at a pH of 1.

The system showed significant TCLP reductions. With a few exceptions, the percent reduction for copper, nickel, and zinc (not RCRA hazardous) was in the 90 percent range. In every extraction, the TCLP for lead was successfully reduced below the RCRA limit from initial levels as high as 27 mg/L. Chromium and arsenic TCLP concentrations were maintained below RCRA limits. The percent reduction of TCLP arsenic significantly improved in the final two SSM extractions, and the zinc reduction was slightly lower. TCLP concentrations for cadmium remained above the RCRA limits.

Experiments AE-105 and AE-106 were performed under identical conditions to see if acid extraction would work on this soil, and to determine how repeatable the results were. AE-105 and AE-106 were performed using only the coarse fractions of the

Table 15 AE-105: Synthetic Soil Matrix, 1st Experiment

Metal Removal Efficiency from the Soil

	(mq/L)			% **Removal**	
Metal	Untreated	1st Ext	2nd Ext	1st Ext	2nd Ext
As	3.8	2.4	2.6	38%	33%
Cd	**8.3**	2.2	**1.4**	**74%**	**84%**
Cu	**130.0**	15.2	**4.8**	**88%**	**96%**
Cr	**0.1**	0.1	**0.1**	**NA**	**NA**
Ni	**11.8**	2.2	**0.7**	**81%**	**94%**
Pb	**6.9**	2.3	**0.6**	**67%**	**92%**
Zn	**517.0**	154.0	**45.2**	**70%**	**91%**

	Total Metal (mg/kg)			% Removal	
Metal	**Untreated**	1st Ext	2nd Ext	1st Ext	2nd Ext
As	180	450	155	NA	14%
Cd	254	141	53	44%	79%
Cu	5340	472	213	91%	96%
Cr	451	30	16	93%	96%
Ni	434	78	29	82%	93%
Pb	1820	185	112	90%	94%
Zn	14000	3560	1190	75%	92%

Note: Clays were removed from ‘untreated’ soils for AE-105 prior to the experiment.

Table 16 AE-106: Synthetic Soil Matrix, 2nd Experiment

Metal Removal Efficiencies from the Soil

	TCLP .(mg/L)		% Removal
Metals	Untreated	2nd Ext	2nd Ext
As	0.6	2.1	NA
Cd	8.4	1.6	81%
Cu	106	3.4	97%
Cr	0.2	0.1	65%
Ni	11.6	0.6	95%
Pb	24.4	1.2	95%
Zn	501	26.2	95%

	Total.	Metals (mg/kg)		% Removal	
Metal	Untreated	1st Ext	2nd Ext	1st Ext	2nd Ext
As	304	225	111	26%	63%
Cd	246	80	57	67%	77%
Cu	2870	359	125	87%	96%
Cr	195	24	17	88%	91%
Ni	254	36	19	86%	93%
Pb	985	370	196	62%	80%
Zn	9520	1305	599	86%	94%

Note: Clays were removed from ‘untreated’ soils for AE-106 prior to the experiment.

Table 17 AE-120: Synthetic Soil Matrix, 3rd Experiment

Metal Removal Efficiencies from the Soil

	TCLP (mg/L)				Total Metals (mg/kg)		
Metal	Initial	Final	% Remd	Metal	Initial	Final	%Removal
As	4.0	0.8	81%	As	620	530	15%
Cd	41.0	2.1	95%	Cd	970	95	90%
Cr	<0.05	0.1	N/A	Cr	1,320	63	95%
Cu	297.0	21.1	93%	Cu	10,900	536	95%
Ni	35.6	2.8	92%	Ni	979	70	93%
Pb	27.1	2.8	90%	Pb	10,040	213	98%
Zn	669.0	220.0	67%	Zn	20,500	3.080	85%

The initial concentrations and TCLP include the fine fractions of the soil.

Other Solid Samples

		mg/L for TCLP metals, mg/kg for soil Sample metals						
Sample & Description	% of Soil	As	Cd	Cr	Cu	Pb	Ni	Zn
Rinsed settled soil Total	12%	450	33	250	837	2730	58	1800
Rinsed settled soil TCLP		0.7	1.0	0.8	21.5	81.2	15	44.3
Estimated Initial Fines Conc.		630	686	1980	17200	19500	1370	25200
Rinsed filter sludge Total	22%	1070	25	1430	1350	31700	82	1090
Rinsed filter sludge TCLP		1.1	0.8	1.1	19.0	101.0	1.5	21.1

Table 18 AE-121: Synthetic Soil Matrix, 4th Experiment

Metal Removal Efficienct from the Soil

	TCLP (mg/L)				Total Metals (mg/kg)		
Metal	Initial	Final	% Remova	Metal	Initial	Final	% Removal
As	4.2	0.7	84	As	730	150	79%
Cd	48.9	2.4	95%	Cd	1,130	188	83%
Cr	<0.05	<0.05	N/A	Cr	1,640	93	94%
Cu	298.0	12.1	96%	Cu	12,400	641	95%
Ni	35.9	2.8	92%	Ni	1,410	128	91%
Pb	26.0	2.3	91%	Pb	10,800	315	97%
Zn	719.0	154.0	79%	Zn	26,300	4,760	82%

The initial concentrations and TCLP include the fine fractions of the soil.

Other Solid Samples

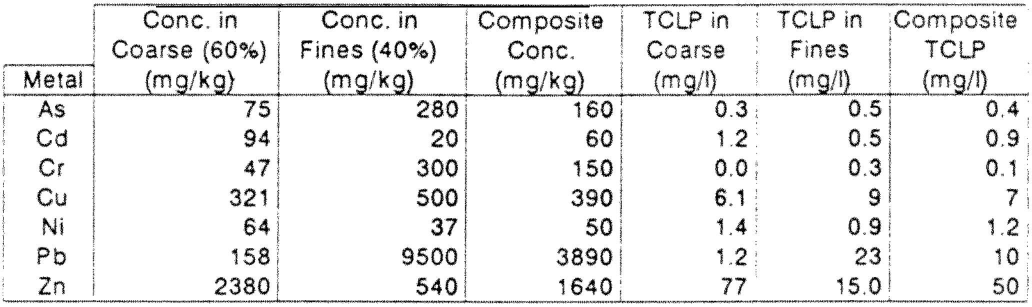
		mg/L for TCLP metals,, mg/kg for soil sample metals						
Sample & Description	% of Soil	As	Cd	Cr	Cu	Pb	Ni	Zn
Rinsed settled soil Total	10%	170	20	153	346	1,200	27	745
Rinsed settled soil TCLP	10%	0.6	0.5	0.4	7.9	26.2	0.7	21.0
Estimated Initial Fines Conc.		630	686	1,980	17,200	19,500	1,370	25,200
Rinsed filter sludge Total	33%	670	35	727	1,106	24,070	86	1.170
Rinsed filter sludge TCLP	33%	1.2	1.2	0.7	20.3	50.8	2.1	32.5

soil -- the fines were removed using a hydrocyclone before the extraction. The total metals concentrations during these extractions were lower than those for the final two SSM extractions.

AE-120 and AE-121 were performed using the new system configuration with the same objectives as before: complete soil recovery and analysis. The TCLP for the two fine soil fractions (filter sludge and settled soil, which represent approximately 40 percent of the original soil by weight) was within treatment standards, except for lead and one cadmium value. The total metal concentration in the fines was within the salient California or EPA standards for all metals except for lead and arsenic.

Based on the quantities of soil recovered in each fraction and the total metal and TCLP concentrations in each recovered fraction, a composite "final" soil concentration was calculated. These composite results are given in Table 19. The results show that the composite total metals concentrations for arsenic, cadmium, chromium, copper, nickel, and zinc were within the treatment objectives. The only metal which was not extracted in appreciable quantities was lead. The lead appears to be concentrated in the filter sludge, which is the finest soil fraction.

Table 19 SSM Soil Composite Results Using Data from AE-120 and AE-121



Metal	Conc. in Coarse (60%) (mg/kg)	Conc. in Fines (40%) (mg/kg)	Composite Conc. (mg/kg)	TCLP in Coarse (mg/l)	TCLP in Fines (mg/l)	Composite TCLP (mg/l)
As	75	280	160	0.3	0.5	0.4
Cd	94	20	60	1.2	0.5	0.9
Cr	47	300	150	0.0	0.3	0.1
Cu	321	500	390	6.1	9	7
Ni	64	37	50	1.4	0.9	1.2
Pb	158	9500	3890	1.2	23	10
Zn	2380	540	1640	77	15.0	50

The composite samples show compliance with TCLP limits for everything but lead and cadmium. Given its apparent extractability, the cadmium may be removed by using a longer rinse or more rinsewater.

The TCLP and total metals concentration for lead would have been within the EPA and California regulatory limits if the coarse sand and rinsed settled soil (the coarser fines from the cyclone overflow) were composited together. The remaining fines, which represent between 20 and 25 percent of the original soil, would have to either undergo additional treatment for the removal of lead or stabilization and disposal.

Overall, the extractions using SSM showed that five of the six metals (all except lead) in the soil are readily treated using 20-minute residence times to the prescribed limits for total metals, and four of the six metals (all except cadmium and lead) are treatable to the TCLP limits. Based on the first year and results from other soils, the cadmium may be treatable using a 30 to 40-minute extraction, coupled with more extensive rinsing. Lead is treatable in the bulk of the soil provided that the fines (representing 20 to 25 percent of the SSM) are first removed. These fines may be amenable to treatment using different methods.

3.5 PEDRICKTOWN, NJ SOIL

Site History

Soil was obtained from the National Lead Superfund site in Pedricktown, NJ. The facility crushed and processed lead-acid batteries through an on site furnace for lead reclamation. The soil was contaminated with copper, lead, and zinc, but was selected for testing primarily due to its high levels of lead.

Soil Description

The screening results and particle size distribution are given in Table 20 and Figure 9, respectively. The soil is sandy, with some clays and few large particles (> 1/8") present. The raw soil is reddish in color with some visible clays. Eight percent of the soil would pass through a 150 micron screen. The density of the soil ranged from 1.58 to 1.89 g/cc. The average initial TCLP lead is 510 mg/L, and the average initial total lead is 26,200 mg/kg, which are high, even compared to the SSM. Table 20 shows the distribution of lead throughout the different fractions. The concentration of lead in the fines (-100 mesh) was extremely high (over 13 percent), but even the coarse fractions of the soil contained appreciable quantities of lead. The bulk of the lead (over 70 percent) was present in the fraction of soil between 150 and 850 microns in size.

Table 20 Pedricktown, NJ, Screen Analysis

Mesh	Micron	Weight (g)	% on	Pb (mg/kg)
+5	4000	124 on	6.2%	12,000
+9	2190	160 on	8.0%	12,000
+20	841	342 on	17.1%	34,500
+40	420	550 on	27.5%	34,500
+60	250	458 on	22.9%	34,500
+100	149	216 on	10.8%	34,500
-100	N/A	160 thru	8.0%	132,000
			Overall:	33,000

Microscopic examination revealed that the soil was very grainy, with orange-red particles throughout the granules. There were also many very dark particles mixed in with the soil. The bulk of the particles appeared to be beige or yellowish-orange in color.

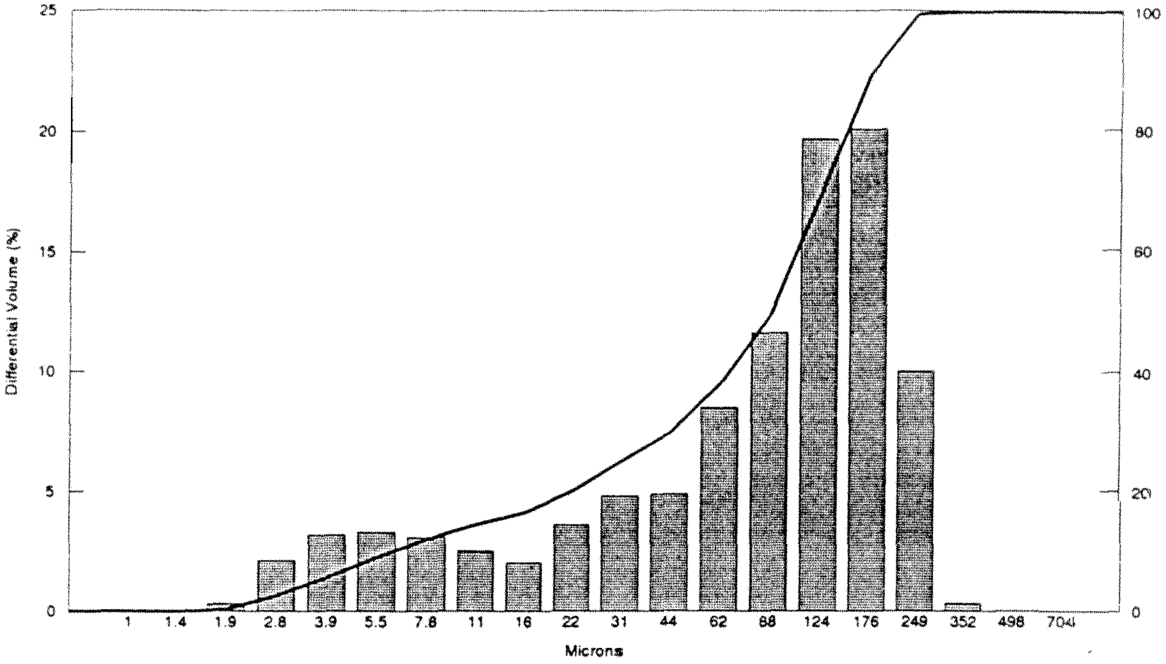


Figure 9 Pedricktown, NJ, Soil Particle Size Distribution

Discussion of Results

Two extractions were performed using the Pedricktown soil, AE-107 and AE-114. The results from these extractions are presented in Tables 21 and 22, which show the initial and final TCLP and metals concentrations. Data from samples taken at different residence times are also given in Table 22. The AETS system dramatically reduced the TCLP lead in both extractions. The TCLP concentration was reduced by 95 percent in one experiment and by 99 percent in the other. During the first experiment, the concentrations were reduced to just above the RCRA limit of 5 ppm. Based on these results, CHMR anticipates that the TCLP can be reduced below the RCRA limit if a longer residence time is used. The rinse system for the treated soil malfunctioned during the second extraction. Inefficient rinsing tends to increase the TCLP values for the soil, because the entrained acid in the soil contains high concentrations of highly mobile metal contaminants. The high TCLP values for this soil were attributed to the problems with rinsing. However, a confirming experiment could not be performed because CHMR had insufficient soil.

The data for AE-107 shows that a 20 minute, one-step extraction can remove the majority of the lead from the Pedricktown soil. The residence time data from experiment AE-114 show that more than 90 percent of the lead was removed after only five minutes. The final total lead concentration is above the EPA surface soil limit, but well below the EPA limit for soils two feet below the surface. The total level is approximately equal to the California treatability limit for lead.

Table 21 AE-107: Pedricktown Soil, 1st Experiment

Metal Removal Efficiencies from the Soil

	TCLP (mg/L)		% Removal
Metal	Untreated	2nd Ext	2nd Ext
Pb	520.0	5.1	99.02%

	Total Metals (mg/kg)			% Removal	
Metal	Untreated	1st Ext	2nd Ext	1st Ext	2nd Ext
Pb	29,200.0	1,430.0	1,310.0	95.10%	95.51%
Cu	192.0	92.3	68.3	51.93%	64.43%
Zn	239.0	345.0	195.0	NA	18.41%

NOTE: 1st extraction soil was dewatered and rinsed on the screen. The 2nd extraction soil remained in tank overnight, then rinsed on the screen.

Table 22 AE-114: Pedricktown Soil, 2nd Experiment

Metal Removal Efficiency from the Soil

	TCLP (mg/L)		
Metal	Initial	Final	% Removal
Pb	503.0	23.1	95.41%

	Total Metals (mg/kg)		
Metal	Initial	Final	% Removal
Pb	23200.0	1,040.0	95.52%

Timed soil samples

Soil	Pb(mg/kg)
5 minute	1,790
10 minute	**1,930**
20 minute	**2,210**
30 minute	**954**
40 minute	**1,080**

The purpose of AE-114 was to find a suitable residence time for this soil. Although 95 percent of the total lead is removed after 5 minutes, some more studies may be needed to determine how long is necessary to reduce the TCLP lead to below acceptable levels.

As anticipated from the particle size distribution, the Pedricktown soils generated a small amount of fines (less than 1 percent of the original soil). This material was not separately analyzed.

These results indicate that AETS has the potential for remediating the contaminated soil found on the Pedricktown site.

3.6 PALMERTON, PA SOIL

Site History

This soil is from the Superfund site in Palmerton, PA. The site is a mountain-side adjacent to the Zinc Company of America, a zinc smelting company. Because of deposition of zinc, cadmium, copper and lead, the mountain-side has become completely defoliated. The soil was chosen for testing because of high levels of zinc, and also because it contained some lead and cadmium. This soil is RCRA hazardous because of the cadmium level.

Soil Description

The particle size distribution is given in Figure 10. The Figure represents 15 percent of the soil, and so approximately 6 percent is under 20 microns. The soil was loam and sand, with some clays and large particles (>1/8") present. The soil was also blackish-brown in color with some visible yellow clays, tree bark, and vegetation. The soil is well-weathered, and most of the fines and organic content have been washed out over the years.

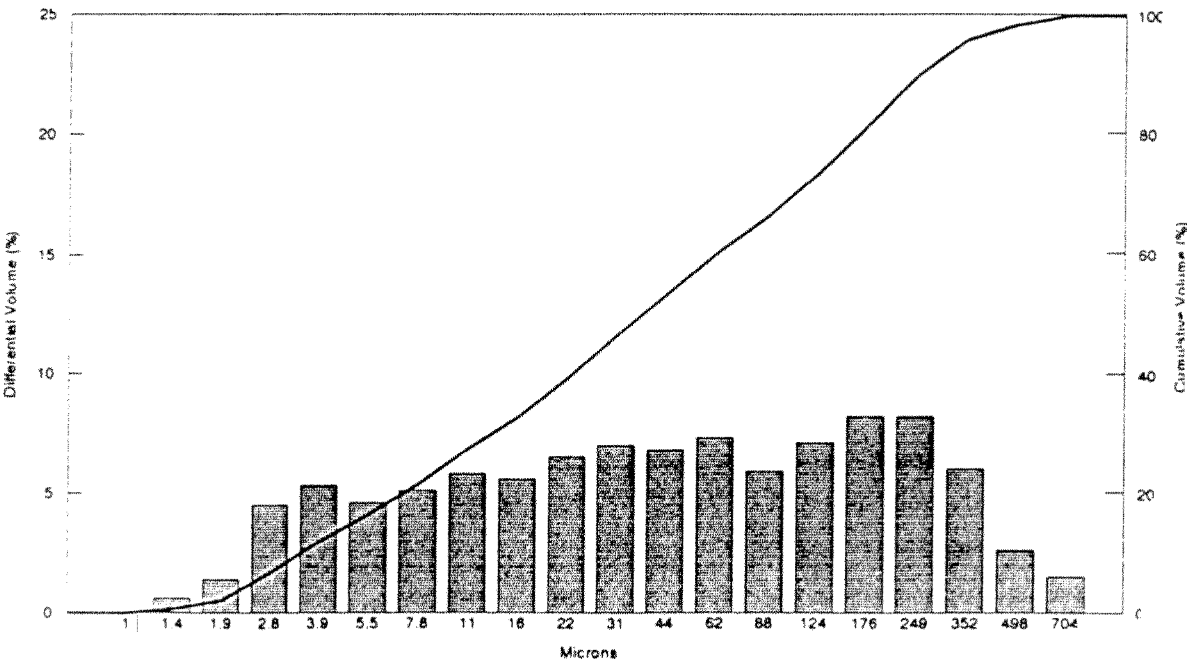


Figure 10 Palmerton Soil Particle Size Distribution

Discussion of Results

Only one extraction was performed using this soil because the project possessed only limited quantities. TCLP and total metals concentrations before and after the extraction are summarized in Table 23.

The soil was hazardous because of the cadmium TCLP levels. AETS reduced the cadmium TCLP value well below the limit. Zinc TCLP values were also reduced. Copper values remained about the same, and lead actually increased. This indicates that the extraction partially solubilized the lead, but did not efficiently remove it. Lead in this soil is expected to be in the form of sulfides, which are not easily solubilized.

The data in Table 23 shows that the only metal in excess of the federal limits was lead (over 500 mg/kg). Two metals exceeded the California total metals limits: zinc and cadmium. Extraction using AETS reduced the total zinc concentration by over 90 percent, and the residual was well within the prescribed limits. The extraction produced a similar 90 percent drop in cadmium levels, which were well within the prescribed limits. The total lead concentrations were reduced to very near, but still above, the federal limits of 500 mg/kg for surface soils, but below the concentrations for subsurface soils and below the California total lead requirement. Total copper concentrations were also reduced.

Table 23 AE-108: Palmerton Soil Experiment

Metal Removal Efficiencies from the Soil

	TCLP (mg/L)			% Removal	
Metal	Untreated	Screen	Tank	Screen	Tank
Cd	2.60	0.17	0.25	93.46%	90.38%
Pb	0.66	2.03	3.68	N/A	N/A
Cu	0.16	0.15	0.23	6.25%	N/A
Zn	70.5	4.26	3.76	93.96%	94.67%

	Total Metals (mg/kg)			% Removal	
Metal	Untreated	Screen	Tank	Screen	Tank
Cd	137.0	11.6	9.0	91.53%	93.46%
Pb	898.0	844.0	588.0	6.01%	34.52%
Cu	166.0	93.7	54.9	43.55%	66.93%
Zn	9,150.0	707.0	352.0	92.27%	96.15%

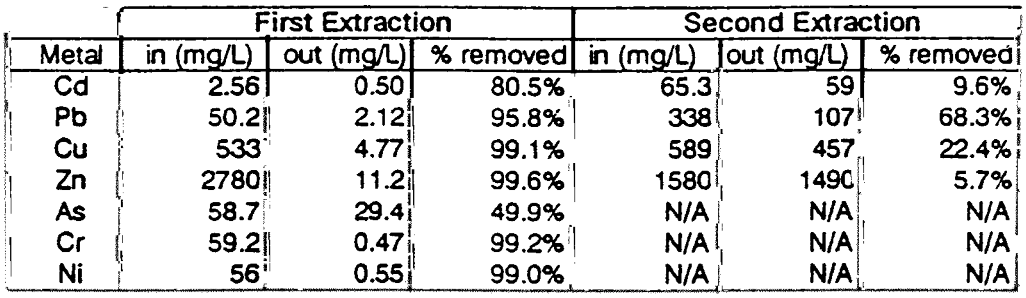
During the extraction, some of the soil was rinsed in the tank and some was rinsed on the screen. When rinsing on the screen, the soil was moved across a shaker/screen while being sprayed with the rinsate. The experiment demonstrated that tank rinsing is the more thorough of the two methods for removing all of the extractant.

3.7 ACID REGENERATION

Regeneration of the acid figured prominently in the success of the extraction system. In general, the reductions obtained from the pilot system exceeded those obtained during the first year, laboratory-scale experiments. One explanation for this is during the first year experiments, the extractant would tend to become saturated in metal chlorides, and thereafter no metals would be dissolved. By attaching a regeneration system which removes the metals and reforms the acid directly to the extraction tank, the metals concentration in the extractant solution never builds up sufficiently to approach equilibrium.

Specifics of the acid regeneration system are considered proprietary. Analyses of the inlet and outlet extraction concentrations were conducted for nearly every extraction. Results from two of the analyses are given in Table 24 and 25.

Table 24 Regeneration System Metal Removals for AE-105



	First Extraction			Second Extraction		
Metal	in (mg/L)	out (mg/L)	% removed	in (mg/L)	out (mg/L)	% removed
Cd	2.56	0.50	80.5%	65.3	59	9.6%
Pb	50.2	2.12	95.8%	338	107	68.3%
Cu	533	4.77	99.1%	589	457	22.4%
Zn	2780	11.2	99.6%	1580	1490	5.7%
As	58.7	29.4	49.9%	N/A	N/A	N/A
Cr	59.2	0.47	99.2%	N/A	N/A	N/A
Ni	56	0.55	99.0%	N/A	N/A	N/A

*N/A means the metal was not analyzed for.

NOTE: ‘in’ and 'out' refer to the concentration of total metals sampled as they were going into and coming out of the acid regeneration system.

Table 25 Regeneration System Metals Removal for AE-107

	First Extraction			Second Extraction		
Metal	in (mg/L)	out (mg/L)	% removed	in (mg/L)	out (mg/L)	% removed
Pb	1200	78.2	93.5%	975	88.3	90.9%
cu	299	5 . 4	8 98.2%	325	404	- 24.3%

NOTE: 'in’ and 'out' refer to the concentration of total metals sampled as they were going into and coming out of the acid regeneration system.

The results show that the acid regeneration system was capable of removing the majority of metals from the acid stream. Results from two-stage extractions, however, do show that the removal efficiency tended to decrease during the second extraction. From the efficiency information, the required size of the regeneration system may be calculated based on the size of the regenerated stream and the metals concentration within.

The removal efficiencies for arsenic in the acid regeneration system were lower than that typical for other metals. This may be attributable to the form of arsenic ion -- typically AsO_4^{-3} -- which differs from the typically cationic form of other metals.

It is anticipated that for soils with high concentrations of metals, such as the Pedricktown or SSM soils, a larger extractant regeneration system would be required than for soils with relatively low concentrations of contaminants.

3.8 SOIL POST-TREATMENT

It is anticipated that the soils treated by AETS will eventually be returned to the ground from which they were taken. The acid used during AETS will undoubtedly remove some of the natural soil alkalinity, and produce a soil with depleted calcium, and other nutrients. Therefore, it is anticipated that lime and fertilizer will be added to the soil before placing it into the ground.

The addition of lime is anticipated to decrease the TCLP values for the soil. Therefore, in order to conduct conservative tests which would tend to overestimate rather than underestimate the TCLP in the resultant soils, CHMR did not add any lime or nutrients to the soil after the extractions.

To determine the overall condition of the soils, CHMR had several samples analyzed at an agricultural laboratory. The results from these analyses show that the soil pH's tended to increase during the rinse step and after the extraction. Measured pH's of treated soils varied between 4.9 and 6.6. Soil calcium levels also varied, from above the optimum range for Pedricktown soils after treatment, to very low for the Butte soil. Soluble salts levels tended to be within the normal range for soils. Concentrations of phosphates, potash (potassium oxide), and magnesium tended to be low after treatment in AETS. The results suggest that the soils will support growth, after addition of small quantities of lime and nutrients.

3.9 FINES TREATMENT

CHMR performed additional laboratory-scale experiments to determine the treatability of the fines fractions of the soil. At the time of this report, the results from only two experiments were available. The first experiment, conducted with the fines from the Pedricktown soil, showed a reduction of lead concentrations in a fines:water slurry from 20,300 mg/kg to 2,300 mg/kg. A second experiment conducted with a soil from a battery breaker site in North Carolina showed reductions from 1,750 mg/kg to 550 mg/kg in the fines: water slurry.

Based on this positive result, CHMR is continuing investigations to develop a simple treatment system for the fines fraction. It is anticipated that such a treatment system will be applicable to both the fines fractions in soils and possibly sediment treatment.

4.0 CONCLUSIONS

The results indicate that the Acid Extraction Treatment System is capable of treating a wide variety of metals present in many different types of soil. Additional conclusions may be drawn regarding the treatment system design, and specific aspects of the technology. These are discussed in subsequent sections. In addition, a final treatment system design is presented, and an economic analysis of it is given.

4.1 SOIL AND METAL TREATABILITY

Table 26 summarizes the soil treatability across the soils and metals tested. Where individual soil fractions were separated during the extraction, and analyzed separately, the table shows the composite results if the entire soil had been remixed. The results show that AETS treated virtually all the soils tested to both reduce the total metals concentrations to below currently regulated concentrations and reduce the TCLP to below the currently regulated concentrations. Major exceptions included cadmium, which consistently failed the TCLP for SSM soil, and lead, which failed both the TCLP and total metals requirements for SSM soils. Lead was also not reduced below the EPA surface soils concentration (500 mg/kg) for the Pedricktown soil, although it was reduced below the EPA subsurface and California total metals concentrations.

Table 26 Qualitative Results of Extractions

	Soil				
Metal	SSM	Butte	King of Prussia	Pedricktown	Palmerton
As	*, T,L	*,T,L			
Cd	*,T		*,T,L		*,T,L
Cr	*,T, L		*,T,L	*,T,L	
Cu	*,T, L	*,T, L	*, T, L		*, T, L
Ni	*,T, L		*,T, L		
Pb	*	*,T, L		*, T, L	*,T,L
Zn	*,T, L	*,T, L		*, T, L	*,T,L

Key: * -- Metal is present in that soil
T- - Successful treatment for total metals
L- - Reduction in leachability to below standards.
Boldface and larger fonts indicate high initial concentration (at least double the regulatory standards)

The total lead result for the Pedricktown soil is not surprising: the soil started with nearly 3 percent lead, which was reduced to approximately 0.1 percent during a single-step extraction. A second extraction is probably necessary to reduce the total concentration further.

Neither the total lead concentrations nor the TCLP lead concentrations were reduced to below the regulatory limits during the extractions using the entire SSM soil. They were reduced, however, during earlier extractions using only the coarse fraction of the soil. Based on the results of the extractions, it appears that if the finest 20 percent of the soil had been removed, the remaining soil would have been treatable using AETS. CHMR is currently performing some experiments using the fines fractions to determine if alternative extraction procedures could be used to remove lead from the fine fractions of the soil.

The cadmium result for SSM is extraordinary in that the portion of the soil which failed the TCLP for cadmium was the coarse fraction (+100 mesh). The fines passed the TCLP. Most probably, the TCLP level in the coarse fraction could be reduced if a longer extraction time were used. The Palmerton soil demonstrates that cadmium is treatable using AETS -- the soil is hazardous only because of the TCLP value for cadmium, and that was reduced by over 90 percent using AETS.

4.2 AETS PROCESS DESIGN

Based on the results of the experiments, the basic design of the AETS process is unchanged from that shown in Figure 1. The results have provided further information and clarification concerning the following aspects of the required design.

- Soil Pretreatment System
- Extraction System
- Dewatering and Rinse Systems
- Acid Regeneration System
- Post-treatment System

These components are discussed below.

Soil Pretreatment Svstem

The soil pretreatment system is shown in Figure 11. The soil is first passed through a grizzly, designed to remove particles larger than about 1 by 2 inches in size. The underflow from the grizzly passes directly into an attrition scrubber, which is operated at relatively high solids to liquid ratios. If makeup liquid is required in the scrubber, it may be'supplied as regenerated acid from the extraction system. In the final section of the scrubber, more liquid may be added if necessary to further slurry the soil and make it easier to sieve.

Once through the scrubber, the soil passes directly onto a 6 mm wet screen. The wet screen is sprayed with acid from the regeneration or extraction systems. The overflow from the screen includes coarse gravel and bits of trees and other material, which will be allowed to drain on a pad, and may possibly be rinsed to remove excess small particles clinging to larger ones. The drainage from the coarse particles will either be passed directly back onto the screen, or (if it is rinsewater), may be clarified, treated to remove metals, and reused.

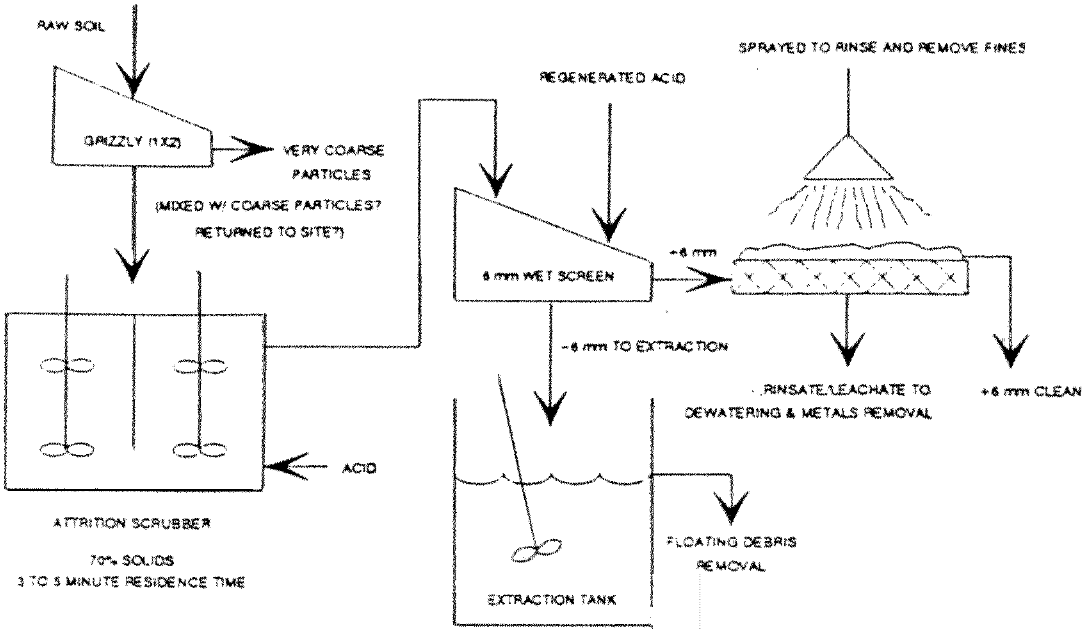


Figure 11 AETS Pre-treatment

The underflow from the 6 mm screen will be placed directly into the extraction tank for further processing.

The very coarse materials originally removed in the grizzly may or may not be contaminated. If they are, they may be rinsed with the coarse particles (if necessary to remove dirt and other clinging debris), or washed using debris washing techniques. If they are uncontaminated, they can be returned directly to the site.

Extraction System

The extraction system consists primarily of a tank, or series of tanks, which provide the soil with the appropriate contact time with acid. The tanks are well-mixed to prevent solids from settling during the extraction. The soil is extracted at approximately 20 percent by weight solids.

Figure 12 shows one possible system. The soils are fed to two extraction tank system in series, which are intended to overcome problems associated with the residence time distribution in continuously stirred tank reactors. Additional residence time will be provided by the scrubber and sieving systems.

The soil slurry passes from the first tank to the second, then to a hydrocyclone. The pilot plant used 2-inch hydrocyclones. Subsequent discussions with vendors and experts on hydrocycloning suggest that a 4-inch cyclone may provide a better split.

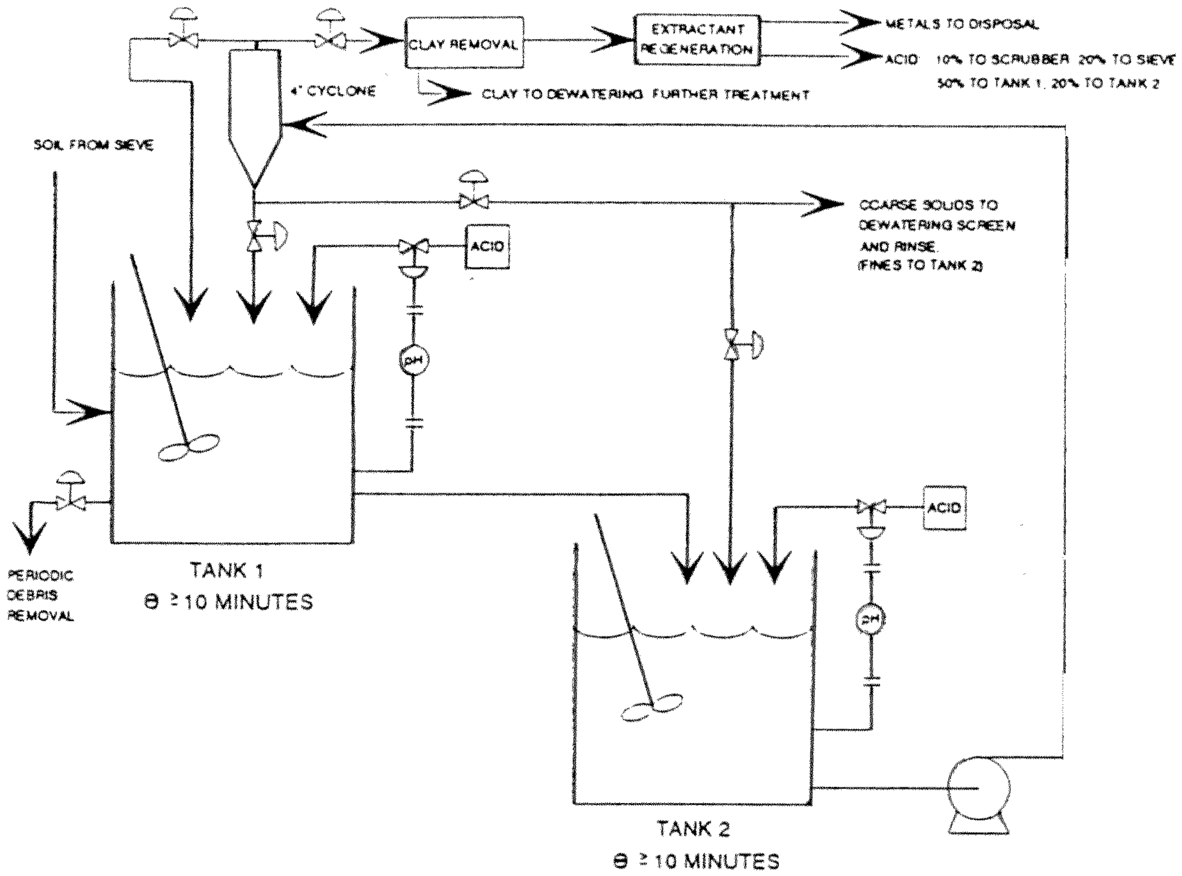


Figure 12 Extraction System

Therefore, the system is drawn using 4-inch cyclones. These will be manifolded together as required for the system flow. Both the overhead and underflow from the cyclone may be split, depending on the requirements of the individual soil. A portion of the overflow may pass. directly into Tank 1, depending on the capacity of the clay dewatering and acid regeneration systems. It is anticipated that sometimes, particularly during start up, a portion or all of the underflow may also be cycled back to Tank 1 and/or Tank 2. Otherwise, the underflow will pass to the coarse solids dewatering and rinse system.

The overflow, meanwhile, will be clarified to remove clays and other solids. Then the acid extractant will be regenerated. It is anticipated that approximately one-half of the regenerated extractant will be passed directly back into Tank 1. The remaining portion will be split among the scrubber (~ 10 percent), the sieve system (25 percent), and Tank 2 (15 percent).

Rinse and Dewatering Systems

AETS is anticipated to require two rinse and four dewatering systems. Rinses will be required for both the fine and coarse solids. Dewatering will be required of both the fines and coarse solids both before and after they are rinsed.

A dewatering and rinse system for the coarse solids is shown in Figure 13. The system consists of a 200 mesh dewatering sieve, followed by a rinse tank, and a second sieve system, The underflow from the dewatering sieve, which will contain some fines, is passed back to the extraction tank. The fines are anticipated to build up in the extraction tank and to be removed with the sieved solids.

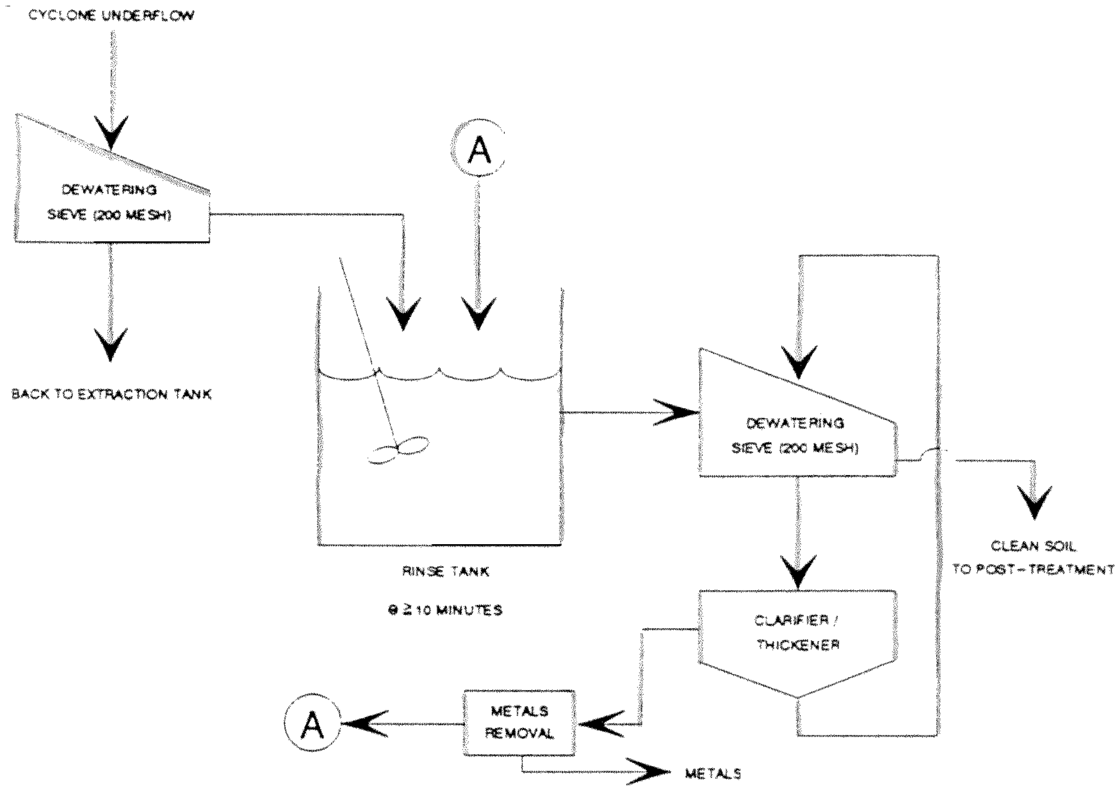


Figure 13 Coarse Solids Dewatering and Rinsing System

The overflow from the dewatering sieve is passed into a rinse tank, where it is rinsed and well-mixed for 10 minutes or more. From there it passes to a second dewatering sieve, also 200 mesh. The underflow from this sieve is flocculated and clarified. The solids from the floc tank are carefully placed atop the dewatering sieve for removal with the clean soil. The clarified rinsate is further processed to remove the metals and then recycled to the rinse tank.

The fines dewatering and rinse system is shown in Figure 14. The fines are first sieved to remove any particles larger than 100 mesh, which are returned to the extraction tank. They are then sent to a clarification unit, and allowed to flocculate. The clarified extractant is regenerated and returned to the extraction system. The thickened clays are further treated (if necessary), then rinsed, and thickened again. The clarified rinsate is treated to remove metals, then returned to the rinse system.

The thickened, rinsed clays are further thickened in a filter press and sent to soil post-treatment.

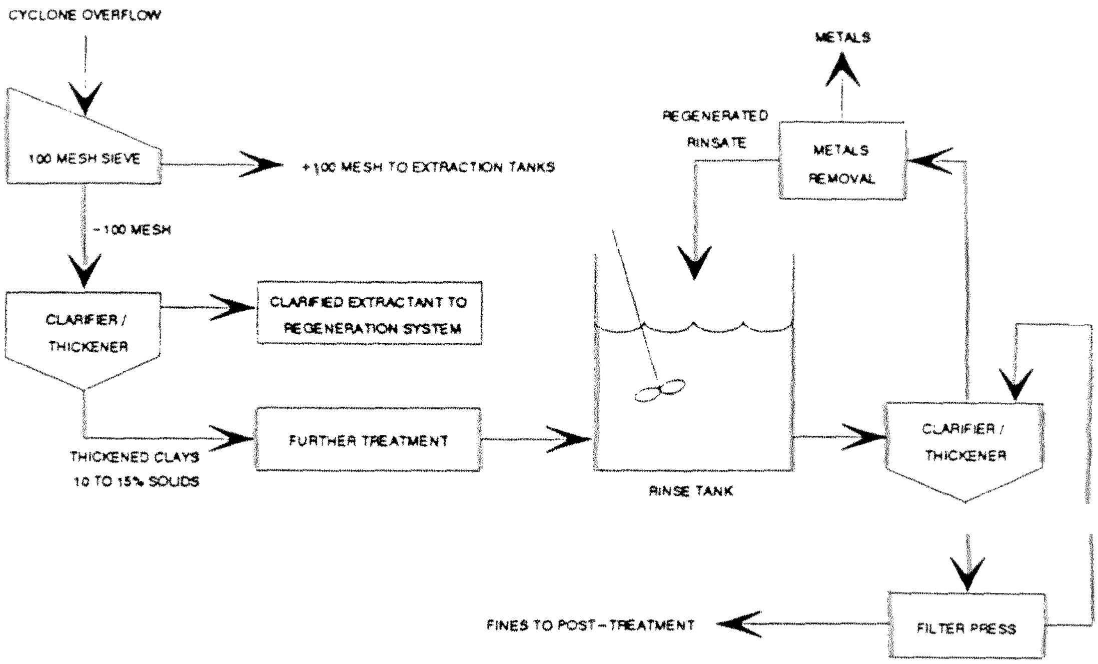


Figure 14 Fines Dewatering and Rinsing

Acid Regeneration System

AETS employs a proprietary acid regeneration system.

Soil Post-Treatment

The purpose of soil post-treatment is two-fold: to remix soil fractions which have become separated during processing and to return the soil to its native condition.

The soils are anticipated to be remixed using front-end loaders or other earth-moving equipment. The soils will be mixed with a small amount of lime to return the soil buffering capacity. In addition, fertilizers and topsoil may be added. Experiments to determine the exact post-treatment requirements are on-going.

It should be emphasized that the TCLP results to date have not included any post-treatment. It is anticipated that the addition of lime, and other neutralizing agents will help stabilize the metals in the soils. In addition, any significant addition of topsoil or fill will dilute both the TCLP and total metals results. Neither lime nor topsoil were added during the experimental program, and their addition is not included in a determination of whether or not the AETS treated soil is hazardous.

5.0 AETS ECONOMICS

To estimate the economics of remediating a site using AETS, capital and operating costs for various sized and configured systems were determined. These are summarized in Table 27.

Table 27 AETS Cost Summaries Under Various Conditions

Process and Site Parameters						Costs		Total Cost per yd^3	
Feed Rate yd^3/hr	Extraction Res. Time (min)	% Fines (<50 μm)	% of Fines Disposed	Metals conc. (mg/kg)	Site size (1000 yd^3)	Capital Costs (million $)	Operating Costs ($/yd^3)	Capital paid off over one site ($/yd3)	Capital paid off over two sites ($/yd^3)
301	24	15	2	5,000	150	4.5	41	83	71
20	24	15	2	5,000	100	3.6	51	104	88
20	36	30	25	15,000	60	4.5	82	178	147
20	24	15	25	15,000	80	4.1	71	141	121
15	24	15	2	5,000	60	3.2	61	133	111
15	36	30	25	15,000	30	3.8	92	243	191
15	36	15	2	5,000	30	3.3	61	189	146
10	36	30	25	15,000	20	3.2	112	301	237

Notes: 1. Plant is anticipated to operate only 1 shift per day.
2 No metal recovery value is assumed; all metal sludges are disposed.

5.1 COST CALCULATIONS

Capital costs were calculated by summing the following:

General Costs	Including site preparation, pilot work, trailers, and permitting. These represent approximately 8 to 11 percent of total Capital Costs.
Pretreatment	Costs associated with coarse and very coarse removal, scrubbing, and coarse rinsing/processing. (11 to 15 percent of total capital).
Extraction Cost	Costs associated with contacting the soils with acid, including hydrocycloning the soil (7 to 9 percent)
Acid Regeneration	Costs associated with metals removal and acid reformation. (31 to 41 percent)
Dewater/Rinsing	Costs associated with dewatering and rinsing coarse solids and thickening and processing fines. (21 to 25 percent)

Soil Post-treat	Costs associated with mixing; post-treatment and fertilization. (3 to 4 percent)
Miscellaneous	Costs associated with other required piping instruments, etc. (7 to 9 percent)

The costs for each element were increased by 10 percent for engineering, 23 percent for transportation and final installation costs, 5 percent for start up and shakedown costs, 2 percent for spare parts, and 10 percent for contingency. The most uncertain costs were those determined for the regeneration system. To the extent possible, these costs were overestimated, so that the final unit costs were conservatively determined.

Operating costs included labor (a total of between 3 and 4 operators, plus a supervisor, 2 to 4 excavators (with excavation equipment), a health and safety officer, maintenance and engineering), maintenance equipment costs, utilities, chemicals, disposal, and reseeding.

The capital and labor costs were combined by assuming a 10 percent cost of capital; depreciation over either 1 or 2 years; operations 1 shifts per day (2000 hours/year) for one year per plant site; moving and reassembly costs of $150,000 plus 15 percent original capital (if the plant is depreciated over two years); and plant downtime of 10 percent of operating hours for unanticipated shutdowns (i.e., equipment failure).

5.2 COST SUMMARY

Table 27 gives a cost summary for AETS at several different process configurations. The table shows the effects of varying six critical parameters (feed rate, extraction time, percent fines, percent fines disposed (rather than treated), metals concentrations, site size and the number of sites treated with each set of equipment).

Note that the table includes costs for mobilization, pilot plants, excavation, replacing soil, and reseeding the ground as well as soil treatment. Thus, the costs represent the *total costs* of treatment using the Acid Extraction Treatment System.

For 15 and 20 cubic yard per hour plants, the table gives the cost under best conditions (first row), cost under worst conditions (second row), and cost under intermediate conditions (third row). The table also gives the cost under best conditions for the largest plant anticipated (30 yd^3/hr), as well as the cost under worst conditions for the smallest plant anticipated (10 yd^3/hr). In this way, the table should bracket the costs. For reasonably sized plants, the anticipated treatment costs range between $100 and 180 per cubic yard.

The costs for the most commonly employed alternative (stabilization and disposal), range between $180 or $450 per cubic yard, depending on the size and circumstances of the site, with typical costs about $250 per cubic yard. Thus, AETS is generally competitive with stabilization and disposal. It is also a more environmentally sound alternative because of the potential for reclaiming the metals found at the site.

APPENDIX A

EQUIPMENT LISTS

This appendix gives a detailed list of the equipment used in the Acid Extraction Treatment System pilot-scale plant operation.

B. 1 MAJOR EQUIPMENT

This section describes all of the larger pieces of equipment that were used in the actual extraction process.

Attrition Scrubber

- Manufactured by Denver Corporation
- Serial number 195-264-001

The scrubber was made custom for CHMR with dual 230 V, three-phase motors and a special rubber lining to prevent corrosion from the acidic solution. The scrubber was modified to be drained out of the cleaning port instead of the 6-inch flanged outlet due to the batch application. Six casters were attached to the base of the scrubber for safety purposes when moving the scrubber for cleaning, etc.

Slurrv Pump

- Manufactured by Galigher Corporation, A Division of BGA International
- Model number 1.5 VRA 1000
- Serial number 0248592

This pump was custom modified for the acid environment with which it was to be used. The pump head was coated with a gum rubber lining with a Buna-N impeller. The pump was driven by a 2 horsepower, 1800 RPM, 230 volt, three-phase motor, The motor was connected to the pump by an adjustable V-belt drive. The pump features a 2 $^{1}/_{2}$-inch inlet and a 2-inch outlet, both flanged. The sheaves, belts, and motor for the pump were supplied by Allegheny Process Equipment.

Rubberized Pump

- Manufactured by GRI
- Model number 08107-002

This pump was centrifugal with a rubber head to handle the acid. The pump malfunctioned due to the abrasion, and was later repaired and used to pump to the 1-inch cyclone.

Two-Inch Cyclone

- Manufactured by Krebs Engineering
- Model number U2-1436
- Serial number 48034

This was the primary cyclone for the AETS. This cyclone separated the coarse sand from the clay fraction. The 2-inch cyclone featured an adjustable apex that was later replaced by a fixed plastic apex. The cyclone had 1$^1/_4$-inch threaded inlets and outlets.

One-Inch Cyclone

- Manufactured by Krebs Engineering
- Model number PC1 -S312
- Serial number 44869

This cyclone was used to dewater the clay from the 2-inch cyclone. It was also used to separate the clay from the extractant or rinsate. The inlet and outlet to the cyclone were $^3/_8$-inch and 1-inch, respectively.

pH Controller

- Cole-Parmer pH/ORP/CD Pump System Series 7142
- Model number 7142-55
- Serial number 22941

This controller featured a diaphragm pump and two-way acid/base operation. Once calibrated, the controller needed no supervision or adjustments.

Extract Filter

- Manufactured by Harmsco Industrial Filter
- Model number H1F7
- Serial number 6390

This was an up-flow type filter with the inlet coming from the extract pump, and the outlet going to the acid regeneration system. The filter contained seven filter cartridges, either 5 or 10 μm in size.

Extract Pump and Controller

- Pump was manufactured by Sherwood
- Model number CMNP-1231-W
- E-TRAC "S" Type AC inverter/controller was manufactured by T. B. Wood's Sons Company
- Model number AFC-2000-7B2S
- Serial number 05200-R-090

The speed of the centrifugal pump was varied by the digital controller, allowing the pressure to the filter to be controlled.

Shaker Sieve and Screens

- Manufactured by Liquatex Separators, Inc.
- Model number L22-1-0
- Serial number LI80883

The 2 by 2 foot shaker was the most diverse piece of equipment used in the acid extraction system, serving three purposes. First, it was used to separate the +8 mesh (>$^1/_8$") particles from the raw soil. Next, it was used to dewater the soil after each extraction. Finally, the shaker was used to dewater the soil after the rinsing stage.

8.2 MINOR EQUIPMENT AND PIPING

This sections describes the minor equipment and plumbing used during the course of the research.

Transfer Pumps

- Manufactured by March Inc.
- Model number 1A-MD-1
- Manufactured by Little Giant Pump Company
- Model number 4E-34NR
- Serial number YY-352-3272

These were submersible pumps used to transfer various liquids, such as extractant, rinsates, etc., while preparing for or cleaning up after extractions.

Rinse Regeneration Pump

- Manufactured by Little Giant Pump Company
- Model number LG-100
- Serial number WW-2029603

This peristaltic pump was used to pump the rinsate to the rinsate regeneration system.

Plumbing

Various piping was used to plumb the system together, including:

- 1 1/2" ID PVC pipe from the extraction tank to the slurry pump
- 1” ID Tygon tubing for the cyclone outlets
- 3/4" ID PVC pipe everywhere else
- PVC fittings including:
    - unions
    - tees
    - 45° elbows
    - 90° elbows
    - caps
    - flanges
    - all thread nipples
    - reducer bushings
    - bulkheads
    - ball valves
    - gate valves
    - gauge guards (with pressure gauges)

APPENDIX B

QUALITY ASSURANCE/QUALITY CONTROL

As specified in the project Quality Assurance Project Plan (QAPP), the Quality Assurance/Quality Control (QA/QC) procedures during the study incorporated two levels:

- Analytical laboratory QA/QC procedures and checks; and,
- Process QA/QC procedures and checks.

The analytical QA/QC program was mainly concerned with the quality of data received from the analytical laboratory. To this end, duplicate samples were used, split samples were sent to two different laboratories, and blank samples were submitted to the laboratory for analysis. In addition, the laboratory periodically performed internal duplicate and spike analyses, as required in the analytical methods and in their QA/QC programs.

Process QA/QC procedures and checks involved methods to check the data received from the process experiments. To this end, duplicate experiments were performed under identical conditions to determine if similar results were obtained.

The results from these QA/QC procedures and checks are summarized in the tables below.

Analytical Laboratorv QA/QC

The results from select duplicate and split samples from several analyses are presented below. These results indicate that, in general, the relative percent differences were within the required 25% for duplicate samples. However, some discrepancies did occur. These were resolved typically by rechecking the data or repeating the analyses. TCLP values in the table are in units of mg/l and total values are given in units of mg/kg.

EXPERIMENT	METAL	ANALYSIS (TOTAL/TCLP)	RESULT #1	RESULT #2	RELATIVE PERCENT DIFFERENCE.
AE-102	Pb	Total	77	98	21%
AE-102	Zn	Total	770	582	24%
AE-1 20	As	Total	620	730	15%
AE-120	Cd	Total	970	1,300	25%

AE-120	Cr	Total	1,300	1,320	1 %
AE- 120	Pb	Total	10,040	12,300	18%
AE-120	Ni	Total	980	1,410	30%
AE-120	Cu	Total	10,900	10,600	3%
AE-107	Pb	TCLP	520	503	3%
AE-105	Cd	TCLP	8.29	8.36	1 %
AE-105	Ni	TCLP	11.6	11.8	2%

The analytical laboratory use of spikes and duplicates was reviewed, and found to consistent with the prescribed QC checks.

Process QA/QC

In order to determine how consistently the overall process was performing, and also to serve as a QC check on the overall combined process, laboratory analytical, and sampling procedures, CHMR duplicated several entire experiments. These experiments included runs AE-102 and 104; AE-105 and 106; and AE-115 and 116. Typical results from these duplications are given in the table below, which shows the results from the AE-115 and 116 experiments.

	INITIAL SOIL TOTAL METALS (mg/kg)			FINAL SOILS TOTAL METALS (mg/kg)		
Metal	**AE-115**	**AE-116**	**RPD**	**AE-115**	**AE-116**	**RPD**
Cr	1020	1240	22%	37	89	58%
Cu	1240	1660	25%	17	18	6%
Ni	335	518	35%	4	6	33%

The results from these analyses indicate a reasonable degree of consistency between runs, with average relative percent differences of less than 25 percent.