Applying Solidification/Stabilization Treatment to Brownfield Projects

by Charles M. Wilk

Long used in treating radioactive and hazardous wastes, solidification/stabilization (S/S) is also an increasingly popular treatment in the remediation of contaminated land, particularly brownfield redevelopment, since the treated wastes can often be left on site to improve the property for subsequent construction. This article discusses the application of S/S treatment to various wastes, the tests used to study and verify treatment, and the basics of implementing S/S treatment in the field. It also presents examples of S/S treatment at four brownfield sites: a former wood preserving facility, a manufactured gas plant, an electric generating station, and a shopping mall development.

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 reagent into the contaminated media or waste. The treatment protects human health and the environment by immobilizing contaminants within the treated material. Immobilization within the treated material prevents migration of the contaminants 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, site remediation, and brownfield 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 of according to RCRA hazardous waste management regulations. RCRA-listed wastes destined for land disposal are required to be treated in order to reduce the risks posed by the wastes after land disposal. EPA has identified S/S as the best demonstrated available technology (BDAT) for 57 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 resulting treated waste 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; 25% of selected remedies for Superfund sites include the use of S/S (see Figure 1).[3]

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, new initiatives in U.S. liability law and funding are encouraging the remediation

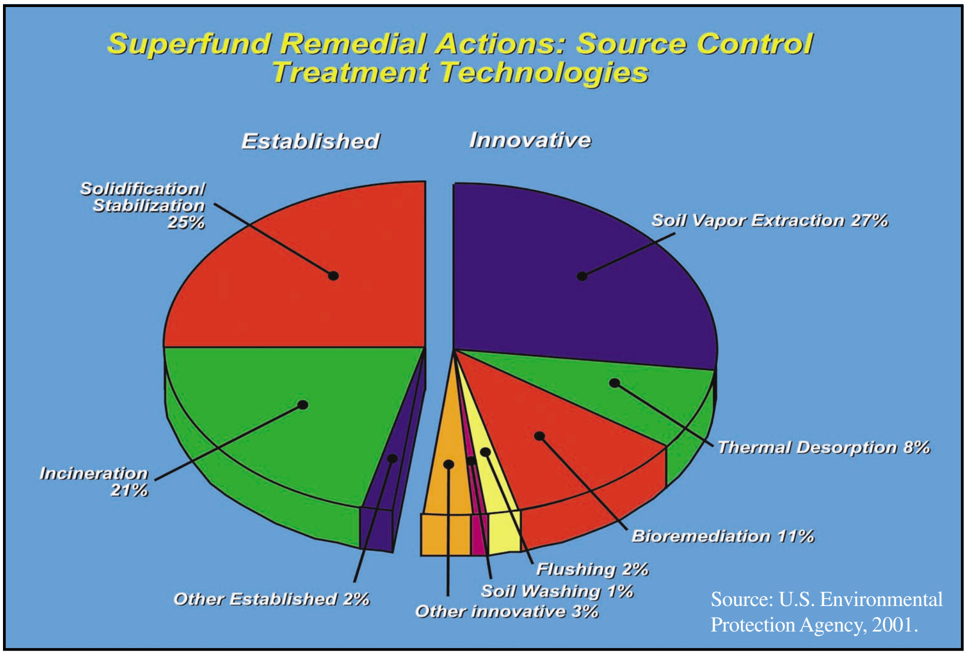

Figure 1. Frequency of S/S treatment use compared to other technologies at U.S. Superfund sites where sources of contamination have been addressed.[3]

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, resulting in significant cost savings.

S/S is an effective treatment for a wide variety of organic and inorganic contaminants present in contaminated soil, sludge, and sediment (see Table 1).[4] The ability to treat various contaminants 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. 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.

Table 1. Effectiveness of S/S on general contaminant groups for soil and sludge.[4]

	Contaminant Groups	Effectiveness Soil/Sludge
Organic	Halogenated volatiles	❏
	Nonhalogenated volatiles	❏
	Halogenated semivolatiles	■
	Nonhalogenated semivolatiles and nonvolatiles	■
	PCBs	▼
	Pesticides	▼
	Dioxins/furans	▼
	Organic cyanides	▼
	Organic corrosives	▼
Inorganic	Volatile metals	■
	Nonvolatile metals	■
	Asbestos	■
	Radioactive materials	■
	Inorganic corrosives	■
	Inorganic cyanides	■
Reactive	Oxidizers	■
	Reducers	■

■ = Demonstrated Effectiveness: successful treatability test at some scale completed;
▼ = Potential Effectiveness: expert opinion that technology will work;
❏ = No Expected Effectiveness: expert opinion that technology will not/does not work.

HOW S/S WORKS

Although the terms "solidification" and "stabilization" sound similar, they describe different effects that the binding reagents create to immobilize hazardous constituents. Solidification refers to changes in the physical properties of a waste. 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 waste, including 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]

Effects of Binding Reagents 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 popular S/S treatments and have been applied to a greater variety of wastes than any other S/S binding reagent.[1] Cement is frequently selected for the reagent's ability to (1) chemically bind free liquids, (2) reduce the permeability of the waste form, (3) encapsulate waste 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 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[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 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 treating wastes contaminated with inorganic hazardous constituents. Generally, for inorganic-contaminated wastes, the hazard resides in the heavy metals content. Heavy metals-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 (i.e., hazardous constituent leaching) and can be disposed as nonhazardous waste. Many RCRA-listed wastes require treatment to the maximum extent practical to reduce their potential hazards when land disposed. S/S treatment is used on RCRA-listed wastes 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 reagent for metal contaminants 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 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 binding free water in a waste into cement hydration products, creating waste with more physical integrity, such as a granular solid or monolith, and reducing the hydraulic conductivity of the waste. Cement-based S/S treatment has been effective in the treatment for a variety of hazardous constituents, including halogenated and nonhalogenated semivolatiles and nonvolatiles, metals, polychlorinated biphenyls (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 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 reagents 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 waste to the atmosphere.

Physical and Chemical Tests

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. 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 United States are TCLP and the unconfined compressive strength 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 contaminants 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 unconfined compressive strength (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 waste when this treated waste is managed other than in a municipal landfill. The TCLP relies on extracting the sample waste with a diluted organic acid (acetic acid), thus simulating conditions of codisposed organic waste, such as in a municipal landfill. Many S/S-treated wastes 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 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. Ultimately, project managers and regulators should consider the final disposal environment of the treated waste to determine the appropriate test to use.

EXAMPLE PROJECTS

S/S has been used to treat wastes ranging from common industrial wastes to Superfund site debris. Currently, there is great interest in brownfield redevelopment. The examples below describe the use of S/S treatment at four brownfield 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 site redevelopment that is protective of human health and the environment.

Figure 2. In situ S/S treatment at a former wood preserving facility in Port Newark, NJ.

Former Wood Treating Facility

Two types of mixing techniques were used to treat soils contaminated by wood preserving operations at a former wood treating facility in Port Newark, NJ (see Figure 2).[14,15] Approximately

Figure 3. Close-up view of in situ blender at Port Newark, NJ.

3.2 ha 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 of soil from 0.6 m to 3.7 m. This treatment involved (1) pre-excavation of contaminated material, (2) placement of the stockpiled material back into the excavated area in lifts, and (3) S/S treatment of each lift with an in situ blender head (see Figure 3). Performance standards set for the treatment of the soil included attaining a minimum of 0.17 MPa unconfined compressive strength. S/S-treated soils exceeded this requirement. Another 20,000 m^3 of contaminated soil was treated ex situ using a pugmill to mix Portland cement into contaminated soil. Contaminated soil mixed with the pugmill was placed on top of the in situ treated soils in a 0.6-m layer. This layer was carefully compacted to have the similar structural properties as soil-cement. This soil-cement-like layer achieved unconfined compressive strengths of greater than 1.7 MPa, 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.

Former Manufactured Gas Plant Site

The second example is the former location of a manufactured gas plant (MGP) in Cambridge, MA, which heated coal and oil to produce gas for lighting and heating. Byproducts from this process include coal tars and other organic compounds that behave as dense nonaqueous phase liquids (DNAPLs) and light nonaqueous phase liquids (LNAPLs) when in groundwater. Experts estimate that there are more than 4000 medium–large former MGP sites in the United States. Cement-based S/S treatment can be an effective means to address contamination at former MGP sites. At this site, cement was mixed into the soil while the soil remained in place by using a specialty auger system (see Figure 4).[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. An overlapping drilling (auger) pattern is used to ensure complete mixing and treatment of the area. Approximately 79,000 m^3 of contaminated soil to a depth 6.5 m was treated at the site. S/S not only successfully treated the soil for MGP contaminants, but also improved the physical properties of the soil for property redevelopment. Redevelopment at this site includes a parking structure, office and retail space, and a hotel.

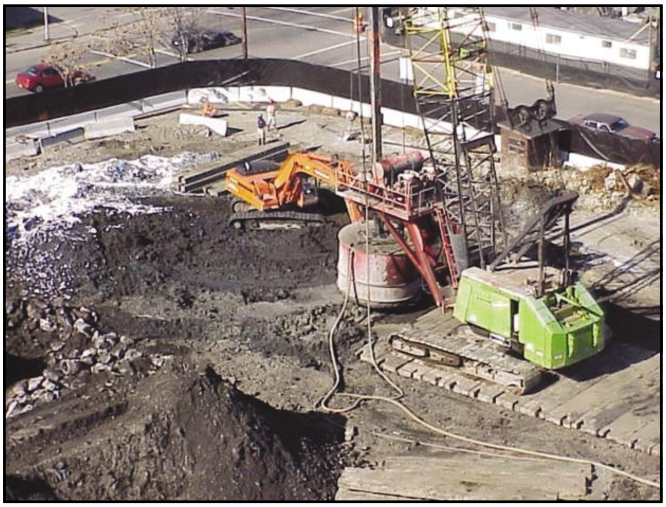

Figure 4. S/S treatment at a former MGP site in Cambridge, MA.

Former Electric Generating Station

An area in Boston, MA, which included a series of abandoned warehouses, had been used for residential, light industrial, commercial, and bus maintenance.[17] These old buildings are now being renovated for offices or torn down to construct new residences and revitalize the 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 of the remediation was to integrate the remediation into the

Figure 5. Ex situ S/S treatment of lead- and arsenic-contaminated soils in Boston, MA.

Figure 6. S/S treatment of harbor dredge in Newark, NJ.

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 2140 m^3 of material was excavated at the site. Rather than disposing of the contaminated material off-site, the material was treated and reused at the site (see Figure 5). Off-site transportation and disposal would have cost the property owner an additional $500,000 above and beyond the estimated treatment costs. Additional savings of $30,000 were realized through the reuse of the material as pavement base for a planned parking lot on the property. As a result of the S/S treatment, petroleum and lead in the soil were successfully treated and contained at the site.

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, NJ. 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 sediments have undergone cement-based S/S treatment. This treatment immobilizes heavy metals, dioxins, PCBs, and other organic contaminants in the sediment.

The treatment changes the sediment from an environmental liability into a valuable structural fill. Dredged sediment was transported by barge to a pier. At the pier, cement was mixed into the sediment while it remained in the barge (see Figure 6). The mixing method used an excavator-mounted mixing head. The treated material was removed from the barge and used as structural fill. This structural fill has already been used at two properties: an old municipal landfill in Port Newark, NJ, and the location of a coal gasification facility (later a wood preservation facility), called the Seaboard site. Treated sediment was used as structural fill to cover approximately 8 ha of the Newark landfill. Covering the landfill with competent structural fill allowed redevelopment of

Figure 7. Brownfield redevelopment at Jersey Gardens Mall, NJ.

the landfill property into a shopping mall (see Figure 7). The 65-ha Seaboard site has been designated for brownfield redevelopment. More than 1.1 million m^3 of treated sediments already covers this site.

Beginning in May 2001, approximately 2.3 million m^3 of New York- and Newark-dredged sediment was processed into structural fill. A large-scale stationary pugmill was used to mix Portland cement into the sediment at a cement addition rate of 8%. This structural fill was used to cap a property and develop a golf course in Bayonne. Ocean disposal of some New York harbor dredge sediment continues to be banned. Treatment by S/S to create fill material for reuse in upland locations is expected to be a viable option for millions of cubic meters of dredged material in the future.

CONCLUSION

As the examples above demonstrate, solidification/stabilization 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 S/S technology in remediation. In addition to protecting human health and the environment by immobilizing contaminants within the treated material, S/S-treated soils have improved construction characteristics, allowing the soil to be reused at the redevelopment site. Given its advantages, S/S treatment can be expected to continue being a valuable tool in waste management, remediation, and brownfield redevelopment.

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