Applying Solidification/Stabilization for Sustainable Redevelopment of Contaminated Property

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ABSTRACT

In use since the 1950s for treating radioactive and hazardous wastes, solidification/stabilization (S/S) has become a popular treatment technology for remediation of contaminated land, particularly brownfields. S/S treatment contributes to sustainable redevelopment of contaminated property since the treated material can often be left onsite and reused thus diverting it from landfills, conserving transportation fuel and replacement fill, and avoiding risks posed to the surrounding community. This article discusses S/S treatment basics, performance testing, and examples of successful full-scale projects.

INTRODUCTION

Solidification/stabilization (S/S) is a widely used treatment for the management and disposal of a broad range of contaminated media and wastes, particularly those contaminated with substances classified as "hazardous" in the United States. The treatment involves mixing a binding agent into the contaminated media or waste. The treatment protects human health and the environment by immobilizing hazardous constituents within the treated material. This immobilization prevents migration of these constituents to human, animal, and plant receptors. S/S treatment has been used to treat radioactive wastes since the 1950s and hazardous waste since the 1970s.[1] S/S continues as a cornerstone treatment for the management of radioactive and hazardous waste, and sustainable site remediation and redevelopment.

The U.S. Environmental Protection Agency (EPA) considers S/S an established treatment technology and a key treatment in the management of industrial hazardous wastes. These wastes are regulated in the United States under the Resource Conservation and Recovery Act (RCRA). RCRA hazardous wastes are grouped into two classes: RCRA-listed and RCRA-characteristic. RCRA-listed hazardous wastes are wastes produced by industry that are generally known to be hazardous. These wastes are "listed" in RCRA regulations and must be treated, stored, and disposed according to RCRA hazardous waste management regulations. RCRA-listed wastes destined for land disposal are required to be treated in order to reduce hazards posed by the wastes after land disposal. EPA has identified S/S as the best demonstrated available technology (BDAT) for over 50 RCRA-listed hazardous wastes.[2] RCRA-characteristic wastes are less routinely produced wastes that are found to be hazardous due to a characteristic of the waste. For RCRA-characteristic wastes, S/S can often be used to eliminate the hazardous characteristic. Once the hazardous characteristic has been addressed, the treated material can be reused or disposed of at lower cost.

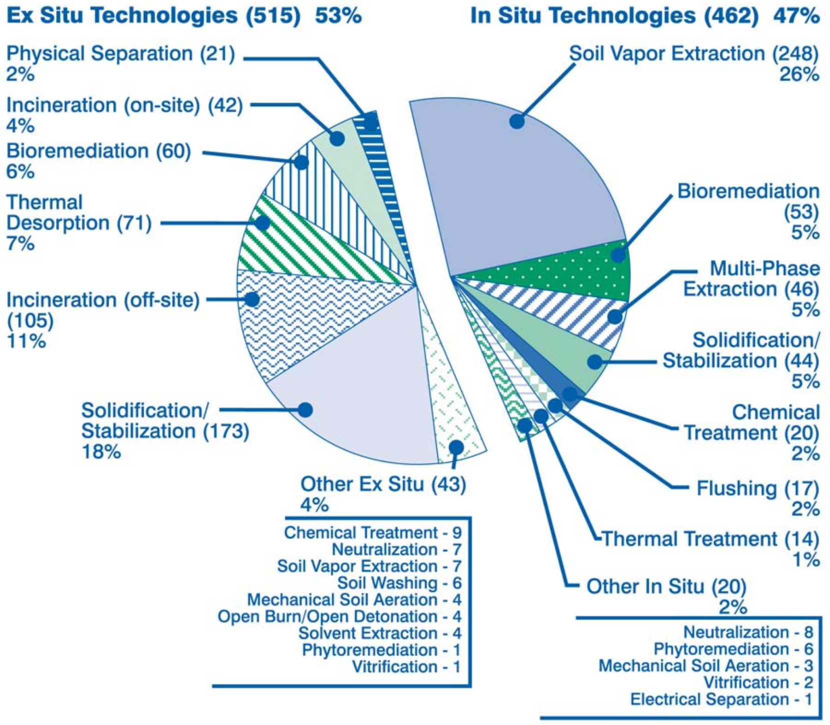
S/S treatment is used to treat contaminated media during the remediation of contaminated properties. The permitting requirements for hazardous waste management facilities under RCRA include requirements for owners of these facilities to remediate previously contaminated areas at the facility. These are known as RCRA corrective actions and S/S can be applied to address these contaminated areas. However, the best-known and documented remediation program in the

United States is conducted under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The CERCLA program is used to remediate abandoned or uncontrolled properties where hazardous substances have been released and pose a danger to human health and the environment. Because the program is funded by a tax collected from petroleum and chemical manufacturers, and by potentially responsible parties that caused the contamination, it is commonly called the "Superfund" program.

S/S is the most frequently selected treatment for controlling the sources of environmental contamination at Superfund remediation sites; 23% of selected source-control remedies for Superfund sites include the use of S/S (see Figure 1).[3] S/S is an effective treatment for a wide variety of organic and inorganic hazardous constituents present in contaminated soil, sludge, and sediment.[4] The ability to treat various hazardous constituents within the same media is a key reason why S/S is so frequently used in remediation. Adding to the versatility of S/S treatment is the fact that contaminated material can be treated *in situ* (i.e., in place) or ex-situ as already segregated waste or excavated material.

Figure 1.

Figure 8: Source Control Treatment Projects
(FY 1982 - 2005)*
Total Number of Projects = 977



Cumulatively, more than half of source control treatment projects have been ex situ, although the single most common treatment technology has been in situ soil vapor extraction.

**Includes information from an estimated 74 percent of FY 2005 records of decision and amendments available as of October 2006 and project data available in CERCLIS as of October 2006.*
Sources: 3, 4, 7. Data sources are listed in Section 6.

A more recent development in U.S. remediation programs is the advent of brownfield initiatives. Brownfields are previously used industrial or urban properties that have not been redeveloped because of potential environmental contamination and the associated liabilities. However, initiatives in U.S. liability law and funding are encouraging the remediation and reuse of brownfield sites. The benefits to society are considerable and include the reduction of urban sprawl and preservation of fertile farmland. S/S treatment is increasingly being used to address contamination at brownfield sites as developers are realizing that S/S not only deals with the contamination, but it also allows the treated material to be reused for significant cost savings.

On-site treatment of contaminated material and its reuse contributes to sustainable development of a site. Mobile treatment plants can be transported to a remediation site to treat excavated material there. *In situ* mixing methods can be used to mix S/S binding agents directly into contaminated material while it remains in place. Managing treated material on site diverts it from landfills, conserves transportation fuel and replacement fill, and avoids risks posed to the surrounding community by truck transits.

The effectiveness and increasingly extensive use of S/S treatment for industrial hazardous waste and remediation 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.

HOW S/S WORKS

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

Effects of Binding Agents

Portland cement is a generic material principally used in concrete for construction. This material is also a versatile S/S binding agent with the ability to both solidify and stabilize a wide variety of contaminated material. Portland cement-based mix designs are popular S/S treatments and have been applied to a greater variety of contaminated material than any other S/S binding agent.[1] Cement is frequently selected for its ability to (1) chemically bind free liquids, (2) reduce the permeability of the treated material, (3) encapsulate hazardous constituent particles surrounding them with an impermeable coating, (4) chemically fix hazardous constituents by reducing their solubility, and (5) facilitate the reduction of the toxicity of some contaminants. This is accomplished by physical changes to the contaminated material form and, often, chemical changes to the hazardous constituents themselves. Cement-based S/S has been used to treat contaminated materials 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[7] effect of this material when mixed with hydrating portland cement. CKD and slag have minor cementitious properties and are sometimes used for economy. Lime and LKD can be used to adjust pH or to drive off water by using the high heat of hydration produced by these S/S binders. Limestone can be used for pH adjustment and bulking.

Treatment of Free Liquids. Land disposal of liquid waste or solid-form waste with a free liquid portion is prohibited by RCRA land disposal restrictions. S/S is often used to solidify liquids so that the waste can be land disposed. RCRA requires that free liquids be chemically bound.[8] Portland cement is often used as the S/S binding agent for these wastes since cement reacts with water, chemically binding the water in cement hydration products. An unconfined compressive strength (UCS) 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 agents, 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 treating materials contaminated with inorganic hazardous constituents. Generally, for inorganic-contaminated materials, the hazard resides in the heavy metals content. Heavy metals-contaminated materials 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 material. After treatment, the material no longer exhibits the hazardous characteristic (i.e., hazardous constituent leaching) and can be disposed as nonhazardous material. Many RCRA-listed contaminated materials require treatment to the maximum extent practical to reduce their potential hazards when land disposed. S/S treatment is used on RCRA-listed contaminated materials to comply with this requirement. In the case of 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 an S/S agent for metal hazardous constituents because it reduces the mobility of inorganic compounds by (1) formation of insoluble hydroxides, carbonates, or silicates; (2) substitution of the metal into a mineral structure; and (3) physical encapsulation.[9-11] S/S treatment can also reduce the toxicity of some heavy metals by changes in valence state.[1,6]

Treatment of Organic Contaminants. Treatment of material contaminated by organic hazardous constituents generally relies on cement's ability to solidify the material, through changes to its physical properties. These changes may include binding free water in a waste into cement hydration products, creating material with more physical integrity, such as a granular solid or monolith, and reducing the hydraulic conductivity of the material. Cement-based S/S treatment has been effective in the treatment for a variety of hazardous constituents, including halogenated and nonhalogenated semivolatiles and nonvolatiles, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, organic cyanides, and organic corrosives. Treatment of certain organics may require additional attention. Large concentrations of oils and greases may prevent the hydration of cement by coating the cement particle with oil or grease, thus preventing water from coming into contact with the particle.

Some organics can affect the setting time of cement and should be carefully evaluated. Additives and field techniques can often moderate these undesirable effects. Binding agents such as quicklime can produce a significant amount of heat quickly when mixed with water. The hydration reaction is exothermic. This fast evolution of the heat can pose challenges in the S/S treatment of materials contaminated with volatile organic compounds (VOCs) and other compounds, such as PCBs.[12] Air collection and treatment devices may be necessary to avoid transfer of the VOCs from the contaminated material to the atmosphere.

Physical and Chemical Tests

Most S/S projects require treatability studies and final performance testing of the treated contaminated material. These tests can be placed into two groups: physical and chemical. EPA's publication *Stabilization/Solidification of CERCLA and RCRA Wastes* [8] provides descriptions of the various tests used in the United States. It is important to note that the only tests that are required by regulation or policy in the U.S. are toxicity characteristic leaching procedure (TCLP) and the unconfined compressive strength (UCS) test. Furthermore, these tests are applicable by regulation or policy only in limited circumstances. Regulators generally select the appropriate physical and/or chemical tests for a specific project using best professional judgment based on the hazardous constituents and media (soil, sludge, or sediment) and the planned use of the site.

Physical Tests. The commonly specified physical tests in project performance standards include the paint filter test (pass/fail), hydraulic conductivity ($<1X10^{-5}$ cm/sec), and UCS (>0.34 MPa (>50 psi)).[8,13]

Chemical Tests. The most commonly specified chemical test is the TCLP, which is frequently applied because it has some relationship to regulations written into the RCRA program. However, there has been considerable discussion about the appropriateness of applying the TCLP to S/S-treated material when this treated material is managed other than in a municipal landfill. The TCLP relies on extracting hazardous constituents from the sample with a diluted organic acid (acetic acid), thus simulating conditions of co-disposed organic waste, such as in a municipal landfill. Many S/S-treated materials are disposed in monofills or treated and left onsite. The TCLP may not be the best simulation of these disposal scenarios. To address this concern, EPA has begun to apply the synthetic precipitation leaching procedure (SPLP) in lieu of the TCLP. The SPLP (EPA Method 1312-SW846) is designed to simulate 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. Ultimately, project managers and regulators should consider the final disposal environment of the treated material to determine the appropriate test to use.

EXAMPLE PROJECTS

S/S has been used to treat a variety of material from common industrial wastes to contaminated environmental media at Superfund sites. The examples below describe the use of S/S treatment at several sites. In each case, the treated material was beneficially reused onsite or at another location. Reuse of treated material saved developers significant costs, while providing for sustainable redevelopment that is protective of human health and the environment.

Former Wood Treating Facility, Port Newark, N.J.

Two types of mixing techniques were used to treat soils contaminated by wood preserving operations at former wood treating facility in Port Newark, New Jersey.[14, 15] (Figure 2). Approximately 3.2 hectares (8 acres) of soils at the site were contaminated with arsenic, chromium, and polycyclic aromatic hydrocarbons (PAHs). *In situ* soil mixing was used to treat 17,000 m^3 (22,000 cu yd) of soil from 0.6 m (2 ft) to 3.7 m (12 ft). This treatment involved: (1) pre-excavation of contaminated material, (2) placement of the stockpiled material back into the excavated area in 2 m (6 ft) lifts, and (3) S/S treatment of each lift with an *in situ* blender head (Figure 3). Performance standards set for the treatment of the soil included attaining a minimum of 0.17 MPa (25 psi) UCS. S/S-treated soils exceeded this requirement. Another 20,000 m^3 (26,000 cu yd) of contaminated soil was treated ex-situ using a pugmill to mix portland cement into contaminated soil. Contaminated soil mixed by pugmill was placed on top of the *in situ* treated soil in a 0.6 m (2 ft) layer. This layer was carefully compacted to have the similar structural properties as that of soil-cement. This soil-cement-like layer achieved UCS strengths of greater than 1.7 MPa (250 psi), providing an excellent base for pavement placed over the entire site. The mix design for both of these mixing techniques called for an addition rate of 8% portland cement by wet weight of the soil. Future use of the site is as a shipping container storage area.

Figure 2.

Figure 3.

Former Manufactured Gas Plant Site, Cambridge, Mass.

Experts estimate that there are more than 4000 medium-large former manufactured gas plant (MGP) sites in the United States. Before the common distribution of natural gas, urban areas relied on MGPs to provide gas for lighting and cooking. MGPs heated coal and oil to produce “town gas”. Byproducts from this process included coal tars—polycyclic aromatic hydrocarbons (PAHs) and other organic compounds that behave as dense non-aqueous phase liquids (DNAPLs) and light non-aqueous phase liquids (LNAPLs) when in groundwater.

Cement-based S/S can be an effective means to address contamination at former MGP sites. At this site in Cambridge, Mass., cement was mixed into the soil while the soil remained in place by using a specialty auger system.[16] As the auger penetrates the soil, cement grout is pumped through the mixing shaft and exits through jets located on the auger flighting, mixing cement into the contaminated soil (Figure 4). An overlapping drilling (auger) pattern is used to ensure complete mixing and treatment of the area. Approximately 79,000 m^3 (103,000 cu yd) of contaminated soil to a depth 6.5 m (22 ft) was treated at the site. Cement-based S/S not only successfully treated the soil for MGP impacts, but also improved the physical properties of the soil for property redevelopment. Thus contributing to the sustainable development. Developers of the property earned the prestigious Brownfield Phoenix Award and the office building built at the property was rated as Leadership in Energy & Environmental Design (LEED) Platinum by the U.S. Green Building Council.

Figure 4.

Former Electric Generating Station, Boston, Mass.

A series of abandoned warehouses used for residential, light industrial, commercial, and bus maintenance comprised an area in Boston Mass.[17] These old buildings are now being renovated for offices or torn down to construct new residences to create a new and revitalized community. The centerpiece of this new area is the Central Power Station. The Central Power Station, built in 1890, was an engineering marvel at the time. When first opened, the plant was considered to be the biggest electric generating plant in the world and powered the first subway system in the United States. The plant has not generated electricity in 90 years and has been vacant since the 1950s.

In 1994, during renovation of the abutting building, free-floating oil was discovered in the sewer. Various underground storage tanks and oil/water separators were known to exist on both properties. Cleanup efforts from the abutting property were futile as pump and treat efforts brought more oil onto this site. In 1997, oil was found on the Central Power Station site during site assessment activities conducted by the abutting property owner. In addition, lead was found in the soils from the ash fill from the power station. In 1999, the current owner purchased the property from the metropolitan Boston transit authority and designed a remediation of the entire contaminant plume located on both properties. The objective was to integrate the remediation into the redevelopment. This was accomplished by minimizing off-site disposal costs by treating the materials on-site for reuse during construction.

Cement-based S/S treatment was used to address lead- and petroleum-contaminated soils at the site. Remediation of the contaminated soils involved recovery of free product through tank structure removal and pumping, along with cement-based S/S of contaminated soils and fill. A portable S/S treatment plant was mobilized to the site. Approximately 2,100 m^3 (2,800 cu yd) of material was excavated there. Rather than disposing of the contaminated material off-site, it was treated and reused at the site (Figure 5). Off-site transportation and disposal would have cost the property owner an additional $500,000 over the treatment costs. Additional savings of $30,000 were recognized through the reuse of the material as pavement base for a planned parking lot on the property. As a result of the treatment, petroleum and lead in the soil were successfully managed at the site. Cement-based solidification/stabilization was used at this brownfield project to safely treat lead- and petroleum- contaminated soils, transforming an environmental liability into an economic asset.

Figure 5.

Reuse of New York Harbor Sediments

Newly effective federal regulations restrict the ocean disposal of sediments dredged from the harbors of New York and Newark, N.J. The New York Port Authority is faced with a critical situation: find land-based disposal/uses for tens of millions of cubic meters 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 S/S treatment.[18] Millions of cubic meters of the sediment have undergone cement-based S/S treatment. This treatment immobilizes heavy metals, dioxins, PCBs, and other organic hazardous constituents in the sediment. The treatment changes the sediment from an environmental liability into a valuable structural fill.

For one of the earlier projects, dredged sediment was transported by barge to a pier. At the pier, cement was mixed into the sediment while it remained in the barge (Figure 6). The mixing method used an excavator-mounted mixing head. The treated material was removed from the barge as structural fill which was used at two properties. The first property was an old municipal landfill in Port Newark, N.J. The treated sediment covered about 8 hectares (20 acres) of the landfill. This competent structural fill allowed redevelopment of the landfill property into a shopping mall (Figure 7). Developers of the Jersey Gardens Mall earned the prestigious Brownfield Phoenix Award for the redevelopment of the property.

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 brownfields redevelopment. More than 1.1 million m^3 (1.5 million cu yd) of treated sediments already covers this site. At another site in Bayonne, N.J., New York and Newark dredged sediment was processed through a large-scale stationary pugmill and reused as structural fill to create the Bayonne Golf Club in New York Harbor.

Figures 6 and 7:

Hercules 009 Landfill Superfund Site, Brunswick, Ga.

The Hercules 009 Landfill started as a borrow pit during construction of Georgia State Highway 25 (Spur 25), bordering the property on the west. Hercules Incorporated used the 3-hectare (7-acre) borrow pit area for disposal of toxaphene production related waste. Toxaphene was one of the most heavily used insecticides in the United States until 1982, when the EPA cancelled the registrations of the pesticide for most uses; all uses were banned in 1990. The remedial action contractor used an excavator to blend portland cement into the contents of the landfill. The mix design called for adding 15% portland cement by weight into the landfill contents. Toxaphene-impacted soils taken from area and properties around the landfill were also treated with a 3% cement addition. This treated soil was used in the cover design of the S/S-treated landfill providing a low-permeability and structural component. The Superfund site has been redeveloped by paving the top of the landfill. It is now used as a parking area for an automobile dealership (Figure 8).

CONCLUSION

S/S treatment is used in the United States to treat industrial waste and contaminated media at remediation sites. S/S treatment protects human health and the environment by safely immobilizing hazardous constituents within the treated material. EPA considers S/S to be an established treatment technology and has selected the technology at 23% of the nation's Superfund program sites where the sources of contamination have been addressed. S/S technology can be used to treat a wide range of hazardous constituents within the same media or waste. This versatility is a key reason for the high frequency of use of the technology in remediation. On-site treatment and reuse of treated material contributes to the sustainable remediation and redevelopment of contaminated sites.

ABOUT THE AUTHOR

Mr. Charles Wilk is Program Manager for waste management at the Portland Cement Association. He is responsible for providing technical assistance on the use of cement for waste management applications in the U.S. and Canada. These applications include cement-based solidification/stabilization treatment for remediation of contaminated property. Mr. Wilk has eight years of experience at the United States Environmental Protection Agency in the RCRA (hazardous waste management) and CERCLA ('Superfund") programs and over twenty years in the cement industry. Mr. Wilk earned a Bachelor of Science degree in Environmental Sciences and a Masters in Business Administration. He is a Licensed Environmental Health Practitioner in the State of Illinois, is certified as a Qualified Environmental Professional and a Leadership in Energy & Environmental Design Accredited Professional. He has authored a number of technical papers and articles in international journals and conference proceedings concerning the use of cement for waste management. He can be reached at cwilk@cement.org or (847) 972-9072. PCA's website on S/S treatment is found at www.cement.org/waste.

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