IN SITU STABILIZATION/SOLIDIFICATION OF PCB-CONTAMINATED SOIL

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ABSTRACT

Under the SITE program, a demonstration has been performed on the International Waste Technologies' (IWT) in situ stabilization/solidification process utilizing the Geo-Con deep-soil-mixing equipment. This was the first field demonstration of an in situ stabilization/solidification process. The demonstration occurred in April 1988 at the site of a General Electric Co. electric service shop in Hialeah, Fla., where the soil contained polychlorinated biphenyls (PCBs) and localized concentrations of volatile organics and heavy metal contaminants. The demonstrated process mixed the contaminated soil in situ with a cementitious proprietary additive, called HWT-20, and water.

The technical criteria used to evaluate the effectiveness of the IWT process were contaminant mobility measured by leaching and permeability tests and the potential integrity of solidified soils indicated by measurements of physical and microstructural properties. Performance of the Geo-Con deep-soil-mixing equipment was also evaluated.

The process appeared to immobilize PCBs. However, due to the very low PCB concentrations in the leachates, caused in part by the low concentrations of PCBs in the soils, confirmation of PCB immobilization was not possible. Physical properties were satisfactory except for the freeze/thaw weathering tests, where considerable degradation of the test specimens occurred. The microstructural analyses showed the process produced a dense, homogeneous mass with low porosity, which shows a potential for long-term durability.

The Geo-Con deep-soil-mixing equipment performed well, with only minor difficulties encountered, which can be easily corrected. The HWT-20 additive was well dispersed into the soil, as evidenced by the relatively uniform change in chemical and physical characteristics of treated versus untreated soils.

The estimated remediation cost with operation of the 1-auger machine, used for the demonstration, is \$194/ton (\$150/yd^3). For larger applications, using Geo-Con's 4-auger machine, costs would be lower.

INTRODUCTION

Concern by the public and many government groups exist over using landfills for the containment of hazardous wastes. In response to the Superfund Amendments and Reauthorization Act of 1986 (SARA), the Office of Research and Development (ORD) and the Office of Solid Waste and Emergency Response (OSWER) of the Environmental Protection Agency (EPA) have established a formal program to accelerate the development, demonstration, and use of new or innovative technologies. This program is called Superfund Innovative Technology Evaluation or SITE (1). The major objective of the SITE Program is to develop reliable cost and performance information on innovative alternative technologies, so that they can be adequately considered in Superfund decision making.

The International Waste Technology (IWT) in situ stabilization/solidification process, utilizing their proprietary additive HWT-20, and the injection and deep-soil-mixing technology of Geo-Con, Inc. were evaluated (2). IWT claims that their additive chemically bonds to the contaminants and creates a hardened, leach resistant, concrete-like solidified mass when treating soils containing organics. The demonstration to evaluate the technology was performed at a closed electric service shop in Hialeah, Fla., contaminated with polychlorinated biphenyls (PCBs). In addition, one small area contained volatile organics (VOCs) and low levels of priority pollutant metals. The owner is required by the local regulatory authorities to remediate the site for PCBs. The SITE program demonstration was carried out on two 10x20-ft test sectors selected by the owner and known, from prior soil sampling, to be high in PCBs. The remediation test was performed in April 1988 and lasted six days. Pretreatment soil sampling occurred in March and posttreatment sampling in May 1988. The SITE Program evaluation analyses were performed independently of those required by the local authorities.

PROGRAM OBJECTIVES

The objectives of this SITE Project were to evaluate the IWT/Geo-Con, Inc. in situ stabilization/solidification technology in the following areas:

1. Immobilization of the PCBs in the soil.
2. Effectiveness, performance, and reliability of the Geo-Con deep-soil-mixing equipment used for the in situ solidification.
3. Potential long-term integrity of the solidified soils.
4. Degree of soil consolidation (solidification) produced by the HWT-20 additive.
5. Costs for applying this technology on a commercial scale.

APPROACH

The following technical criteria were used to evaluate the effectiveness of the process:

- o Mobility of the contaminants -- Sampling was conducted in areas of high PCBs, the primary contaminant targeted for immobilization, as well as volatile organics and heavy metals, with the analytical emphasis on leaching characteristics. Three leachability tests were performed: the Toxicity Characteristics Leaching Procedure (TCLP) and two leach tests that evaluate performance of the solidified mass, MCC-1P and ANS 16.1, both originally developed for the nuclear industry. Permeabilities were also measured before and after soil treatment. The permeabilities indicate the degree to which the solidified material permits the passage of water through the soil mass, and thus, the degree of water contact with the contaminants.

o Durability of the solidified mass -- Core samples of treated soils were analyzed to determine uniformity and long-term endurance potential. The analyses obtained the following:

  -Integrity of the treated soil.
  -Unconfined compressive strength (UCS), which is an indication of long-term durability.
  -Microstructural characteristics as a source of information on treated soil porosity, crystalline structure, and degree of mixing.
  -Freeze/thaw and wet/dry weathering test data on weight loss; permeability and UCS tests of the weathered samples provided indications of short-term durability.

The stabilization/solidification process utilized the deep soil injection and mechanical mixing equipment of Geo-Con, Inc. A batch mixing system prepared a feed slurry of approximately 57 wt% solids of HWT-20 additive. The slurry was pumped to the injection and mixing auger. Supplemental water was also fed to the auger; the quantity of water was dependent on the moisture content of the soil, i.e., whether the sample was from above or below the water table.

The mixing auger consisted of one set of cutting blades and two sets of mixing blades attached to a vertical shaft rotating at 15 rpm. Two conduits in the hollow auger shaft allowed for the injection of the additive slurry and supplemental water from the base of the auger. HWT-20 was injected on the downstroke, with further mixing occurring upon auger withdrawal.

The soil columns, drilled to a diameter of 36 in., were positioned to provide an overlapping pattern to insure treatment of the entire area. About 25% of each soil column overlapped the other columns.

Two 10x20-ft sectors were treated, each containing 36 soil columns. One sector was treated to a depth of 18 ft and the other to a depth of 14 ft. The depth of injection was determined by the need to treat all soils containing PCBs above 1 mg/kg. The nominal HWT-20 additive rate used was 15 lb of dry additive per 100 lb of dry soil. For the actual demonstration, the additive rates were 0.17 and 0.19 lb/lb dry soil for sectors B and C, respectively.

PROBLEMS ENCOUNTERED

The low quantity of contaminants along with dilution resulting from the soil blending operation caused some difficulties in evaluating the technology. The PCB concentrations in the untreated soil, with the exception of a few points, were below 300 mg/kg, with the largest value measured being 950mg/kg. After soil treatment, due to the mixing of the more highly contaminated soils with soils of lower PCB concentration plus some dilution from the addition of HWT-20 and water, the maximum treated soil concentration was

170 mg/kg, with the remaining samples 110 mg/kg and below. Therefore, due to the low mobility of PCBs, the leachate values were very near the detection limit of PCBs in water of 1.0 ug/L. For a few samples at the end of the analytical program, the PCB analysis procedure was modified to allow measuring to a detection limit of 0.1 ug/L. Even with the increased sensitivity of the analytical method, the ability of the stabilization/solidification process to immobilize PCBs cannot be confirmed by this project.

Only 3 out of 34 sample point locations were found to contain volatile organics (VOCs) and heavy metals. This did not provide a sufficient number of points to evaluate immobilization of these contaminants. In addition, the soil mixing, upon injection of the HWT-20, severely reduced the concentration of the VOCs and metals in the treated soil, further complicating the evaluation.

RESULTS

The results are presented in three parts: immobilization of the contaminants, durability of the solidified mass plus supporting physical tests, and operations of the deep-soil-mixing equipment of Geo-Con.

Mobility of Contaminants

Solidification and stabilization are treatment processes that are designed to accomplish one or more of the following (3):

- o Improve the handling and physical characteristics of the waste.
- o Decrease the surface area of the waste across which the transfer of contaminants can occur.
- o Limit the solubility of hazardous constituents, such as by pH adjustment.
- o Change the chemical form of the hazardous constituents, such as by chemical bonding.

Solidification obtains these results primarily by producing a monolithic block of treated waste with high structural integrity. Stabilization techniques limit the mobility of waste contaminants or detoxify them, whether or not the physical characteristics of the waste are changed or improved (4). This is accomplished usually through the addition of materials, such as treated organophilic clays (5) which may provide for chemical bonding, to ensure that the hazardous constituents are maintained in their least mobile form.

For each test sector, pretreatment and posttreatment samples were collected at the same locations. Seventeen samples were collected in each sector. The soil was analyzed for PCBs, and a corresponding TCLP leach test was performed. Therefore, for each leachate concentration measured, the soil concentration was known. Results of treated soils could be compared to those of untreated soils by comparing the quantity of PCBs in the extract to that in the solid specimen being leached--regardless of the fact that localized soil concentrations changed significantly as a result of the soil blending operation.

The maximum PCB concentration measured was 950 mg/kg of untreated soil,with most of the samples under 300 mg/kg. The untreated soil TCLP leachates showed PCB concentrations up to 13 ug/L. Soil samples with PCB concentrations below 63 mg/kg had leachate concentrations below the detection limit of 1.0 ug/L.

All soil samples with more than 300 mg/kg PCBs had measurable leachate concentration. For the untreated soil samples with PCB concentration between 63 mg/kg and 300 mg/kg, only some leachate samples had detectable quantities.

After additive injection and mixing,the maximum treated soil concentration was 170 mg/kg, with all the other samples below 110 mg/kg. All leachates of treated soil samples were below 1.0 ug/L. In addition, seven treated soil leachates from the higher concentration soils were analyzed a second time with detection limits reduced to 0.1 ug/L. Four of the samples were below the revised detection limit. Thus, it appears that the IWT process may immobilize PCBs,but due to the very low values measured, absolute confirmation was not possible. The results from the highest PCB concentration soil samples are provided in Table 1.

Volatile organics, specifically xylenes,chlorobenzenes,and ethylbenzenes,were found in three untreated soil samples with a total concentration up to 1,485 mg/kg. Once the soil was disturbed by the injection and mixing operation, the maximum treated soil total VOCs was reduced to 41 mg/kg. The total VOCs for the untreated soil TCLP leachates was 2.5 to 7.9 mg/L and for the treated soil, 0.32 to 0.61 mg/L. This reduction in VOC concentrations in the leachates is equivalent in order of magnitude to the reduction in VOC concentrations in the soil. Since the VOC concentrations were over a wide range and only three samples were collected, immobilization of the VOCs could not be determined. In addition, IWT claims to have tailored their additive specifically for PCB immobilization.

Heavy metals, primarily lead, copper, chromium, and zinc, were found in only three untreated soil samples,with a maximum total metals concentration of 5,000 mg/kg. After the remediation operation,the heavy metals concentrations in the soil samples were reduced to between 80 and 279 mg/kg. The total metals in the untreated soil TCLP leachate ranged from 0.32mg/L to 12.65 mg/L, and in the treated soil leachate from 0.12 mg/L to 0.21 mg/L. These total metal concentrations are quite low compared to their detection limits and any likely applicable regulatory levels. Due to the limited quantity of data and the low soil concentrations, immobilization of heavy metals could not be determined, although it would be anticipated to occur, since most cementitious processes immobilize heavy metals.

The leachate analyses from leach tests MCC-1P and ANS 16.1 showed all analyte concentrations, PCBs and VOCs, below detection limits. Thus, these tests provided only limited information and did not help in confirming immobilization of PCBs or VOCs.

The permeabilities of the treated soils ranged from 10^{-6} to 10^{-7} cm/s. There was a substantial permeability reduction compared to the untreated soils, which averaged about 1.8×10^{-2} cm/s. Even though the treated soil permeabilities were greater than the EPA guideline value of 1×10^{-7} cm/s, which is targeted for hazardous landfill liners, the four to five order-of-magnitude permeability reduction in treated soil will cause groundwater to flow around, not through, the solidified monolith.

In summary, it appears from the

Table 1. PCBs in soils and leachates.

Sample Designation*	Untreated Soil mg/kg	Untreated Soil TCLP Leachate ug/L	Treated Soil mg/kg	Treated Soil TCLP Leachate ug/L
	PCB Concentrations			
B-6	650	12.0 (15.0)**	49	<1.0 (0.15)**
B-7	460	400.0 (250)**	82	<1.0 (0.12)**
B-8	220	<1.0	9.6	<1.0
B-11	950	7.2 (0.33)**	170	<1.0 (<0.10)**
B-12	140	1.1	16	<1.0
B-13	250	<1.0	---	---
B-16	300	3.7 (0.50)**	100	<1.0 (<0.1)**
B-17	495	3.0 (1.0)**	100	<1.0 (0.2)**
B-21	---	---	60	<1.0
B-22	---	---	114	<1.0
C-1	98	<1.0	20	<1.0
C-3	94	<1.0	57	<1.0
C-7	150	<1.0	22	<1.0
C-10	86	<1.0	80	<1.0 (<0.10)**

* Selected locations of highest PCB concentrations.

** Repeat leachate analysis of existing TCLP leachate analyzed to a detection limit of 0.1 ug/L.

leach tests that PCBs were probably immobilized. In addition, the low permeability of the solidified mass, minimizing water contact with the PCBs, reduced PCB mobility. Nevertheless, PCB immobilization as a result of the IWT/Geo-Con process was not confirmed by the SITE demonstration.

Durability of the Solidified Mass

The ability of the solidified mass to maintain its integrity over a long period of time cannot be determined quantitatively. However, tests were performed that indicated the potential for long-term durability. Unconfined compressive strength provides an indirect measure of structural integrity. The results obtained from the demonstration test ranged from 75 psi to 866 psi and averaged about 410 psi. These values easily exceed the EPA guideline minimum of 50 psi (6). Most other stabilization/solidification processes typically give UCS values in the range of 15 psi to 150 psi (7). Therefore, these results were quite satisfactory.

The effects of weathering can break down the internal structure of the solidified soil potentially producing paths for water flow, which would increase permeability and the potential for contaminant leaching. Wet/dry and freeze/thaw weathering tests were performed. These tests, which involved conditions more severe than exposed solidified material would see in the field, provided an indication of short-term treated soil integrity under natural weathering conditions.

The results for the wet/dry tests showed very small cumulative relative weight losses, averaging approximately 0.1% difference between test specimens and controls. However, the results for the freeze/thaw tests were unsatisfactory, with the cumulative relative weight losses ranging from 0.5% to 30%, and averaging about 6.3%. On a few of the weathered samples, UCS tests were performed. For the wet/dry test specimens, the values obtained were equivalent to the unweathered samples. However, for the freeze/thaw tests, samples with cumulative relative weight losses greater than 3.0% showed reduced UCS values, approaching zero at 10% weight loss. Permeability tests were performed on a few freeze/thaw specimens with weight losses up to 6.0%, with results the same as for the unweathered samples.

Microstructural studies were performed on untreated and treated soil samples. Each sample was studied by scanning electron microscopy, optical microscopy, and x-ray diffraction. Treatment of the contaminated soil produced a dense, homogeneous mass with low porosity. There were no variations in quartz and calcite quantity in the vertical and horizontal directions, even though the original soil was a layered structure. These two sets of observations indicated that the Geo-Con auger provided good mixing for the injection of HWT-20 additive into the soil. These results indicated that the solidified mass has a potential to be highly durable.

Other physical properties of the untreated and treated soils were measured, such as bulk density, moisture content, total organic carbon, and particle size distribution. The bulk density of the soil upon treatment increased 21% as a result of addition of additive plus water of 32 wt%. This resulted in a volume increase of 8.5%. While the volume increase was modest, for a remediation to a depth of 18 ft the ground rise was about 18 in., which could provide land contouring difficulties in many locations. The organics content of the soil was quite low, usually below 0.1 wt%, and would not provide any interferences in the cement hydration reactions. The average of the results for untreated and treated soils are provided in Table 2.

Operations

Equipment performance during the six-day demonstration was smooth, and there were a minimum of operational problems. Each soil column treatment took 30 min. A few operating difficulties were encountered and can be eliminated with some simple engineering design changes. The difficulties were:

- Control of the various flow streams could not be maintained automatically, and manual flow control was needed. This resulted in some uneven additive additions, which with sufficient mixing by the injection auger, did not lead to discernible physical property variations.
- The auger positioning deviated from the targeted point in some locations. This produced areas of poor column overlap, which resulted in areas low in additive.
- Supplemental water addition was lost late in the program as a result of a major leak in the auger header. To save time, operations continued without the supplemental water.

Costs

The IWT/Geo-Con in situ stabilization/solidification system is economical. Remediation costs using the 1-auger machine, used for the demonstration, are \$194/ton (\$150/yd^3). For larger applications, Geo-Con would use its 4-auger machine and costs would be lower.

CONCLUSIONS

The following conclusions can be drawn from the results of the SITE project demonstration:

- PCB do appear to be immobilized by the process. However, due to the very low PCB concentrations in the soil and leachates, it could not be confirmed.
- The physical properties of the treated soil were satisfactory, which would indicate a potential for long-term durability. For each of the test samples, high unconfined compressive strength, low permeability, low porosity, and poor freeze/thaw weathering test results were obtained.
- Operations were well organized and ran smoothly; the difficulties experienced should be readily correctable.

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Table 2. Average soil properties.

	Sector B		Sector C	
	Untreated	Treated	Untreated	Treated
Moisture Content, wt%	11.8	19.0	13.2	17.3
Bulk Density, g/mL	1.51	1.85	1.56	1.94
Permeability, cm/s	1.46×10^{-2}	5.5×10^{-7}	3.5×10^{-2}	2.7×10^{-7}
Unconfined Compressive Strength, psi	--	290	--	536
Weathering Tests				
Wet/Dry, wt% lost	--	0.39*	--	0.34*
Freeze/Thaw, wt% lost	--	7.2*	--	6.0*
pH	8.1	--	8.5	--
Oil and Grease, wt%	0.3	--	0.1	--
TOC, mg/kg	4,380	--	2,300	--

* These values represent the weight loss of the test specimens. The wet/dry weight losses of the controls were approximately 0.1% less. For the freeze/thaw controls, the absolute weight losses were in the range of 0.3% to 0.4%.

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