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Project Summary

Onsite Engineering Report for Solidification/Stabilization Treatment Testing of Contaminated Soils

Judy Hessling, Michael L. Smith, Steve Giti-Pour, John Miller, and Jerry Isenburg

The mechanism of lead fixation by portland cement, quicklime/fly ash, and cement kiln dust/fly ash on a Superfund soil was evaluated. Elevated levels of lead (~25,800 ppm) at the site indicated lead was the primary contaminant of concern and solidification/stabilization (S/S) was chosen as the best demonstrated available technology (BDAT) for treating the soil.

The study was performed in two phases on all samples: analyzing for toxicity characteristic leaching procedure (TCLP) extractable lead and evaluating the effectiveness of the treatment technology with various physical and chemical tests. Each binder was evaluated at three different binder-to-soil (B/S) ratios. In addition, one aliquot of soil was pretreated by heating to remove organic carbon from the soil and then treated with portland cement. The binder-to-soil ratios were determined by the generalized acid neutralization capacity (GANC) test, developed at the U.S. Environmental Protection Agency's (EPA) Center Hill Facility (CHF), to standardize data collection and interpretation in S/S testing.

Concentrations of lead in the TCLP extracts from Phase I exceeded lead's 5 mg/L TCLP regulatory limit established to classify wastes as characteristically toxic. These results indicate the original binders failed to stabilize lead present in the soil. Results from Phase II indicate that higher B/S ratios were able to stabilize lead and reduce the concentration of leachable lead to below the TCLP regulatory limit of 5 mg/L. The test wherein soil was pretreated by heating to remove organic carbon indicated the organic carbon content of the soil may have affected the ability of the binders to stabilize lead. A lower B/S ratio was needed to stabilize lead in the heated soil than in the unheated soil.

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

Introduction

This study was done for the EPA to supply information to the BDAT data base for soil remediation. The data base will be used to develop soil standards for Land Disposal Restrictions.

S/S refers to treatment processes that are designed to accomplish one or more of the following objectives:

- to improve handling and physical characteristics of the waste by producing a solid from liquid or semi-liquid wastes,
- to reduce contaminant solubility in the treated waste, and/or
- to decrease the exposed surface area across which transfer or loss of contaminants may occur.

The objective of this S/S study was to obtain (1) six sets of pre- and posttreatment sample data on the leachability of lead and (2) experimental design and operating data that could be used to evaluate the performance of the S/S treatment system. Three binders, at two B/S ratios each, were evaluated in this study: portland cement, quicklime/fly ash, and cement kiln dust/fly ash (Phase I). Additional studies (Phase II) were done because of the failure of the six original binder mixes to effectively stabilize lead. Phase II studies used three new binder mixtures, and in addition, one portion of soil was first heated to reduce the organic carbon content of the soil and then treated with a binder to stabilize lead. This was done to determine if the soil's high organic carbon content (17%) adversely affected the original binder mixtures' ability to stabilize the lead present in the soil.

Procedure

During the remedial investigation of the site, samples of soil, groundwater, surface water, and sediments were collected and analyzed, primarily for total lead. Low concentrations of other metals and target compound list (TCL) organic contaminants were also detected, but they were of minor significance and did not pose significant environmental hazards. Low concentrations of polychlorinated biphenyls (PCBs) were detected in two samples in the parts-per-billion range.

The soil tested consisted of a dark brown, sandy, silty clay with a high organic content (17% total organic carbon [TOC]) and an average permeability of 1.57 x 10^{-6} cm/s. Four buckets of raw soil were collected for the treatability tests. The soil was homogenized by blending the four buckets of soil in a 55-gal steel drum then quartering the soil according to ASTM Method C702-87 (Method B). The study was conducted in two phases. The three binder systems used during the pilot scale S/S testing consisted of (1) 100% Type I portland cement, (2) 40% quicklime and 60% fly ash, and (3) 67% cement kiln dust and 33% fly ash. The GANC test, used to determine the optimum B/S ratios, generated graphs that indicate pH versus equivalents of acid/alkali. These graphs were then used to predict the acid and alkaline response that would occur with various B/S ratios. These data were then used to select the ratios that fall in the pH range that has been shown to immobilize lead (pH 8.0 to 11.0 for portland cement, pH 8.5 to 10 for quicklime/fly ash, and pH 8.5 to 10 for the cement kiln dust/fly ash) at the number of acid equivalents (i.e., 2 eq/kg) used in the TCLP leach tests. The soil/binder mixes were prepared in a planetary rotary mixer in accordance with the protocols in ASTM Method C305. The order of soil, binder, and water addition for preparation of the solidified samples was as follows:

1. Raw soil was sieved to less than 3/8 in. mesh size to crush the 2- to 3-cm spheres formed by the soil mixing/homogenization step and to make the soil more amenable to the treatment process.
2. Soil and binder were dry blended.
3. Water was added until the mixture passed the flow table test (ASTM Methods C230 and C109 - Section 103).

For each B/S mix in Phase I, six 2-in. diameter by 4-in. long cylinders and one 4-in. diameter by 1-in. long cylinder (used to determine set time) were prepared. All molded samples were covered with a thin plastic sheet and placed in a concrete test cure box for a 28-day curing period. The cure box was maintained at 75°F, and water was kept standing in the bottom of the box to maintain moist storage.

Because of the failure of the six original binder mixtures in Phase I to meet the TCLP regulatory limit of 5 mg/L established for lead in treated soils and because the results of further GANC tests indicated that higher B/S ratios would improve the stabilization capacity of the treated samples by decreasing lead leachate levels, additional S/S studies (Phase II) were done to determine the optimum binder mixes for the soils. The same binders were used in this phase. The soil, however, was solidified with three new B/S ratios: (1) 45% portland cement; (2) 31% quicklime with 46.5% fly ash; and (3) 93% cement kiln dust with 46.5% fly ash.

In addition, to determine if the speculation that the heavy organic content of the soil (17%) may have been the reason the six original mixtures failed to stabilize the lead in the soil, the soil was heated for 24 hr at 310°C to remove the organic carbon from the soil. The sample was then treated with portland cement at a B/S ratio of 20% based on the soil dry weight before ignition. Molded samples from Phase II of the treatability study were prepared in a manner similar to those prepared in Phase I. Six replicate molds were solidified for each of the B/S mixes except for the heated soil mix. Because of the small volume of soil available, only three molds were solidified for the heated soil.

Results

Table 1 shows the physical characteristics for the binder mixtures that solidified during Phase I and Phase II of the study. Tables 2 and 3 summarize the results of the lead analysis performed on TCLP leachate of the pretreatment and posttreatment samples collected in Phase I.

A comparison of the results in Tables 2 and 3 indicates the inability of the binders to stabilize lead. It was theorized that the high organic content of the soil may have inhibited the ability of binders to stabilize lead. Based on personal observation, as well as analytical data, the organic content was believed to be mainly humus material containing cellulose molecules. Alkali present in the binder mixes may have acted as catalysts for oxidative reactions between atmospheric oxygen and cellulose molecules. The products of these reactions are acid groups. Alkali present in the mixes would neutralize the acid groups in the humus material rather than stabilize the lead present in the soil.

Because of the failure of the original binders, Phase II was done to determine if the soil could be effectively treated by the stabilization process and to determine the effect of the soil's organic content on the stabilization process. Tables 4 and 5 summarize the results of the lead analysis performed on the TCLP extracts of the pretreatment and posttreatment samples collected in Phase II.

A comparison of results in Tables 4 and 5 indicates the increased B/S ratios employed in Phase II were able to reduce the amount of leachable lead to below the regulatory limit of 5 mg/L. Phase II results also indicate the removal of organic carbon from the soil improves the stabilization capacity of the binder mixes. This is shown with the 20% portland cement binder mixture; the amount of leachable lead was reduced from 14 mg/L (Table 3) in soil containing organic carbon to <0.2 mg/L (Table 5) in soil that had been heated to remove the organic carbon.

The binders that set during the 28-day curing period also exceeded the unconfined compressive strength criteria of 50 psi. Portland cement mixtures showed the greatest strength. In addition, the removal of organic carbon from the soil improved the compressive strength of the 20% portland cement binder mixture which can be seen by comparing Mix Nos. 2 and 10 (Table 1).

Conclusions

Results from the study indicate the soil can be treated to reduce the amount of leachable lead to below the regulatory limit of 5 mg/L with the binder mixtures established in Phase II. Portland cement mixtures appear to provide the best results for stabilizing lead in the contaminated soil used in these tests. Furthermore, all the solidified samples, regardless of their

Table 1. *Physical Characteristics of Cast Samples*

Mix No.	Binder Recipe*	Unconfined Compressive Strength, kPa	Moisture Content, %	Wet Density, kg/m³	Dry Density, kg/m³
1	16% pc	462	60	1480	590
2	20% pc	503	55	1510	675
3	8.5% ql/12.75% fa	241	58	1460	609
4	10.5% ql/15.75% fa	207	55	1490	665
7	45% pc	2612	†—	—	—
8	31% ql/46.5% fa	197	—	—	—
9	93% ckd/46.5% fa	178	—	—	—
10‡	20% pc	1618	—	—	—

*pc = Portland cement.
ql/fa = Quicklime/fly ash.
ckd/fa = Cement kiln dust/fly ash.
†Data not available for these tests.
‡Heated soil.

Table 2. *TCLP Lead Concentrations in Pretreatment Soil Samples from Phase I (mg/L)*

Sample ID	Portland Cement (100%) Binder/soil* 16%	Portland Cement (100%) Binder/soil 20%	Kiln Dust and Fly Ash (2:1) Binder/soil 36%	Kiln Dust and Fly Ash (2:1) Binder/soil 42%	Fly Ash and Quicklime (3:2) Binder/soil 21.25%	Fly Ash and Quicklime (3:2) Binder/soil 26.25%
A	86	84	90	95	84	87
B	90	96	88	96	88	87
C	85	112	88	84	86	88
D	73	87	89	82	88	88
E	82	89	95	82	87	89
F	84	89	91	81	86	91
Average	83	93	90	87	86	88
Standard deviation	5.7	10.2	2.6	6.9	1.6	1.5

* Binder-to-soil ratio calculated on a dry weight basis.

Table 3. *TCLP Lead Concentrations in Posttreatment Soil Samples from Phase I (mg/L)*

Sample ID	Portland Cement (100%) Binder/soil * 16%	Portland Cement (100%) Binder/soil 20%	Kiln Dust and Fly Ash (2:1) Binder/soil 36%	Kiln Dust and Fly Ash (2:1) Binder/soil 42%	Fly Ash and Quicklime (3:2) Binder/soil 21.25%	Fly Ash and Quicklime (3:2) Binder/soil 26.25%
A	91	16	68	56	120	49
B	83	13	62	56	110	46
C	83	16	67	53	140	49
D	85	12	61	52	110	32
E	82	16	61	54	120	36
F	86	11	64	55	120	63
Average	85	14	64	54	120	46
Standard deviation	3.3	2.3	3.1	1.7	11	11

* Binder-to-soil ratio calculated on a dry weight basis.

Table 4. *TCLP Lead Concentrations in Pretreatment Soil Samples from Phase II (mg/L)*

Sample No.	Portland Cement (100%) Binder/soil,* 45%	Kiln Dust and Fly Ash (2:1) Binder/soil, 139.5%	Fly Ash and Quicklime (3:2) Binder/soil, 77.5%	Portland Cement (100%)† Binder/soil, 20%
A	81	85	81	110
B	83	84	85	120
C	85	84	91	120
D	87	83	88	NA‡
E	84	84	88	NA
F	85	83	88	NA
Average	84	84	87	117
Standard deviation	2.0	0.8	3.4	5.8

*Binder-to-soil ratio calculated on a dry weight basis.
†Soil heated before treatment to remove organic carbon.
‡NA = Not applicable; only three samples collected because of the sample volume available.

binder type, exhibited lower leaching potential for lead at the higher B/S ratios.

The results from the study also indicate the organic content of the soil may affect the ability of binders to stabilize lead in the soil. The soil that was heated to remove organic carbon showed better stabilization properties than did the soil where the organic carbon was not removed.

Full characterization of the soil being treated should be performed to determine what soil characteristics may be present that may inhibit the stabilization process and to determine what pretreatment procedures should be performed on the soil to improve the stabilization process.

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Table 5. *TCLP Lead Concentrations in Posttreatment Soil Samples from Phase II (mg/L)*

Sample No.	Portland Cement (100%) Binder/soil,* 45%	Kiln Dust and Fly Ash (2:1) Binder/soil, 139.5%	Fly Ash and Quicklime (3:2) Binder/soil, 77.5%	Portland Cement (100%)† Binder/soil, 20%
A	<0.2	1.3	0.45	<0.2
B	<0.2	1.5	0.58	<0.2
C	<0.2	1.3	0.44	<0.2
D	<0.2	1.6	0.46	NA‡
E	<0.2	1.6	0.53	NA
F	<0.2	1.5	0.62	NA
Average	<0.2	1.5	0.51	<0.2
Standard deviation	0.0	0.1	0.08	0.0

*Binder-to-soil ratio calculated on a dry weight basis.
†Soil heated prior to treatment to remove organic carbon.
‡NA = Not applicable; only three samples collected due to small sample volume available.

Judy Hessling, Michael L. Smith, Steve Giti-Pour, and John Miller are with IT Environmental Programs, Inc., Cincinnati, OH, 45246, and Jerry Isenburg is with University of Cincinnati, Center Hill Facility, Cincinnati, OH 45224.
***Richard P. Lauch** is the EPA Project Officer (see below).*
The complete report, entitled "Onsite Engineering Report for Solidification/ Stabilization Treatment Testing of Contaminated Soils." (Order No. PB93-166 965/AS; Cost: $27.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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