Principles and Use of Solidification/Stabilization Treatment for Organic Hazardous Constituents in Soil, Sediment, and Waste

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ABSTRACT

Solidification/stabilization (S/S) treatment involves mixing a binding reagent into contaminated media or waste. S/S treatment protects human health and the environment by immobilizing hazardous constituents within the treated material. S/S has been effective in treating a large variety of hazardous constituents in many different forms of waste and contaminated media. The U.S. Environmental Protection Agency (EPA) has identified S/S as Best Demonstrated Available Treatment Technology (BDAT) for at least 50 commonly produced industrial hazardous wastes. EPA has selected S/S treatment for over 20% of its Superfund site source control remediation projects.

Much of the published literature and actual treatment project experience has to do with treatment of inorganic hazardous constituents including radioactive materials. Radioactive wastes and environmental contaminants are often mixtures of inorganic and organic hazardous constituents. In recent years S/S is increasingly being used to address soil and sediment contaminated with organic hazardous constituents. Many of these remediation projects include polycyclic aromatic hydrocarbons (PAH) or polychlorinated biphenyls (PCB).

The paper and presentation will discuss the chemical and physical mechanisms that can immobilize inorganic and organic hazardous constituents within S/S-treated material. The paper will also discuss examples of recent full-scale projects where S/S has been used to successfully treat organic hazardous constituent contaminated soil and sediment both in-situ and on excavated material.

INTRODUCTION

Solidification/Stabilization (S/S) is a widely applied treatment for the management/disposal of a broad range of wastes; particularly those classified as hazardous. S/S treatment has been used to treat wastes since the 1950’s. Among the earliest uses of S/S treatment in the U.S. was the solidification of radioactive waste.(1) S/S continues as a cornerstone treatment technology for the management of hazardous waste radioactive waste, and contaminated media from environmental remediation. The U.S. Environmental Protection Agency (EPA) considers S/S an established treatment technology. S/S is a key treatment technology for the management RCRA wastes. EPA has identified S/S as Best Demonstrated Available Technology (BDAT) for over 50 Resource Conservation and Recovery Act- (RCRA-) listed hazardous wastes.(2) For RCRA characteristic waste, S/S can be used to eliminate the hazardous characteristic allowing less expensive disposal of the treated waste. S/S is the most frequently selected treatment technology for controlling the sources of environmental contamination at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or “Superfund” program remediation sites. Over 20 percent of selected source control remedies for these sites include the use of S/S. (3)

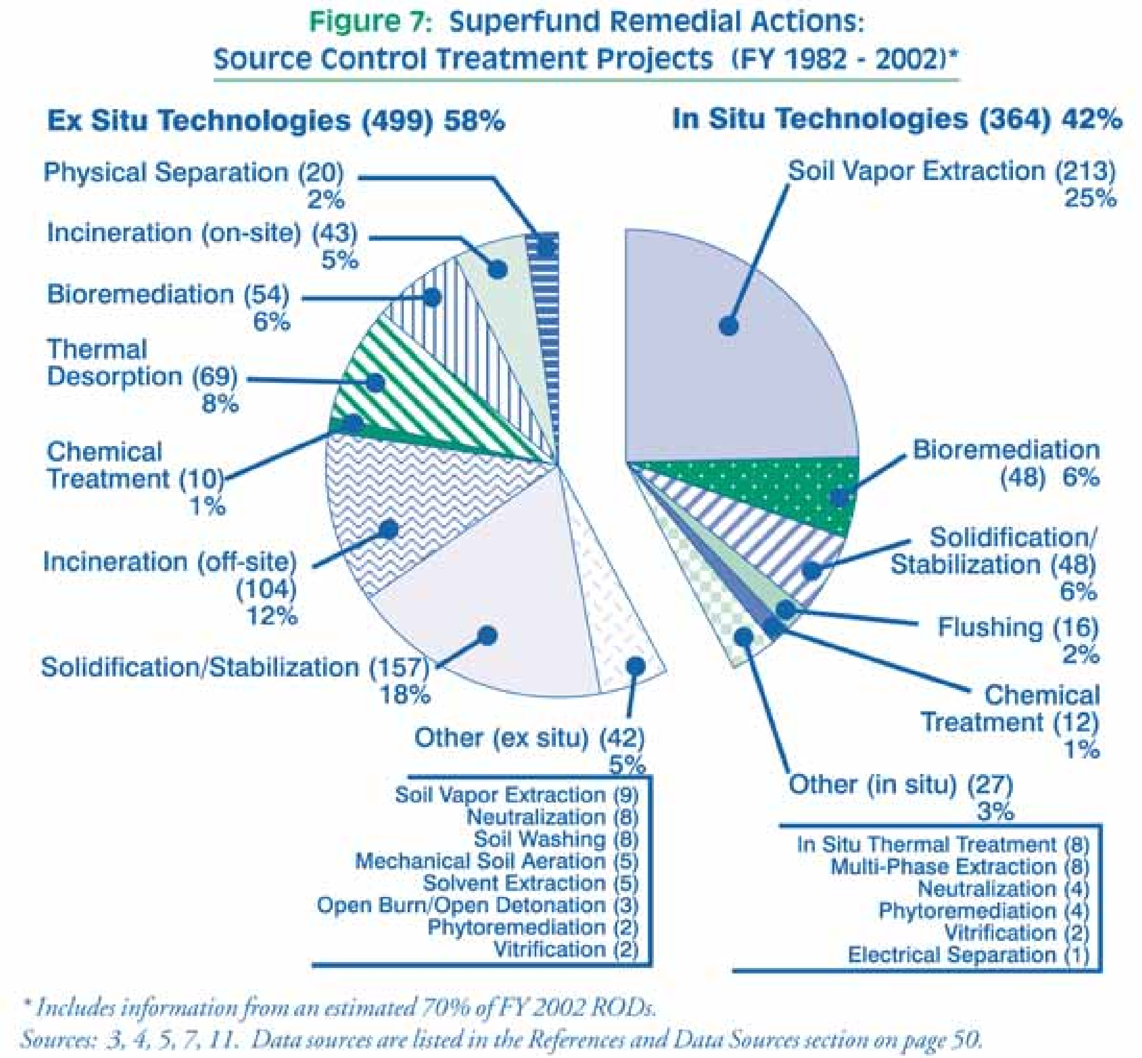

Fig. 1. Selection rate of treatment technologies at CERCLA Source Control Remedies (3).

Sources at these sites are often contaminated soil, sludge or sediment. S/S has been effective treatment for soil and sludge contaminated with a broad variety of organic and inorganic contaminants.(4) Contaminated material can be treated *in-situ* (in-place) or *ex-situ* as already segregated waste or excavated material. The extensive use of S/S on RCRA and Superfund waste makes it important that environmental professionals understand the physical, chemical, and regulatory aspects of the technology as well as how to apply the technology in the field.

Although the terms *solidification* and *stabilization* sound similar, they describe different mechanisms used to immobilize hazardous constituents. *Solidification* refers to changes in the physical properties of a waste. The desired changes usually include an increase of the compressive strength, a decrease of permeability, and encapsulation of hazardous constituents. *Stabilization* refers to chemical changes of the hazardous constituents in a waste. The desired changes include converting the constituents into a less soluble, mobile or toxic form. S/S treatment involves mixing a binding reagent into the contaminated media or waste. Binding reagents commonly used include portland cement, cement kiln dust (CKD), lime, lime kiln dust (LKD), limestone, fly ash, slag, gypsum and phosphate mixtures and a number of proprietary reagents. Due to the great variation of waste constituents and media, a mix design should be conducted on each subject waste. Most mix designs are a blend of the inorganic binding reagents listed above. Binding reagents that are organic have also been tried. These include asphalt, thermoplastic and urea-formaldehyde. Organic binding reagents are rarely used in commercial scale due to their high cost compared to inorganic binders.(5)

PRINCIPALS OF TREATMENT

Cement's Effect on Waste

Portland cement is a generic material principally used in concrete for construction. This material is also a versatile S/S binding reagent with the ability to both solidify and stabilize a wide variety of wastes. Portland cement-based mix designs have been the popular S/S treatments and have been applied to a greater variety of wastes than any other S/S binding reagent. Cement is frequently selected for the reagent's ability to:
(a) chemically bind free liquids, (b) reduce the permeability of the waste form,
(c) encapsulate waste particles surrounding them with an impermeable coating
(d) chemically fix hazardous constituents by reducing their solubility, and
(e) facilitate the reduction of the toxicity of some contaminants. This is accomplished by physical changes to the waste form and often, chemical changes to the hazardous constituents themselves. Cement-based S/S has been used to treat wastes that have either or both inorganic and organic hazardous constituents. Mix designs often include byproducts or additives in addition to portland cement.(6) Fly ash is often used to capitalize on the pozzolanic effect of this material when mixed with hydrating portland cement.(7) CKD and slag have minor cementitious properties and are sometimes used for economy. Lime, LKD can be used to adjust pH or to drive off water due to the high heat of hydration. Limestone can be used for pH adjustment and bulking.

Treatment of Free Liquids

Land disposal of wastes with free liquids is prohibited by RCRA land disposal restrictions. S/S is often used to treat these wastes so that they can be land disposed. RCRA policy requires that free liquids in waste be chemically bound.(8) Portland cement is often used as the S/S binding reagent for these wastes since cement reacts with water, chemically binding the water in cement hydration products. An unconfined compressive strength of at least 0.34 MPa (50 psi) is specified to verify that wastes treated for free liquids have had the liquids bound chemically rather than absorbed.(8) This specification is more easily met with the use of cement than other reagents, since the main use of cement in construction is the attainment of compressive strength.

Treatment of Inorganic Contaminants

The most popular use of S/S is in the treatment of wastes contaminated with inorganic hazardous constituents. Generally, for inorganic-contaminated wastes, the hazard resides in the heavy metals content. Heavy metal-contaminated wastes are frequently determined to be RCRA-characteristic wastes due to the leaching potential of the heavy metals. These wastes have failed the toxicity characteristic leaching procedure (TCLP). Frequently S/S treatment is used to reduce the leaching potential of the hazardous constituent from the waste. After treatment, the waste no longer exhibits the hazardous characteristic (hazardous constituent leaching) and can be disposed as a RCRA solid waste. Many RCRA-listed wastes require treatment to the maximum extent practical to reduce their potential hazards when land disposed. S/S treatment is often used on RCRA-listed wastes to comply with this requirement. At remediation projects S/S is often the only reasonably available technology to treat the large volumes of heavy metals-contaminated soil, sludge, or sediment resulting from these operations.

Cement is uniquely suited for use as a S/S reagent for metal contaminants. It reduces the mobility of inorganic compounds by (a) formation of insoluble hydroxides, carbonates, or silicates; (b) substitution of the metal into a mineral structure; and (c) physical encapsulation.(9, 10, 11) S/S treatment can also reduce the toxicity of some heavy metals by changes in valence state.(1, 6)

Treatment of Organic Contaminants

The treatment of wastes contaminated by organic hazardous constituents generally relies on cement's ability to solidify the waste. Treatment by solidification relies on changes to the physical properties of the waste. These changes may include, (a) binding of free water in a waste into cement hydration products, (b) creation of waste with more physical integrity such as a granular solid or monolith, and (c) reducing the hydraulic conductivity of the waste.

Cement-based S/S treatment has been effective in the treatment for a wide variety of hazardous constituents including, halogenated and nonhalogenated semivolatiles and nonvolatiles, PCBs, pesticides, organic cyanides and organic corrosives.

Treatment of certain organics may require additional attention. Large concentrations of oils and greases (>20%) may prevent the hydration of cement by coating the cement particle with oil or grease thus preventing water from coming in contact with the particle. Some organics can effect the setting time of cement and should be carefully evaluated. Additives and field techniques (such as use of a water/cement grout rather than dry cement powder) can often moderate these undesirable effects.

Binding reagents such as quicklime can produce significant amount of heat quickly when mixed with water. The hydration reaction is exothermic. This fast evolution of the high heat of hydration of lime can pose challenges in the S/S treatment of materials contaminated with volatile organic compounds and specific other compounds such as polychlorinated biphenyls (PCBs).(12) Air collection and treatment devices may be necessary to avoid transfer of the VOCs from the waste to the surrounding atmosphere.

Testing Effectiveness

Most S/S projects require treatability studies and final performance testing of the treated waste. These tests can be placed into two groups- physical and chemical. The commonly specified physical tests in project performance standards include the paint filter test (pass/fail), hydraulic conductivty ($<1X10^{-5}$ cm/sec), and unconfined compressive strength (0.34 MPa (50 psi)).(8, 13)

The most commonly specified chemical test is EPA's TCLP. There has been considerable discussion about the appropriateness of applying the TCLP to S/S treated waste. The TCLP relies on extracting the sample waste with a diluted organic acid (acetic acid), thus simulating conditions of waste co-disposed organic waste such as in a RCRA Subtitle C municipal landfill. Many S/S-treated wastes are disposed in monofills or treated and left in-situ. The TCLP may not be the best simulation of these disposal scenarios. To address this concern, the EPA has begun to apply the Synthetic Precipitation Leaching Procedure (SPLP) in lieu of the TCLP. The SPLP is designed to simulate waste exposure to acid rain. This procedure is similar to the TCLP except that a weak solution of inorganic acids (sulfuric and nitric acids) is used. For S/S projects east of the Mississippi River the solution is adjusted to a pH of 4. For projects west of the River, the solution is adjusted to a pH of 5. Project managers and regulators should evaluate the final disposal environment of the treated waste to determine the appropriate test to use.

EXAMPLE PROJECTS

Lead-Acid Battery Waste: 90^{th} South Battery Site

An example of cement-based S/S being applied ex-situ to metal-contaminated soil includes the 90^{th} South Battery Site Project in West Jordan, UT.(14) This project was conducted by EPA Region XIII as an Emergency Response. At this site, EPA treated about 1900 m^3 (2500 cu yd) of contaminated soil and waste. Waste at the site apparently resulted from "midnight dumping" of lead-acid batteries recycling wastes. Lead plates, lead slag, and battery casing material were found at the site. Soil at the site was contaminated with lead and small areas were contaminated with sulfuric acid. The waste piles and soil were treated ex-situ by first excavating the material, screening and crushing over-size to <32 mm (<1-1/4 inch).. To adjust the pH of the material, approximately 5% by weight of limestone fines were mixed into the soil pile with a front-end loader. A mobile pugmill was erected at the site. The binding reagent used was a 3:1 blend of portland cement/cement kiln dust. The binding reagent was mixed into the contaminated material with a pugmill. The binding reagent blend was added to the material in amounts ranging from 15% to 17% by weight. About 10% of water by weight was also added. TCLP concentrations for lead in the untreated soil at the site ranged from 5 to 200 ppm. The untreated soil had total lead concentrations between 5000 and 60,000 ppm and total arsenic concentrations up to 1600 ppm. After treatment the TCLP concentrations for lead ranged from below detection limits to 0.72 ppm. For arsenic the TCLP concentrations in the treated soil was undetectable. The treated waste was granular, contrary to most people's perception that the treatment always results in monoliths. The treated soil was beneficially re-used, compacted as a sub-base for a pavement at the municipal landfill. The paved area was used for composting operations.

PCB-Contaminated Soils: Yellow Water Road Superfund Site

Improper management of transformers and capacitors lead to contamination of soil with PCBs and subsequent remediation at Yellow Water Road Superfund site in Baldwin, Florida.(15) EPA Region IV conducted a remedial action at the site. Site area soil with PCB-contamination above 10mg/kg was excavated and stored on-site. In all, 3419 m^3 (4472 cu yd) of contaminated soil with PCB concentrations up to 660 mg/kg was readied for treatment. The EPA selected remedy included cement-based S/S. A pugmill was used to mix the soil with portland cement. The treated soil was placed into a dedicated landfill (monofill) constructed at the site.

In-Situ Treatment of Refinery Oily Sludge Storage Basin

S/S treatment is often applied *in-situ*. S/S contractors have developed a variety specialized equipment to mix binding reagents into contaminated soil, sediment or sludge while these materials remain in place. An example of *in-situ* treatment is RCRA closure of a refinery oily sludge basin located in the Midwest.(16, 17) The basin operated for 30 years and served as a collection and settling basin for stormwater and oily sludge. The basin was about 2.2 hectares (5.5 acres) containing about 84,000 m^3 (110,000 cu yd) of sludge and impacted soils.(17) Basin sludge and soil were contaminated with hydrocarbons and heavy metals. Beneath the basin was a thick layer of clay. The closure plan included installation of cement-bentonite slurry and grout walls tied into the clay layer to create a containment system. A mixing device resembling a large drill-mounted "kelly" bar was used to mix portland cement into basin wastes. An overlapping pattern of mixing boring was used to ensure complete treatment. An addition rate of 20% portland cement was used. This resulted in only a 3% volume increase in the waste.

Radioactive Soils: Shattuck Chemical Company Superfund Site

Remediation of the Shattuck Chemical Company Superfund Site in Denver, Colorado included the S/S treatment of radium-contaminated soils.(18) Contamination at the site was the result of ore processing to provide a domestic source of radium. As the need for radium, property ownership, and land use changed, radium-processing residues found their way into facility and surrounding property soils. The EPA Region VIII selected remedy involved S/S treatment of the soil with on-site disposal of the treated material. Approximately 76,000 m^3 (100,000 cu yd) of the soil was treated. The S/S mix design was 70% contaminated soil, 20% flyash and 10% portland cement. The treatment material was placed in an excavation at the site and covered with a cap designed to protect the treated material and attenuate radiation emitted to safe levels.

Brownfield Re-use of New York Harbor Sediments

Newly effective federal regulations restrict the ocean disposal of sediments dredged from the harbors of New York and Newark. The New York Port Authority is faced with a critical situation: find land-based disposal/uses for 10's of millions m^3 of sediments or lose standing as a commercial port for ocean-going ships. One of the technologies now being employed to manage the sediments is portland cement-based solidification/stabilization (S/S) treatment.(19) Millions of cubic meters of the sediments will undergo cement-based S/S treatment. This treatment will immobilize heavy metals, dioxin, PCBs and other organic contaminants in the sediment.

The treatment changes the sediment from a environmental liability into a valuable structural fill. Dredged sediment is transported by barge to a pier. At the pier, cement is mixed into the sediment while it remains in the barge. The mixing method uses an excavator- mounted mixing head. The treated material I removed from the barge and used as structural fill. This structural fill is being used at two properties. The first property is an old municipal landfill in Port Newark, New Jersey. The treated sediments are being used as structural fill to cover about 8 hectares (20

acres) of the landfill. This will allow planned redevelopment of the landfill property into a shopping mall.
The second property called the Seaboard site, was the location of a coal gasification facility and later a wood preservation facility. This 65 –hectare (160-acre) property has been designated for brownfield redevelopment. Over 1.1 million m^3 (1.5 million cu yd) of treated sediments already covers this site.

In-Situ Solidification/Stabilization of a Former Wood-Treatment Site, Renton, Washington

In-situ portland cement-based solidification/stabilization treatment technology was selected to remediate soil at a former wood preserving site in Washington State. [20] The remediation effort was to prepare the site for eventual redevelopment. Known as the J.H. Baxter –Renton Site, the property is a 8-hectare (20-acre) site located on the southeastern shore of Lake Washington near Renton, Washington. A former wood treatment plant operated at the site from 1955 until it closed in 1982. Plant operations included use of chemicals commonly associated with industrial treatment of wood, including creosote and pentachlorophenol (PCP). A 1983 site assessment conducted for possible site redevelopment identified polycyclic aromatic hydrocarbon (PAHs) and PCP in site soil and groundwater.

The Washington State Department of Ecology (Ecology) was responsible for approving the remediation plans for the site. In 1992, the site was divided into the North and South Baxter Properties. In February 2004, Ecology approved remediation contractor plans and specifications for remediation of the upland portion of the South Baxter Property. Ecology’s approval of solidification/stabilization (S/S) treatment of the organic contaminated soil at the J.H. Baxter site was based in part on positive experience with S/S technology at previous clean-ups.

In-situ treatment of contaminated soil at the J.H. Baxter site was selected over common “dig and dump” clean-up plans for several reasons. 1. Excavation of contaminated soil would be complicated and costly. The high water table at the site would have required constant dewatering of an excavation and treatment of the water removed. 2. Transporting excavated contaminated soil and replacement fill would have required major earth-moving equipment and heavy truck traffic through adjacent residential areas. 3. Off-site disposal of nearly 9,000 m^3 (12,000 cu yd) would be costly. In-situ S/S treatment avoided these problems, public risks, and costs.

S/S treatment at the J.H. Baxter site involved mixing portland cement and bentonite into the contaminated soil while the soil remained in-place. These S/S binding reagents were mixed into the soil through the use of a soil mixing auger. The auger was specially designed for use in the soft peaty soil at the site. At 2.5 m (8.5 ft) in diameter, the auger delivered the cement and bentonite grout mixture into the soil primarily through jets in the pilot bit. The S/S mix design was approximately 20% addition of portland cement and 1-2% addition of bentonite. The auger was advanced into the soil up to a depth of 7.3 m (24 ft). An overlapping pattern of mixing columns was used to ensure complete treatment of the soil. Approximately 8,950 m^3 (11,700 cu yd) of soil was treated. S/S treatment at the site was completed in about two weeks.

Solidification/Stabilization treatment protects human health and the environment by reducing or preventing the release of hazardous constituents from treated material. This is accomplished by physical and chemical changes to the treated material. Leaching of organic contaminants from in-situ S/S-treated soil is reduced by changing the permeability of the soil to groundwater and surface water. Reducing the permeability (or hydraulic conductivity) of treated soil by an order of magnitude results in the groundwater and surface water flowing around the treated mass instead of through it.

At the J.H Baxter site performance specifications for the treated soil included a maximum hydraulic conductivity of $1X10^{-5}$ cm/sec and unconfined compressive strength (UCS) of between 0.07 to 0.34 MPa (10 to 50 psi) at 28 days. Successful treatment was accomplished with tested field samples having hydraulic conductivities less than $1X10^{-5}$ cm/sec and UCS of between 0.2 to 0.52 MPa (30 to 75 psi).

Additional remediation at the site included excavation of contaminated sediment from the adjoining lakebed and a lagoon on the site, demolition and removal of concrete tanks, excavation and removal of shallow contaminated soil around the tanks, and contouring and planting of excavated areas.

CONCLUSION

S/S is an established technology used in the management of hazardous waste radioactive waste, and contaminated media from environmental remediation. S/S technology can be used to treat a wide range of hazardous constituents in several different media. An appreciation of the versatility of the treatment technology can be gained by review of example projects. S/S is expected to continue to be an indispensable tool in hazardous and radioactive waste management.

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