Journal of Hazardous Materials, 14 (1987) 5—21
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

A REVIEW OF SOLIDIFICATION/STABILIZATION TECHNOLOGY

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(Received February 27, 1986; accepted July 18, 1986)

Summary

In hazardous waste management, solidification/stabilization (S/S) is a term normally used to designate a technology employing additives to alter hazardous waste to make it non-hazardous or acceptable for current land disposal requirements. The use of this technology to treat hazardous waste may become more important as regulations restrict the use of land for disposing of hazardous waste. This paper reviews the technology and provides information to help assess its potential role in managing hazardous waste. Information is provided to assist the proper selection, use and evaluation of S/S technologies. Regulatory factors affecting its use are also discussed.

Introduction

Disposal to the land has been the major technology used to manage the country's waste materials. Favorable economics, regulations and convenience are major factors which enhance the use of land disposal. However, the Resource Conservation and Recovery Act (RCRA) and the more recent Hazardous and Solid Waste Amendments (HSWA) have provided incentives and controls to reduce the use of land for managing hazardous waste. Regulations require minimum technology standards for designing and operating hazardous waste land disposal facilities. These standards are more strict than earlier ones and therefore increase the costs. The regulations ban the disposal of free liquids into landfills and are also banning selected wastes from land disposal. These factors are favoring the use of technologies other than land disposal for waste managament.

Many technologies being considered for treating hazardous waste may produce residues still requiring management. In many cases, land disposal will be the only option available for these residues, which may be concentrated with toxic contaminants. In addition, waste banned from land disposal must be manageable by an alternative technology. If not, land disposal may still be the only option available. Pretreatment of banned waste may also help make it more acceptable for land disposal.

Solidification/stabilization (S/S) is being considered as a technology available for treating selected banned waste prior to landfilling. It is also being considered for treating residues from other treatment technologies. S/S tech-

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nology has been used for approximately 20 years to manage industrial waste. S/S employs selected materials (e.g., Portland cement, fly ash, lime, etc.) to alter the physical and chemical characteristics of the waste stream prior to disposal in the land.

Technical and regulatory factors ultimately will determine how useful S/S will be in managing hazardous waste. Proper selection, use, and evaluation of the technology will depend upon information available and the knowledge of users, regulators and others involved. The purpose of this paper is to review the technology, provide information to assess its effectiveness to manage hazardous waste and discuss regulatory factors affecting its use.

Definition/terminology for solidification/stabilization

Terminology used to define solidification/stabilization (S/S) for managing hazardous waste varies depending upon the source. Definitions are presented in a key EPA document published in 1982 [1]. This document refers to solidification and stabilization as treatment processes designed to either improve waste handling and physical characteristics, decrease surface area across which pollutants can transfer or leach, or limit the solubility or to detoxify the hazardous constituents. The document further states that solidification implies that these results are obtained primarily by production of a monolithic block of treated waste with high structural integrity. Stabilization is referred to as processes which limit the solubility of detoxify the contaminant even though the physical characteristics may or may not be improved or changed. The term "fixation" was used to mean either solidification or stabilization. Surface encapsulation is defined as a technique to isolate the waste by placing a jacket or membrane of impermeable material between the waste and the environment.

It is important to be sure that one understands what is meant when discussing the technology. The following definitions are being used in this paper:

Solidification. A process in which materials are added to the waste to produce a solid is referred to as solidification. It may or may not involve a chemical bonding between the toxic contaminant and the additive.

Stabilization. Stabilization refers to a process by which a waste is converted to a more chemically stable form. The term includes solidification, but also includes use of a chemical reaction to transform the toxic component to a new non-toxic compound or substance. Biological processes are not considered in this paper.

Chemical fixation. Chemical fixation implies the transformation of toxic contaminants to a new non-toxic form. The term has been misused to describe processes which did not involve chemical bonding of the contaminant to the binder.

Encapsulation. Encapsulation is a process involving the complete coating or enclosure of a toxic particle or waste agglomerate with a new substance, e.g., the S/S additive or binder. Microencapsulation is the encapsulation of individual particles. Macroencapsulation is the encapsulation of an agglomeration of waste particles or micro-encapsulated materials.

As with any subject, definitions often vary and misinterpretations arise because terminology may not be consistent. ASTM Committee D34 is proposing definitions for the various terms commonly used to describe the technology [2]. Regulatory actions and technical guidance by the U.S. EPA concerning S/S may also result in definitions.

Solidification/stabilization technology may also be categorized by the binder used or by the binding or containment mechanisms; or by process types.

Binders

Binder systems can be placed into two broad categories, inorganic or organic. Most inorganic binding systems in use include varying combinations of hydraulic cements, lime, pozzolanas, gypsum and silicates. Organic binders used or experimented with include epoxy, polyesters, asphalt/bitumen, polyolefins (primarily polyethylene and polyethylene—polybutadiene), and urea—formaldehyde. Combinations of inorganic and organic binder systems have been used. These include diatomaceous earth with cement and polystyrene; polyurethane and cement, and polymer gels with silicate and lime cement [3].

Knowledge of the binders being used for waste solidification/stabilization can be important in assessing and therefore selecting the technology. It provides insights into processing requirements, waste pretreatment requirements, waste—binder interactions, and expected product performance.

Binding mechanisms

Another categorization scheme often used separates systems based on waste containment or the binding mechanism. These mechanisms include:

Sorption. Sorption involves adding a solid to take up any free liquid in a waste. Examples are activated carbon, anhydrous sodium silicate, gypsum, clays, and similar particulate materials. Most sorption processes merely remove the liquid onto the surface of the solid (similar to a sponge soaking up water), and do not reduce contaminant leaching potential.

Lime—fly ash pozzolana reactions. This process uses a fine, noncrystalline silica in fly ash and the calcium in lime to produce low-strength cementation. Physical trapping of the contaminant in the cured pozzolana concrete matrix is the primary containment mechanism. Water is removed in hydrating the lime—pozzolana concrete.

Pozzolana—Portland cement reactions. In this process Portland cement and fly ash or other pozzolanas are combined to produce a relatively high strength waste/concrete matrix. Waste containment is primarily by entrapment of waste particles. Soluble silicates may be added to aid processing and to assist in metal containment through the formation of silicate gels. Water is removed in the hydration of the Portland cement. In variations of this technology, gypsum or aluminous cement may be used with or instead of Portland cement.

Thermoplastic microencapsulation. This process blends waste particulates with melted asphalt or similar materials. Physical entrapment is the primary containment mechanism for both liquids and solids.

Macroencapsulation. This process isolates a large volume of waste by jacketing with any acceptable material. A 55-gal (208-l) drum is a simple example. More sophisticated and superior performing macroencapsulation processes employing polyethylenes and similar resins in the containment vessel have been investigated.

Other S/S technologies have been proposed or investigated but are experimental, expensive, difficult to implement, or not widely used. An example would include vitrification (fusing a waste to a vitreous mass).

An understanding of the binder system being used and the basic containment process involved provides an opportunity to evaluate the potential for successfully employing S/S technology to manage a waste. Other factors such as waste character and regulatory requirements are important.

Process types

There are several S/S processing schemes available for consideration. These include:

In drum processing. In this process, the S/S binders are added to the waste contained in a drum or other container. After mixing and setting, the waste—binder matrix is normally disposed of in the drum.

In plant processing. In plant processing refers to a plant and/or process specifically designed for solidification/stabilization of bulk waste material. This may be a process conducted within a plant to manage the waste from an internal industrial operation or may be a plant specifically designed and operated to solidify/stabilize waste from external sources.

Mobile plant processing. Mobile plant processing refers to S/S processes and equipment which either are mobile or can be easily transported from, and set-up site to site.

In-situ processing. The addition of binders directly to a lagoon or the injection of solidifying or stabilizing materials to the soil subsurface, etc., to promote the solidification/stabilization of the contaminated sludge and/or soil are referred to as in-situ processing.

Objectives of S/S technology

The broad objective of S/S technology is to contain a waste and prevent it from entering the environment. In practice this broad objective may be realized by several mechanisms which lead to factors important in assessing S/S technology. These are:

- produce a solid,

- improve handling characteristics of the waste,
- decrease the surface area across which the transport of the contaminant may occur, and
- limit the solubility of the contaminant when exposed to leaching fluids.

Idealistically, the objective is to completely transform the potentially toxic contaminant into a non-toxic form. This objective implies chemical transformation and formation of new compounds. Realistically, chemical changes do not routinely occur with available state-of-the-art S/S technologies. Chemical concepts have, however, been proposed which could improve the potential for meeting the ideal objective. These concepts include passivation or armoring reactions, elemental substitution or diadochy, chemisorption and production of new insoluble compounds. Passivation is the chemical coating of a substance with a rind that prevents further chemical attack. Diadochy is a process that removes elements from the environment by substitution during precipitation of commonly occurring compounds. Different ions have the ability to occupy the same lattice position in a crystal structure. Therefore, elements with similar sizes and charges can substitute for one another in common crystal lattices. Toxic elements can be substituted in stable crystal systems that can prevent release of the element to the environment [4].

Research has explored the use of chemisorbents to help reduce leaching rates of some contaminants when solidified. The concept is to provide an agent which will promote the adsorption of the contaminant to the selected solid phase. Under this system, the sorbent with the adsorbed contaminant can be incorporated into a cemented matrix rather than being entrapped as a liquid in voids in the cemented matrix. Materials such as ion exchange resins, clay and zeolites would be classed as chemisorbents. Chemisorption allows the use of coupling compounds to help contain toxic waste compounds such as oils which are not readily stabilized under normal conditions. The concept is to add an agent to the binder which will chemically react with the binder but which also has available sites for reacting with the waste contaminant [5, 6]. Production of new insoluble compounds involves the solution and reprecipitation of waste in forms that are more stable. Soluble compounds such as chlorides or nitrates can be converted to sulfides or hydroxides.

Advantages and disadvantages

Advantages and disadvantages of S/S will vary with the process, the binders, the waste, site conditions and other unique factors. As an example, processes using pozzolana cementation type reactions are relatively low in cost and easy to use. However, these processes will increase the total volume of end material which must be managed. In many cases, the volume increases can be significant (even double). In the case of encapsulation with polymeric materials, volume increase can be very small and in some cases product performance significantly increased, but sometimes at an increased cost in dollars and difficulty of processing. Specific conditions must be carefully considered when comparing the advantages and disadvantages of S/S processes.

Evaluating S/S

At present there are no established standards and protocols for testing and predicting performance of non-radioactive hazardous waste S/S products. Tests described in RCRA regulations — the Extraction Procedure (EP) and a modification of the EP, the Multiple Extraction Procedure (MEP) — are classification tests (e.g., tests that are used to classify the waste as to whether or not it is hazardous) [7]. However, the EP is used to support waste delisting decisions. In the case of S/S products the MEP can also be used to determine delisting potential of a waste that has been solidified/stabilized. If the S/S product does not pass the MEP it is still considered a hazardous waste and must be managed accordingly.

There are objections to using the MEP for evaluating S/S products. There are claims that the test is too severe because it requires grinding the sample. Grinding increases the surface area susceptible to leaching, thereby counteracting one of the original objectives of S/S. Critics claim that the normal state of most S/S products is in a monolithic form rather than a fine powder form. Others claim that the MEP may pass an unsuitable S/S product because the relatively higher pH of most solidification agents and the limited amount of acid used in the MEP. The EP and MEP are currently undergoing modification to better fit regulatory needs. A new procedure, the Toxicity Characteristics Leaching Procedure (TCLP), is designed to accommodate solidified/stabilized wastes containing organics [8]. The TCLP can require leaching be done at a lower pH than in the EP and MEP depending upon specific conditions encountered during the test. Without care in formulating and processing to achieve better performing products, solidified/stabilized waste materials have a more difficult time meeting leaching requirements for delisting.

Most tests used to test the physical properties of solidified products involve standard concrete testing procedures such as confined and unconfined compressive strength tests, wet—dry, freeze—thaw durability test and similar procedures to help determine structural integrity and durability. These procedures and modifications would appear to be applicable to testing solidified waste products; however, at this time regulatory product performance and acceptance criteria for physical properties have not been established. Therefore, it is difficult to estimate expected product performance from testing results although comparisons among different processes and binders are possible. Ongoing research programs are attempting to develop and evaluate protocols for more definitive testing of S/S processes and products.

A new research project entitled "Investigation of Test Methods for Solidified Waste Characterization — A Cooperative Program" is being conducted by Environment Canada, with assistance from the U.S. Environmental Protection Agency [9]. The project involves the solidification/stabilization of five different waste streams by vendors and the subsequent evaluation and testing of the solidified/stabilized products. Mechanical and chemical tests included in the test program are:

- bulk density,
- unconfined compressive strength,
- water content,
- solids specific gravity,
- equilibrium leach test,
- acid neutralization capacity,
- sequential chemical extraction,
- U.S. EPA toxicity characteristics leaching procedure,
- dynamic leach test,
- freeze/thaw weathering test,
- wet/dry weathering test, and
- falling-head permeability test (triaxial cell).

In addition to the joint Canadian—U.S. EPA Project, research at Louisiana State University (LSU) is investigating the mechanism of waste incorporation in the binder matrix. Using microscopy techniques, some preliminary correlations have been observed between the results of microscopy examination and data obtained from mechanical testing [10]. The potential exists for developing tests useful in predicting field performance. In another project, data are being compiled on the use of simple equipment like a cone penetrometer on solidified waste samples at varying curing stages to determine if correlations exist that allow prediction of the ultimate strength. If correlations do exist, the cone penetrometer may offer an easy and quick quality-control test for S/S wastes.

Research is being conducted on the effects of interfering agents and the concentrations at which the effects become detrimental to solidified/stabilized waste product performance [10, 11]. In this project a synthetic waste sludge with known characteristics in solidified/stabilized by either lime—fly ash, cement—fly ash, or gypsum S/S processes. The processes are generalized versions of proprietary processes. The mixes are spiked with known quantities of interfering agents and mechanical and chemical (leach) testing is used to assess performance.

In order to help correlate data and to make results more meaningful among the research projects, the synthetic sludge is also one of the waste sludges being used in the Canadian—U.S. EPA test project. The LSU investigators are also performing microscopy analysis of samples from the other S/S projects.

The U.S. Nuclear Regulatory Commission (NRC) has developed a position on characteristics which solidified waste must have to be acceptable. Because the NRC waste is somewhat unique (i.e., low level radioactive), and requirements differ, the standard may not be entirely applicable to non-radioactive hazardous waste. This is particularly true of the required biological testing. Even so, the NRC standard which S/S products must meet provides a basis to which processors can work. Such criterion is needed for the non-radioactive S/S hazardous waste. Results from the research projects and data from other sources will aid the development of meaningful criteria.

Factors affecting selection and performance of S/S technologies

Factors which will affect the selection, design, implementation and performance of S/S processes and products are:

- waste characteristics (chemical and physical),
- process type and processing requirements,
- S/S product management objective,
- regulatory requirements, and
- economics.

These and other site specific factors (i.e., location condition, climate, hydrogeology, etc.) must be carefully considered to assure acceptable performance.

Waste characteristics

Waste characteristics are among the most important factors affecting waste solidification/stabilization. Small amounts of some compounds can seriously reduce the strength and containment characteristics of binder/waste mixes used in S/S technologies. Data are available which document the effects of impurities on strength, durability, and permeability of Portland cement and asphalt mixtures [11—13]. Cement (and asphalt to lesser degree) plays a major role in waste S/S technologies; therefore these same effects can be expected. Some waste compounds act as accelerators or retarders and can cause poor performance in S/S products when present in the mix in even minor quantities.

Research conducted in 1978 and 1979 showed that selected organics affect the unconfined compressive strengths and leaching characteristics of fly ash—lime S/S formulation [13, 14]. Adypic acid adversely affected the unconfined compressive strengths. Methanol retarded the setting time of the formulations. Benzene and xylene also acted as retarders but to a lesser extent. Methanol, xylene and benzene increased the concentrations of toxic constituents in leachate from the solidified/stabilized samples.

Investigators have concluded that a significant correlation exists between the effects of organic compounds on lime/fly ash pozzolanic systems and reported effects on the hydration of Portland cement [13]. Therefore, the large amount of information concerning additives and interferances in using Portland cement should also be applicable to S/S systems using pozzolanic reactions. Some organic or inorganic waste containing organics appear to be acceptable for solidification/stabilization using pozzolanas. Wastes such as rolling mill sludges, electroplating residue or oily sludges from petroleum

TABLE 1

Effects of selected chemicals on cement-based/pozzolanic processes [15]

Materials with waste effects	Important functions							
	Flocculant	Dispersant	Wetting agent	Chelating agent	Matrix disruptor	Retarder	Accelerator	Destroys reaction
Carboxylic acids		X				X		d
Carbonyls		X				X		d
Amides			X				Allows for better mixing	
Amines	X						X	d
Alcohols			X			X		d
Sulfonates		X				X		
Glucose/sugar				X		X		d
Chlorinates hydrocarbons					X	X		X
Oil								>25—30%[c]
Calcium chloride					>4%[b]		<2%[b]	>4%[c]
Iron[a]	X				X		X	
Tin					X	X		
Lead					X	X		
Borates					X	X		d
Magnesium	X				X	X		
Gypsum-hydrate						X		
Gypsum-anhydrate							X	d
Silica	X					X[c]		

[a]Ratio of Fe^{2+} to Fe^{3+} important.
[b]Only in certain forms.
[c]By weight.
[d]At high concentrations.

TABLE 2

Vendors identification of factors important in the solidification/stabilization of hazardous waste [15]

Company	Waste type	Important parameters			
	(liquid, solid, sludge)	Reaction mechanism	Critical factors	Organics	Accelerators/retarders
A	All	Cement with silicaceous material	pH, alkalinity — saturated solids content; particle surface area; viscosity	Chelators — negative, non-polar oils treatable up to 20%	Gels — retard
B	All	Cement with silicaceous material	Colloidal gel formation; pH alkalinity; particle size; valence state	N/A	Gels — retard
C	All	Cement with silicaceous material	Like to work at 40% solids — or pumpable; particle size; colloidal gel ⩽ 540 mesh; free water; alkalinity — 20—40% as $CaCO_3$	BOD: 3000—4000 ppm, Organic N: 5000 ppm, TOC: 30,000 ppm — all treatable	N/A
D	All	Self cementing and others	Solids content 10—40% but < 20% need volume reduction; viscosity — use a slump test to measure correct mix consistency; tin, lead may be problems; pH; temperature	up to 25% oil treatable	Gels?

E	All — prefer sludge, solid	Cement and pozzolana	Particle size — smaller size and random distribution preferred; percent solids — only from economic view; mixing, colloids have effect; alkalinity seems more important than pH	N/A	Gels — must be "conditioned" (mixed, destroyed) prior to processing; add drying agent or other materials
F	All — prefer liquid, sludge	Pozzolana, lime, cement	Gypsum — helpful in making tendrils; flat particles — better product; solids content; smaller particles better; spherical particles need more reactants; avoid high speed mixing; pH	Organic coating a problem — overcome by adding more reactant	Gels work against reactions, i.e. Al, Fe; large amounts of sulfates retard set
G	All — matter of economics only	Pozzolana, cement, silicates and 4 or 5 other reactive ingredients; can use up to 30 reagents. All inorganic	Hydrophobic materials need more reagents; mixing has effect; water glass decreases set time; alkalinity; valence state	Better results with high *MW* material; solvents tend to inhibit set; too much oil retards	Sodium inhibits set — overcome by more reagents; chrome appears to be accelerator
H	All — except no biological waste	Cement and silicate	Particle size, shape, and wettability; alkalinity; temperature limited, evaporation a problem; use mixing/vibration technique	Must disperse oil, if present	Silicates and sulfates — accelerators; glucose and borates — retarders (borate can be treated w/sodium metasilicate); gels — difficult to treat, attempt to treat by forming emulsion

refineries have been successfully treated. However, organic wastes containing hydroxyl or carboxylic acid functional groups, such as biological wastes, paint sludges and some solvents, can be expected to delay or completely inhibit the pozzolanic or Portland cement-based reactions responsible for solidification [12].

Table 1 lists selected chemicals that exert adverse effects on Portland- and pozzolana-based S/S processes. In addition to the chemical effect temperature and humidity conditions during setting are important. Temperatures below 0°C (32°F) will cause retardation of set while those over 30°C (86°F) will accelerate setting. Temperatures over 66°C (151°F) may completely destroy the reactions. High humidity can also accelerate setting. Extensive mixing, especially after the gel formation phase may destroy the solids and result in an extremely low strength product.

The waste treatment industry can be a potentially important source of information to better understand and judge the capability to handle waste. While it is difficult to accurately ascertain the amount of research the industry has conducted, their experiences can be valuable. A recently completed study compiled comments on factors important in S/S from selected vendors and others knowledgeable of solidification/stabilization processes [15]. Table 2 is a summary of results.

Inorganics generally are easier to successfully solidify/stabilize than organics with currently available S/S technology (Tables 2 and 3). In addition, it may also be easier to pretreat the waste stream to accommodate hard to handle inorganics. In most cases organic wastes apparently do not enter into the chemical reactions to form new organic—inorganic compounds or complexes which can bind organic contaminants. Organics are probably held by physical entrapment in available pores, although research is indicating that in selected cases, the organics may be present in cement gel phases [16, 17].

Physical characteristics are also important in S/S products. Particle size and shape in the waste and of the hardened binder can play an important role in the performance of treatment processes in the field. Viscosity of mixes can change with particle size and shape and affect water available for reactions. Proper water/binder ratios are important in producing mixes which will yield acceptable strength. Overmixing or undermixing can adversely affect the strength of the final product or even prevent an initial set. The more information available concerning waste and binder characteristics as they relate to proper formulations, the better the opportunity to assure acceptable S/S products.

Retardation of set may or may not be a detrimental condition. In some cases the set is retarded to the point that unacceptable strength or contaminant containment is reached. This will result in an inferior product that will not perform satisfactorily. However, if retardation of the set is merely a delay in the time to reach an acceptable strength, then it is not a significant problem. In this situation, economics and the processing schedule become controlling factors.

TABLE 3

Compatibility of selected waste categories with waste solidification/stabilization techniques [1]

Waste component	S/S treatment type			
	Cement-based	Lime-based	Thermoplastic solidification	Organic polymer (UF)[a]
Organics				
Organic solvents and oils	Many impede setting, may escape as vapor	Many impede setting, may escape as vapor	Organics may vaporize on heating	May retard set of polymers
Solid organics (e.g., plastics, resins, tars)	Good — often increases durability	Good — often increases durability	Possible use as binding agent	May retard set of polymers
Inorganics				
Acid wastes	Cement will neutralize acids	Compatible	Can be neutralized before incorporation	Compatible
Oxidizers	Compatible	Compatible	May cause matrix breakdown, fire	May cause matrix breakdown
Sulfates	May retard setting and cause spalling unless special cement is used	Compatible	May dehydrate and rehydrate causing splitting	Compatible
Halides	Easily leached from cement, may retard setting	May retard set, most are easily leached	May dehydrate	Compatible
Heavy metals	Compatible	Compatible	Compatible	Acid pH solubilize metal hydroxides
Radioactive materials	Compatible	Compatible	Compatible	Compatible

[a]Urea—Formaldehyde resin.

Note: "Compatible" indicates that the S/S process can generally be successfully applied to the indicated waste component. Exceptions to this may arise dependant upon regulatory and specific situation factors.

Process type and processing requirements

The type of S/S activity required (i.e., in-drum, in-plant, etc.) and specific processing requirements (e.g., waste modification, mixing modes, S/S waste transportation, S/S waste placement, storage, etc.) are important factors to be considered in evaluating S/S technology. It is easier to control and provide proper mixing of the waste—binder matrix in a drum or in a plant process than in the in-situ solidification of a pit, pond, or lagoon. Special processing requirements such as treatment to remove interfering agents, use of thermosetting binders, etc., will also affect the evaluation and choice of S/S technology to be used.

S/S product management

The S/S binder—waste management objective (i.e., disposal in landfill, storage, transportation, etc.) will be important in the evaluation and selection of a S/S technology. Depending upon regulatory requirements, placement into a RCRA hazardous waste landfill may not require the same degree of solidification/stabilization as that for delisting. Delisting requires that the material no longer be hazardous, while placement into a RCRA hazardous waste landfill generally does not have to meet that same criteria. Other placement schemes, proposed or used, e.g., placement in drums (plastic or metal) for storage in warehouses or underground mines, in-situ injection into mined cavities, etc., will also effect evaluation and selection of a S/S system. The knowledge, understanding, and consideration of these and other factors such as economics and their interactions are important in selecting the S/S technique or system best suited for the given situation.

Regulatory

Regulatory factors can be expected to play a major role on the use of S/S technologies for managing hazardous waste. With the possible exception of the EP, MEP, or TCLP and a chemical reaction requirement*, there are no set performance criteria which S/S products must meet. For economics and related reasons (e.g., volume increases which reduce available land fill space), a processor will normally produce an S/S waste product which will meet minimum requirements necessary to remove free liquids and/or produce a solid with a structural integrity sufficient to meet their specific processing, transport, and placement requirements.

From a theoretical sense, almost any waste can be solidified and/or stabilized. Additions of large quantities of binders can overcome problems that might make a waste difficult to solidify. Most processors reject wastes that require uneconomical amounts of binder. However, the important point is that systems and processes can be altered to meet different performance

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*The Hazardous and Solid Waste Amendments of 1984 provide that a chemical reaction must take place if an absorbent is to be approved for treating a liquid prior to disposal in a landfill.

criteria. The criteria must be established before attempting to select a particular S/S technique.

Economics

The cost of solidification/stabilization has generally been considered inexpensive as compared to other treatment techniques. This resulted from the availability of rather cheap raw products (e.g., fly ash, cements, lime, etc.) used in the more popular processes, simple processing requirements, and the use of readily available equipment from the concrete and related construction industries. In addition, in earlier uses processing was often driven by a need only to produce a more manageable waste (e.g., removal of liquid) rather than produce a product to pass a more stringent regulatory requirement. The latter would most likely require more additives or more expensive processing and therefore increase cost.

It is impossible to provide accurate costs for stabilization/solidification. Final costs will be dependent upon site specific conditions. Important factors include:

Waste characteristics. The physical form and chemical make-up of the waste to be solidified/stabilized will have an important effect on the cost. If pretreatment of the waste is required to remove excess liquids or to remove and/or alter interfering constituents, costs will be increased.

Transportation. Requirements for transporting raw materials to the plant or site and transporting finished products to disposal will affect costs.

Process. The S/S process and process type selected will effect costs. Cements, fly ash, etc., are cheaper raw materials than are polyolefins, and similar materials. Processing requirements for the latter may also be more expensive. This, however, may be balanced by better performing products. Increased volume caused by the cements and fly ash type processes may also result in the need for added transportation and disposal costs. Process type (e.g., in-drum, in-plant, etc.), also affect economics.

Other factors. Special health and safety requirements will effect costs, as will any special regulatory requirements. QA/QC and associated analytical costs may be a cost factor and must be carefully considered in estimating costs. Regulatory factors will probably play an increasingly important role in the costs of solidification/stabilization. As regulations become more stringent as to what can be disposed to the land, solidification/stabilization processing and product performance requirements may also become more exacting, thus increasing costs.

Conclusions

The role that S/S technology eventually has in managing hazardous waste depends upon regulatory actions and subsequent judicial interpretation and the ability of the technology to meet performance criteria which may be developed. As restrictions on landfilling become stronger and wastes are banned from land disposal, S/S technology could potentially play an important role in making waste forms acceptable for land disposal. Lower permeability, lower contaminant leaching rates, and similar characteristics from S/S may make banned wastes acceptable for land disposal after stabilization. Depending upon the technical requirements of any developed performance criteria and/or the willingness of processors to meet them, S/S technology has the potential for making a major contribution as one of the alternatives for managing hazardous waste.

References

1 P.G. Malone, L.W. Jones and R.J. Larson, Guide to the disposal of chemically stabilized and solidified waste, SW-872, Office of Water and Waste Management, U.S. Environmental Protection Agency, Washington, DC, September 1982.

2 Committee D34, Waste Disposal (Subcommittee D34.09.01 Fixation), ASTM, 1916 Race Street, Philadelphia, PA 191103, 1986.

3 R.W. Telles, M.J. Carr, H.R. Lubowitz and S.L. Unger, Review of fixation processes to manage hazardous organic waste, unpublished report, 1984, U.S. Environmental Protection Agency, Hazardous Waste Engineering Research Laboratory, 26 West St. Clair St., Cincinnati, OH 45268, Attn: Carlton C. Wiles.

4 P.G. Malone and R.J. Larson, Scientific basis of hazardous waste immobilization, In Hazardous and Industrial Solid Waste Testing: Second Symposium, ASTM STP 805, ASTM, 1916 Race Street, Philadelphia, PA 19103, 1983.

5 T.E. Myers, N.R. Francinques, D.W. Thompson and D.O. Hill, Sorbent assisted solidification of a hazardous waste, In Proc. International Conference on New Frontiers for Hazardous Waste Management, EPA/600/9-85/025, U.S. Environmental Protection Agency, Cincinnati, OH 45268, 1985.

6 J.W. Phillips, Applying techniques for solidification and transportation of radioactive waste to hazardous waste, In Proc. National Conference on Management of Uncontrolled Hazardous Waste Sites, Hazardous Materials Research Institute, Silver Springs, MD, 1981, pp. 206—211.

7 Code of Federal Regulations, 40 CFR, Part 261, Appendix II — EP toxicity test procedure, Federal Register, 45, 98, 3317, 1980.

8 Code of Federal Regulations, 40 CFR, Part 261, 271, and 302, Hazardous waste management systems; Identification and listing of hazardous waste; Notification requirements; Proposed rule, Federal Register, 51, 114, June 13, 1986.

9 N.L. Porter-Cathcart, Investigation of test methods for solidified waste characterizations — A cooperative program, study in progress, Waste Management Division, Industrial Programs Branch — EPS, Environment Canada, Ottawa, Ontario K1A 1C8, Canada, 1986.

10 Factors affecting stabilization/solidification of hazardous waste, project in progress, U.S. Environmental Protection Agency, Hazardous Waste Engineering Research Laboratory, 26 West St. Clair St., Cincinnati, OH 45268, Attn: Carlton C. Wiles, 1986.

11 J.N. Jones, R.M. Bricka, T.E. Myers and D.E. Thompson, Factors affecting stabilization/solidification of hazardous waste, In Land Disposal of Hazardous Waste, Proc. 11th Annual EPA Research Symposium, EPA/600/9-85/013, U.S. Environmental Protection Agency, Cincinnati, OH 45268, April 1985, pp. 353—359.

12 J.N. Jones, L.W. Jones and N.R. Francinques, Interference mechanisms in waste stabilization/solidification process: Literature review, unpublished report, 1984. Hazardous Waste Engineering Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH 45268, Attn: Carlton, C. Wiles.

13 B.K. Roberts, The effect of volatile organics on strength development in lime stabilized fly ash compositions, M.S. Thesis, University of Pennsylvania, Philadelphia, PA, 1978.
14 R.L. Smith, The effect of organic compounds on pozzolanic reactions, I.U. Conversion Systems, Report No. 57, Project 145, Horsham, PA 19044.
15 JACA Corporation, Critical characteristics and properties of hazardous waste solidification/stabilization, unpublished report, Hazardous Waste Engineering Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH 45268, Attn: Carlton C. Wiles, 1985.
16 D. Chalasani, F.K. Cartledge, H.C. Eaton, M.E. Tittlebaum and M.B. Walsh, The affects of ethyleneglycol on a cement based solidification process, Hazardous Waste and Hazardous Materials, 3(2) (1986) 169—173.
17 M.B. Walsh, H.C. Eaton, M.E. Tittelbaum, F.C. Cartledge and D. Chalasani, The effect of two organic compounds on a Portland cement based stabilization matrix, Hazardous Waste and Hazardous Materials, 3(1) (1986) 111—123.