

Solidification/Stabilization Treatment and Examples of Use at Port Facilities

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Abstract

Solidification/stabilization (S/S) treatment is used to treat hazardous wastes for disposal and in the remediation/site restoration of contaminated land. S/S is also an increasingly popular technology for brownfields (industrial property) redevelopment, since treated wastes can often be left on-site and to improve the soil for subsequent construction. This article discusses the applicability of the technology to various wastes, basic cement chemistry relating to S/S, tests used to design treatability studies and to verify treatment, basics on implementation of the technology in the field, and two examples of S/S: one allowing the redevelopment of port-side property, another allowing the reuse of dredged material.

Introduction

Solidification/stabilization (S/S) is a widely used treatment for the management/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 1970's. ^[Conner 1990] S/S continues as a cornerstone treatment technology for the management of radioactive waste, hazardous waste, and site remediation and Brownfield redevelopment.

The U.S. Environmental Protection Agency (EPA) considers S/S an established treatment technology. S/S is a key treatment technology for 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 by the EPA 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 Best Demonstrated Available Technology (BDAT) for 57 RCRA-listed hazardous wastes.^[USEPA June 1993] 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. With the hazardous characteristic addressed the treated waste can be disposed at a lower cost or re-used.

S/S treatment is used to treat contaminated media during 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. This is known as RCRA Corrective Action 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 an endangerment to human health and the environment. The remediation program conducted under CERCLA is funded by a tax collected from petroleum and chemical manufacturers and by potentially responsible parties that caused the contamination, commonly called the “Superfund” program. S/S is the most frequently selected treatment technology for controlling the sources of environmental contamination at Superfund program remediation sites. Twenty-five percent of selected remedies for these sites include the use of S/S (see Figure 1).^[USEPA 2001]

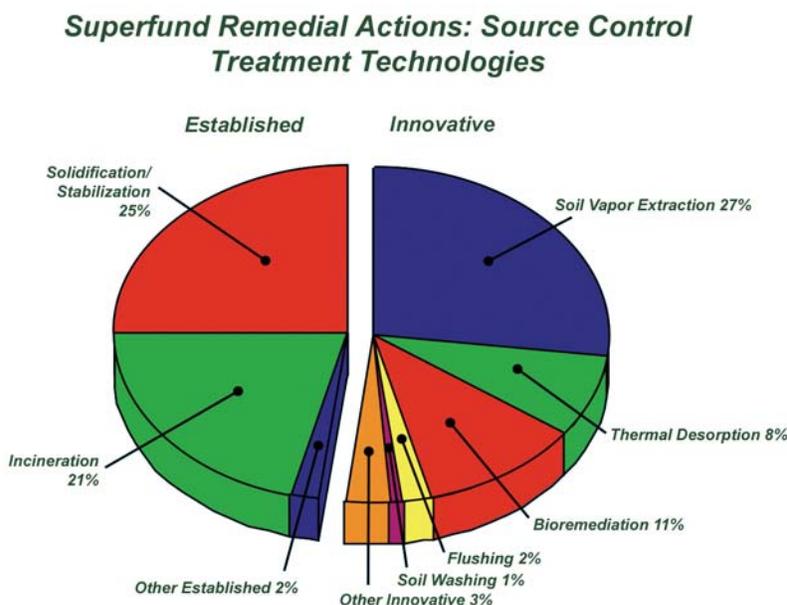


Figure 1. Frequency of S/S treatment use compared to other technologies at U.S. Superfund sites where sources of contamination have been addressed.

A more recent development in U.S. remediation programs is the advent of “brownfields” initiatives. Brownfields sites are typically previously used industrial or urban properties that have not been re-used because of environmental contamination and the liabilities that attach to the properties because of the contamination. Some port authorities, owners of industrial and manufacturing companies, office buildings, and residential units preferred to develop their buildings on farmland or “greenfields” rather than assume the environmental liabilities associated with “brownfields.” New initiatives in U.S. liability law and funding encourage the remediation and re-use of brownfields sites. The benefits to society are great including reduction of urban sprawl and preservation of fertile farmland. S/S is increasingly being used to address contaminated brownfields sites. Developers have quickly realized that S/S treatment can not only successfully address contamination at a brownfields site, but can also allow the treated material to be re-used at the site, resulting in significant cost savings.

S/S is an effective treatment wide variety of organic and inorganic contaminants present in contaminated soil, sludge and sediment. The ability to effectively treat a wide variety of 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 (in place) or ex-situ as already segregated waste or excavated material.

The effectiveness and extensive use of S/S treatment for industrial hazardous waste and in 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

S/S treatment involves mixing a binding reagent into the contaminated media or waste. 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. 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.^[Weitzman 1989]

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 the popular S/S treatments and have been applied to a greater variety of wastes than any other S/S binding reagent.^[Conner 1990] 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.^[Conner 1997] Fly ash is often used to capitalize on the pozzolanic^[ASTM 1998] effect of this material when mixed with hydrating portland cement. 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 utilizing 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 policy requires that free liquids be chemically bound.^[USEPA 1989] 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.^[USEPA 1989] 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 non-hazardous waste. Many RCRA listed wastes require treatment to the maximum extent practical to reduce their potential hazards when the wastes are 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.^[Adaska 1998, Bhatti 1999, & Wilk 1997] S/S treatment can also reduce the toxicity of some heavy metals by changes in valence state.^[Conner 1990 & Conner 1997]

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 the binding of free water in a waste into cement hydration products, creation of 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 wide variety of hazardous constituents, including halogenated and nonhalogenated semivolatiles and nonvolatiles, metals, 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 affect the setting time of cement and should be carefully evaluated. Additives and field techniques can often moderate these undesirable effects.

Caution should be taken when using binding reagents that produce significant amount of heat quickly; such as quicklime when mixed with water. This hydration reaction is very exothermic. This fast evolution of the heat can pose challenges in the S/S treatment of materials contaminated with volatile organic compounds (VOCs) and specific other compounds such as polychlorinated biphenyls (PCBs).^[Einhaus 1991] 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* 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 the Toxicity Characteristic Leaching Procedure (TCLP) and the unconfined compressive strength test. Furthermore, these tests are applicable by regulation or policy only in certain 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 ($<1 \times 10^{-5}$ cm/sec), and unconfined compressive strength (0.34 MPa (>50 psi)).^[USEPA 1989 & Dept. of Army 1995]

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 waste co-disposed organic waste such as in a municipal landfill. Many S/S-treated wastes are disposed in monofills or treated and left on site. 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

The examples below describe the use of S/S treatment on brownfield sites at port facilities. In both cases the treated material was beneficially re-used.. Reuse of treated material saved developers significant cost while providing for site redevelopment that is protective of human health and the environment.

Former Wood Treating Facility, Port Newark, New Jersey 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.^[Defisio 2001 & Wilk 2002] (Figure 2). Approximately 3.2 ha (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 m³ (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 lifts, and (3) S/S treatment of each lift with an in situ blender head (Figures 2-5). Performance standards set for the treatment of the soil included attaining a minimum of 0.17 MPa (25 psi) unconfined compressive strength. All S/S-treated soils had unconfined compressive strengths higher than 0.17 MPa. Another 20,000 m³ (26,000 cu yd) of contaminated soil was treated ex-situ using a pugmill to mix portland cement into contaminated soil. Contaminated soil mixed with the pugmill were placed on top of the in-situ treated soils 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 unconfined compressive 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 a shipping container storage area.



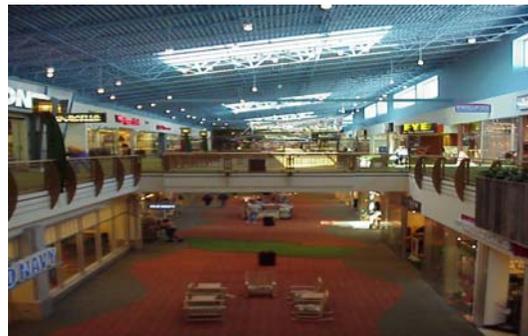
Figure 2 (top left): In-Situ blender at former wood treating facility.
Figure 3 (top right): In-Situ blender head. Figure 4 (lower left): In-Situ blender head mixing cement into soil. Figure 5 (lower right): Typical container storage area at Port Newark, NJ.

Re-Use of New York Harbor Sediments 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 not dredge channels and berths and 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.^[Loest 1998] 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 (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. The first property is an old municipal landfill in Port Newark, NJ. The treated sediment was used as structural fill to cover about 8 ha (20 acres) of the landfill. Covering the landfill with competent structural fill allowed redevelopment of the landfill property into a shopping mall (Figure 7). The second property called the Seaboard site, was the location of a coal gasification facility and later a wood preservation facility. This 65-ha (160-acre) property has been designated for brownfields redevelopment. More than 1.1 million m³ (1.5 million cu yd) of treated sediments already covers this site.

Currently, New York and Newark dredged sediment is processed through a large-scale stationary pugmill in Bayonne, NJ. Approximately 2,300,000 m³ (3,000,000 cu yd) will be treated and re-used as structural fill to create a golf course. This S/S treatment uses portland cement as the binding reagent added at a rate of 8% per wet weight of the dredged sediment. Additional properties owned by the land developer hold capacity for another 2,300,000 m³ (3,000,000 cu yd) of S/S treated sediment when the dredged material becomes available. Due to a ban on ocean disposal of some NY harbor dredge material, cement-based treatment of the dredge producing an engineered fill continues to be considered for other properties near the harbor area.



Figures 6 & 7 (across top): Photographs of New York harbor dredged sediment undergoing S/S treatment. Figure 8 (lower left): Compaction of treated material onto municipal landfill.

Figure 9 (lower right): Interior view of Jersey Gardens Shopping Mall built on landfill.

Conclusion

S/S treatment continues to enjoy significant use in the United States to treat industrial waste and contaminated media at remediation sites. EPA considers S/S to be an established treatment technology and has used the technology at 25% 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. S/S treatment protects human health and the environment by safely immobilizing contaminants within the treated material. S/S treatment is a useful technology for port facilities and nearby Brownfields sites S/S treated soils have improved construction characteristics allowing the soil to be reused at the redevelopment site. 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 waste management, remediation, and port redevelopment.

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