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SULFUR POLYMER CEMENT, A NEW STABILIZATION AGENT FOR MIXED AND LOW-LEVEL RADIOACTIVE WASTE[a]

G. Ross Darnell

Idaho National Engineering Laboratory
National Low-Level Waste Management Program
EG&G Idaho, Inc.
P.O.Box 1625
Idaho Falls, ID 83415
United States of America

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ABSTRACT

Solidification and stabilization agents for radioactive, hazardous, and mixed wastes are failing to pass governmental tests at alarming rates. The Department of Energy's National Low-Level Waste Management Program funded testin of Sulfur Polymer Cement (SPC) by Brookhaven National Laboratory during the 1980s. Those tests and tests by the U.S. Bureau of Mines (the original developer of SPC), universities, states, and the concrete industry have shown SPC to be superior to hydraulic cements in most cases. Superior in what wastes can be successfully combined and in the quantity of waste that can be combined and still pass the tests established by the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission.

Acronyms and Terms

Since the early 1900s, the generic terms "sulfur cement" and "sulfur concrete" have appeared in hundreds of technical papers and reports published on elemental sulfur and sulfur with various experimental additives. Authors of both the early and modern reports have often used those terms to describe totally different substances, which is confusing at best. The documents used in developing this paper generally used the acronyms "SPC" to mean sulfur polymer cement, and "SC" to mean sulfur polymer cement concrete; for continuity, we have continued that practice here. It is important to understand that once the aggregate/waste is added to SPC (the cement), it becomes SC (the concrete), whether either mass is liquefied or solid. Hereafter, the words "cement" and "concrete" refer to the generic family of hydraulic cements and concretes, while "PCC" refers to the specific hydraulic cement concrete known as portland cement concrete.

Progress in the Nation's Nuclear and Mixed Waste Disposal Practices

The U.S. Congress attacked the environmental problem of hazardous waste disposal by pressing for permanent solutions for waste treatment rather than continued remediation through an evolution of laws. The need for an onsite stabilization program at the site of generation was defined in several laws. Those laws were the Resource Conservation and Recovery Act (RCRA); Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); Hazardous and Solid Waste Amendments (HSWA); and Superfund Amendments Reauthorization Act (SARA).[1]

The terms "solidification" and "stabilization" are essentially synonymous in many documents; however, solidification here means conversion of a liquid to a solid--refers primarily to the process of immobilizing the waste within the concrete or SC itself, while "stabilization" means keeping the waste from interacting with its environment for specified periods of time. The government's goals are to decrease the surface-to-mass ratio, thereby reducing the potential surface area exposed to sulfates that attack the concrete; to improve the handling characteristics; to improve the physical characteristics by reducing permeability and leachability; and to further reduce solubility of hazardous components by adjusting the Ph.[1]

As will be demonstrated by citing test results, solidification and stabilization of low-level radioactive waste (LLW) and radioactively contaminated hazardous waste or mixed waste (MW), in SC is in keeping with the government position.

Introduction

Tests conducted by the U.S. Bureau of Mines, universities, and SC contractors were of commercial-grade SC in harsh chemical environments. They did not test SC with those chemicals intermixed in the SC, which must be done to validate SC as an acceptable LLW and MW solidification agent. Nevertheless, those tests offer a reasonable forecast of potential failures and successes of SC as a waste solidification and stabilization agent.

It is assumed that if commercial-grade SC withstands degradation in surrounding concentrations of those chemicals, SC ladened with radioactive and hazardous waste should survive for much longer periods of time in lesser concentrations of the same, or similar, chemicals. Since stabilization is the prime goal, all that test information is valuable. Further, SPC is a thermoplastic and solidifies solely from cooling--it does not require a chemical interaction of components to solidify like concrete does. In other words, those chemicals are trapped in SC, they are not necessarily combined chemically. Chemicals that had little or no destructive effect on construction-grade SC from the exterior are likely to have even less effect on the concrete from the interior because they will be in an anhydrous environment. (SC is impervious to water.)

It is for these reasons that results of these tests are reported. It was these same tests, conducted mostly in the 1970s, that led DOE to conduct 10 years of solidification and stabilization tests in the 1980s.

The perfect waste solidification and stabilization agent has not yet been discovered. SPC will not accommodate all wastes and the statements above are not absolute. However, tests to date show that SC will: solidify a wide range of wastes that have defied solidification in other agents; solidify most of the wastes currently being solidified with other agents; and normally accommodate a higher waste loading than other agents.

This discussion generally follows a chronological path, beginning with commercial development of SPC and SC for application in harsh chemical environs; proceeding with development and testing to Environmental Protection Agency (EPA) and United States Nuclear Regulatory Commission (NRC) requirements for disposal, and follows with safety considerations, continued testing, plans for SPC in treatment and disposal, a summary, and the conclusion.

Developing and Testing SPC and SC for Harsh Chemical Environs

Developmental Background

Pollution abatement efforts during the past 30 years produced sulfur through petroleum refining, natural gas processing, and recovery from geothermal power plants. In 1971, the U.S. Bureau of Mines and The Sulphur Institute joined forces in an effort to find useful construction purposes for the nation's increasing stockpiles of sulfur. In 1973 the Sulphur Development Institute of Canada joined the effort.[2]

Coincidentally, the construction industry has been plagued with concrete failures caused by salt and acidic attack, resulting in multiple billions of dollars in damage that must be repaired (e.g., the tens of thousands of concrete bridges in the United States that are falling apart). Industries involved in fertilizer, metallurgical, and chemical processing had to replace deteriorating concrete frequently. Those failures provided the Bureau of Mines with a potential use for sulfur.

Elemental sulfur had been recognized for its cementing properties since prehistoric times, but it lacked mechanical strength and durability and it shrank too much. All of these problems were caused by changes in the crystalline structure during cooling. Through experimentation, it was discovered that the addition of dicyclopentadiene and oligomers of cyclopentadiene in equal quantities totaling 5wt% of the sulfur phase resulted in an excellent concrete having properties not found in other concretes.[3,4]

Properties of SPC and SC

The various mechanical strengths of SC are approximately double those of PCC and are not specifically cited herein.[5] While it takes the average PCC approximately 28 days to achieve a compressive strength of 4000 psi, SC reaches that strength upon cooling, and continues to gain strength for approximately one month.[2]

SPC is nontoxic, as is SC with construction aggregate.[5, 6] SC is corrosion-resistant, and its impermeability protects steel reinforcing materials from oxidation and subsequent concrete rupture. Where strength and fracture resistance are primary goals, glass fibers, synthetic fibers, epoxy-coated rebar, steel rebar, or a combination thereof can be added.[5, 6] SC is nonreactive with steel. Where controlled shrinkage, minimization of cracks, ductility, and impact resistance are needed, glass fibers are added.[7] Shrinkage, on the average, is 0.01%, slightly greater than PCC.[5, 6] It is resistant to damage by freeze-thaw cycling, and has coefficients of expansion compatible with those of other construction materials such as concrete and reinforcing steel. Creep is roughly half that of PCC.[8, 9] Where SC and PCC are made with the same aggregate, their densities are the same, 150lb/ft^3 on the average.[2] Viscosity of SPC is approximately 50 cp at 135°C (275°F), which is only slightly less fluid than water.[2] The addition of aggregate to SPC converts it to SC, and as more aggregate is added the viscosity increases. Sulfates attack PCC, but have little or no effect on the integrity of SC.[2, 3] (See Figure 1 for concrete degradation effects.)

Impermeability (especially to water) of waste stabilization agents is crucial to environmental enhancement efforts. "Static water-permeation tests were made to compare the permeability of SC and PCC. Five-foot sections of 6-in. diameter plastic pipe were bonded to the surface of 2-in thick slabs of SC and (Type-I) PCC. A 51-in. column of water was placed in each pipe section to provide a 1.84 psi water pressure on the surface of the slabs. The SC showed no loss in water height after 6 months, while the PCC slab showed more than a 1-in./h loss of water height by permeation through the more porous PCC material. There was no penetration of water through the SC slab."[2] The explanation of these test results comes from the physical properties of the two; while they both have approximately the same volume of void space (pores), the voids in SC are not connected, whereas the voids in concrete are.[2, 7]

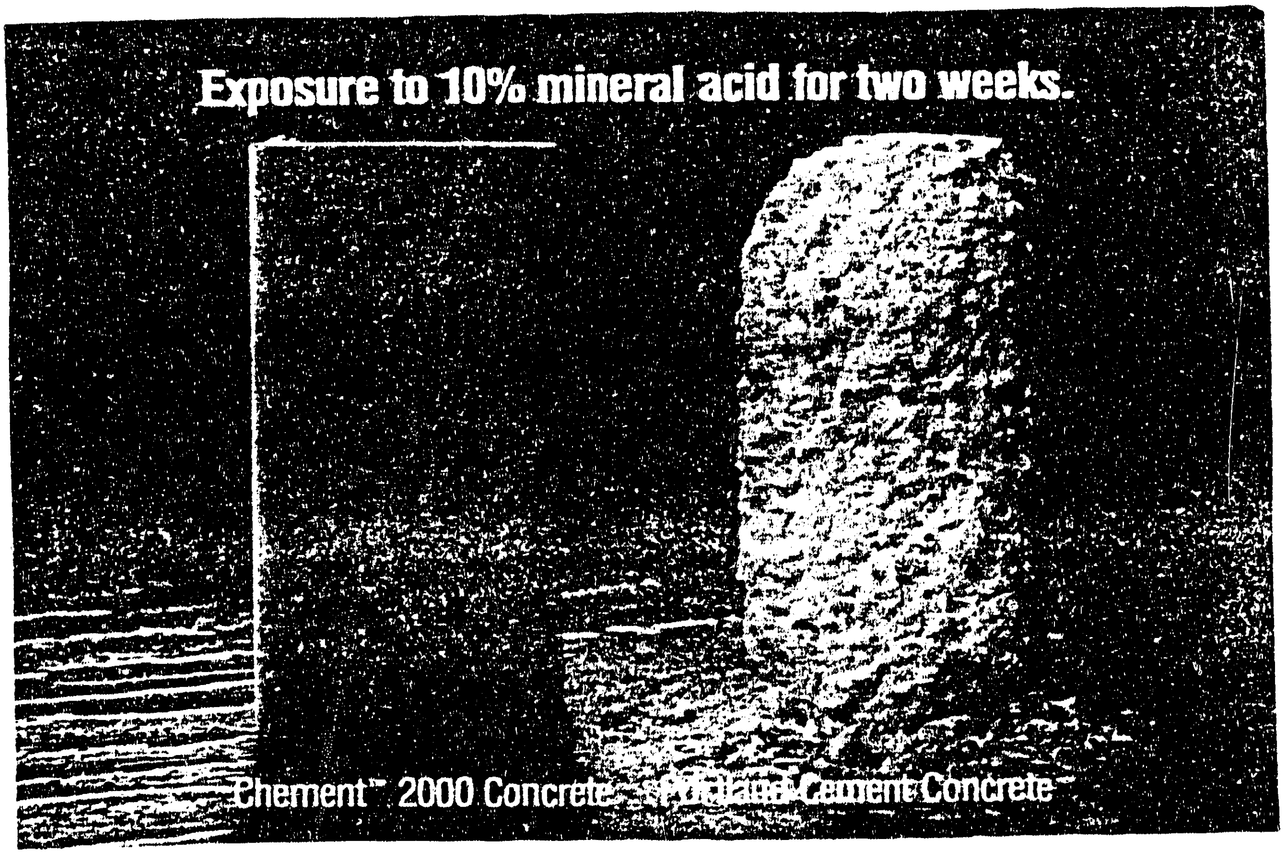

Figure 1. Sulfur Polymer Cement Concrete (Chement 2000®) and Portland Cement Concrete after two weeks of exposure to 10% mineral acid.[b]

In the early 1970s, the Bureau of Mines worked with the EPA to protect miners from radon gas. A spraying concept was developed and patented that applied a 1/4-in.-thick lining of SC on mine walls, which prevented the entrance of radon gas.[10]

The impermeability of properly prepared SC is well established. However, if the SC is cooled too quickly, it will contain an abundance of voids that will connect with each other, or if the aggregate in the SC contains water, tiny steam vents will develop, either one of which will allow both water and gas to penetrate the solidified SC.

Tests of Construction-Grade SC in Successful Applications

SC is a durable, high-strength concrete that is resistant to abrasion and attack by most acids and salts, and is best used where exposed to high concentrations of mineral acids, corrosive electrolytes, salt solutions, and corrosive atmospheres in general.[2, 5, 8] SC has high potential in chemical, metallurgical, and fertilizer applications.[3] The United States Department of Agriculture has approved SC for use as floors in meat and poultry processing plants.[5]

A sampling of reported test results illustrates SC's resistance to adverse chemical conditions. After being exposed to sulfuric acid solutions and copper electrolytic solutions for nine years, SC showed no evidence of corrosion\n or deterioration.[4] In a six-year test in a chemical processing plant, PCC was attacked and completely destroyed in some cases, while SC showed practically no evidence of strength loss or material degradation.[8] After seven years of exposure to a salt environment in a test in a potash chemical storage building, two SC structural support piers were undamaged, while the PCC pier in the same location was heavily damaged by exposure to that environment after only two and a half years.[8]

Studies of the effects of biodegradation on various concretes, including SC, are being conducted by the Universities of Hamburg[11], Vienna,[c]

c. Confirmed in conversation with Mr. Bill McBee, McBee and Associates, on August 15, 1990

and Texas.[12] Since their laboratory experiments have not been published, the lead researcher at the University of Hamburg, Germany, has issued a "Declaration,"[11] wherein he makes three convincing statements. First, "Examinations of shaft bottoms [sewer manholes constructed of SC], which have been built into a sewer for several years [5 years], indicate no possible risk due to growth of thiobacilli." Second, "I consider a direct danger to sulphur [polymer] cement and consequently sulphur concrete through attacks of thiobacilli unlikely." Third, "Cement-stabilized construction materials are disintegrated by thiobacilli, liberating sulfuric acid as a metabolic product; sulfuric acid reacts with the calcium components of the cement and transforms into gypsum." (Thiobacilli is the bacterium strain of most concern to researchers studying biodegradation of concretes.)

Tests of Construction-Grade SC in Unsuccessful Applications

In contrast, SC has been shown to deteriorate in hot concentrated chromic acid solutions, hot organic solvent solutions, sodium chlorate-hyperchlorite copper slimes, and strong alkali (over 10%). SC is not recommended in areas the binder itself often cause an interaction that can retard or prevent solidification.[14, 15]

Because SC is a thermoplastic, it requires no chemical reaction for solidification. Therefore, normal precautions in temperature control, pretreatment of the waste, and assurance that the waste is compatible, will ensure that the SC will always solidify when it cools below 119°C (246°F). Unlike PCC, SPC will accept a wide range of wastes (aggregate) with divergent chemical and physical compositions. SC is easier to use than other thermoplastics (like polyethylene) because of SPC's low viscosity and low-melt temperature.[3, 14]

Incinerators reduce organic waste volume by as much as 300 times. Therefore, the resultant fly ash contains highly concentrated remnants of the original waste. After incineration, heavy metals in the waste that originally fell short of the EPA definition of hazardous waste may well be within the hazardous zone. The curie count per unit volume is also raised, so the waste is still radioactive, is hazardous, and is classified as MW and probably will not pass EPA's TCLP test. Before this waste can be disposed of in licensed disposal facilities, it must be treated sufficiently to allow delisting.[9]

Tests Completed to EPA Standards

MW fly ash was obtained from the Waste Experimental Reduction Facility (WERF) located at the Idaho National Engineering Laboratory (INEL). The MW contained the following components (expressed in weight percentages): zinc 36, lead 7.5, sodium 5.5, potassium 2.8, calcium 0.8, copper 0.7, iron 0.5, and cadmium 0.2. Both lead (Pb) and cadmium (Cd) are listed by the EPA as toxic metals.[9] The fly ash was combined with SPC and was tested to the EPA's Extraction Procedure Toxicity (EP Tox) test,[16] and the Toxicity Characteristic Leaching Procedure (TCLP) test.[17] Both the Cd and Pb were above the concentration limits allowed for under RCRA, so additives were sought that would further reduce the mobility of the toxic metals. Sodium sulfide (Na_2S), which reacts preferentially with Cd and Pb to form highly insoluble metal sulfides, was selected. By adding 7wt% Na_2S to 50wt% SPC and mixing it with 43wt% MW fly ash, the resultant concrete passed the EPA's TCLP test, thus allowing disposal as non-RCRA waste.[14]

EPA's TCLP test requires that the grouted waste be broken into small pieces, thus exposing a huge surface area for leaching tests. Different results are expected in actual disposal, where concrete and SC waste monoliths are properly placed in disposal. Specifically, PCC allows large quantities of water to penetrate the mass when compared to SC, whether broken into small pieces or not, and will allow internal leaching rates not seen in SC monoliths.[2] Additionally, when ferrous metals are included in the waste, that same water penetration will cause earlier rupture of the concrete than of the SC.[4, 5] The end result should show greater superiority of SC over concrete as a waste stabilization agent than indicated by EPA's TCLP test.

SPC has proved effective in reducing the leach rates of reactive heavy metals to the extent that some wastes can be managed as solely LLW. When SPC is combined with mercury and lead oxides (both toxic metals), they interact chemically and form mercury sulfide (HgS) and lead sulfide (PbS), both of which are insoluble in water.[9, 18] The California State Department of Health Services used a dried residue from petroleum refining that contained 600 ppm vanadium (a handling strong bases, strong oxidizing agents, aromatic or chlorinated hydrocarbons, or oxygenated solvents.[2,7]

Ongoing Activities with Construction-Grade SC

Efforts are underway within the SPC industry to improve the consistency of SPC's quality. To that end, in 1990, the American Society for Testing and Materials (ASTM) issued the specification for SPC entitled: Standard Specification for Sulfur Polymer Cement for Use in Chemical-Resistant, Rigid Sulfur Concrete, Designation: C1159-90.

The use of SC in sewers is increasing because of its impermeability and its resistance to abrasion and biodegradation. To meet the demand, 4-K International A/S in Denmark is spending millions of dollars to double its production of SPC for the European market.[d]

d. Confirmed by Mr. William McBee, McBee and Associates, Consultant to 4-K International A/S, on May 29, 1991

That growth is based on the favorable outcome of biodegradation tests conducted by the University of Hamburg.[11] These tests show that SC greatly surpasses concrete in its ability to maintain its mass and strength in sanitation and industrial sewers.[11, 12] The Los Angeles Sanitation District is conducting its own biodegradation tests of SC sewer pipes.[e]

e. Confirmed by Mr. John Redner, Los Angeles Sanitation District, on May 22, 1991

Testing and Modifying SPC and SC for Waste Solidification and Stabilization

At the beginning of the 1980s, the Department of Energy's (DOE) National Low-Level Waste Management Program funded the Waste Management Research and Development Group at Brookhaven National Laboratory (BNL) to research, develop, and test potential LLW stabilization agents. The research was intended to meet the intentions of governmental laws by minimizing costs and radiation exposure to operators, while providing environmental enhancements that would ensure public safety.[13] That effort continues today, and DOE's Hazardous Waste Remedial Action Program (HAZWRAP) has joined the effort by providing funding.

Wastes such as sludges, ion-exchange resins, evaporator concentrate salts, incinerator hearth ash, and incinerator fly ash represent a wide spectrum of physical and chemical properties that have been placed in the difficult-or-impossible-to-encapsulate classification for standard waste solidification and stabilization agents. Their hazardous components were not being retained in the waste to the extent required by the EPA and/or NRC when subjected to the disposal environment.[9, 13] After evaluating potential agents, two thermoplastics, SPC and low-density polyethylene were selected for further development and testing against EPA and NRC testing standards.[13]. PCC was selected as the comparison standard and was tested each time SC was tested,using the same waste components. This section discusses those ef ts.

The Chemistry of Solidification

Some radioactive wastes once thought to be stabilized in concrete were not. Whether or not concrete hardens depends on the chemical hydration reaction dictated by both the chemistry and the amounts of water, cement, waste, plasticizers, and other additives. In other words, elements in the waste and carcinogen) to make SC and thereby reduce the leachable vanadium to 8.3 ppm, which was well below the soluble threshold limit concentration of 24 ppm established by the State of California.[18]

Tests Completed to NRC Standards

The NRC has established a qualifier list of tests under the title "Waste Form Qualification Testing."[19] Where possible, the tests are to the standards of the ASTM, American National Standards Institute (ANSI), and American Nuclear Society (ANS). The tests are: (a) general (guidelines that apply to the conduct of the remaining tests); (b) compression (lower limit recently raised from 60 psi to 500 psi); (c) thermal cycling (30 cycles of temperature change from -40 to 60°C); (d) irradiation (exposure to a minimum dose of 10E+8 Rad); (e) biodegradation (test susceptibility to fungi and bacteria); (f) leach testing (immersion in water for 90 days followed by leachate analysis); (g) immersion testing (check for 500 psi compressive strength following immersion in water); (h) freestanding liquids (check for lower limit of 0.5 vol% liquids); and (i) full-scale testing (pour full-scale monolith followed by tests b and g above).

After the immersion test was completed, compressive strengths of waste-impregnated SC ranged from a low of 1998 psi for 40wt% boric acid, to a high of 6435 psi for 40wt% incinerator ash, with sodium sulfate falling in between. Compressive strength tests after freeze-thaw cycling found some increase and some decrease in strength with different wastes. These were of no consequence in reference to the NRC requirement of >500 psi.[3]

When the leach tests were completed, the leach rate was found to be lower for incinerator hearth ash than for highly soluble sulfate salts. The leach rate was four to eight orders of magnitude less than the leach index established by the NRC. The conclusion was that radionuclides leach slowly in SC.[14]

Successful completion of the biodegradation test and the irradiation test using modified SPC ladened with 43wt% mixed-waste fly ash has been confirmed.[f] f. Confirmed in telecommunications with Mr. Peter Colombo, Brookhaven National Laboratory, on July 1, 1991. Precise data on the test results will be published at a later date.

Research and development resulted in a modified SPC that can now encapsulate many waste types like boric acid salts, incinerator hearth ash, MW fly ash, and sodium sulfate salts that have heretofore defied solidification and stabilization in concrete in any significant quantity. Many of the extensive efforts at testing the waste and developing a formula of cement, water, and various additives to match the waste chemistry can be eliminated. The modified SPC offers a monolithic waste form that is durable in harsh environments.[14]

Conclusion of EPA and NRC Testing

Cement cannot become hardened concrete without the addition of water, whereas SPC and SC require no additive to harden. Comparative test results show that a given quantity of waste requires considerably less SPC than portland cement and water to achieve a stabilized waste form that will satisfy EPA and NRC requirements. The following numerical advantages of SPC over PCC were calculated: 6.7 times less SPC with sodium sulfate, 3.8 times less SPC with boric acid, 1.1 times less SPC with incinerator bottom ash, and 4 times less SPC with incinerator fly ash.[14] Assuming the waste treatment operators receive equal quantities of the wastes cited, they will have 3.9 times less cement and additives to deal with if they use SPC than if they use portland cement and water. That translates to less waste volume for disposal if SPC is used.

One Test to NRC Standards Remains

The NRC's final test, the full-scale test, is required in order to give SPC/SC full credibility as a waste solidification and stabilization agent. Having completed all the lab tests, BNL and INEL plan a production-scale technology demonstration in the near term.[14] A successful test pour of SPC ladened with 43wt% industrial-incinerator fly ash was completed in a 1m x 1m x 1m wooden box containing simulated contaminated scrap metals. Tests of full-scale SPC mixers have been conducted in an effort to select one that can be used for the full-scale tests and continue afterwards as an operational mixer.[20] High on the desirability list is a mixer with a large heated surface area in the mixer blades as well as in the jacket surrounding the mixer for firm control of internal heat. Another priority is to use a weir rather than a valve to avoid flow-control problems. (Valves are prone to failure with shredded steel fragments in the mix, and the requirement for constant heating adds unnecessary complications.)[21,22]

Wastes That Cannot be Combined with SPC for Stabilization

Many common waste streams cannot be solidified in SC in their current state. The combining of sodium nitrate salts with SPC is not recommended because the two compounds, when combined, can cause a "potentially reactive mixture."[14] Another rejection is ion-exchange resins. SC is weakened dramatically by wet aggregate (waste). It was assumed that ion-exchange resins could be dried and solidified in SC. However, that effort proved futile. Unlike many other substances, ion-exchange resins will take on any available water where the resins are exposed at the surface, and will swell and gradually rupture SC.[3] Early discoveries showed that expanding clays could not be used in SC for the same reason.[2,7] Other wastes, like sludges, evaporator bottoms, absorbed liquids, biological waste, animal carcasses, and even dirt must first be treated to a dry condition before being solidified in SC.

The need for incineration or vitrification of the troublesome wet wastes before introduction to any solidification agent has long been recognized in the nuclear industry.[15] Once reduced to glass or ash, the wastes stand a good chance of passing the required NRC and EPA tests when solidified in SC. Of course, each application would have to be tested.

Wastes that Can and Cannot be Solidified in PCC

Concrete continues to be used effectively for solidification of wastes, primarily because it is highly alkaline, which is very good for "immobilized soluble toxic metals."[14] PCC does not perform to requirements when ladened with borates, chlorides, copper compounds, heavy metal salts, lead compounds, magnesium compounds, phosphates, sodium compounds, sulfates and sulfides, tin compounds, and zinc compounds.[14]

Safety Considerations

As a thermoplastic, SC will melt repeatedly, every time its temperature is elevated to 120°C (248°F); however, its poor thermal conductivity (0.2 - 0.5 BTU/h ft °F) is a strong deterrent to melting. When heat is removed, all intact SC will regain its original strength very rapidly. Because SC is a thermoplastic, its mechanical properties are affected by sustained high temperature, and its highest operational temperature is 88°C (190°F)[5]. Because SC can always be melted and regain its strength upon cooling, it is a recoverable resource. More specifically, if a given solidification and stabilization specimen did not pass its tests, it could be melted and combined with more SC, or different additives, so as to pass those tests.

Unlike concrete, SC can be maintained in the recommended pouring-temperature range in a mixer for long periods of time, yet remain plastic and workable until placement.[8] Mixers for concrete must be cleaned out after every mixing operation, whether the mixer is empty or not, and the excess concrete and wash solutions must be routed through a separate treatment process. Failure to clean the concrete mixer usually requires replacing it and committing the mixer itself as contaminated waste. The ability to hold molten SC in the mixer for several days, or even weeks, awaiting the next pour, offers many operational and radiological safety advantages.[21]

The recommended mixing temperature for SPC and SC is 127 to 138°C (260 to 280°F), which will minimize gaseous emissions. Upon reaching 150°C (302°F), SPC/SC will produce hydrogen sulfide (H_2S), commonly called rotten-egg gas, which is poisonous and flammable.[8] That problem is avoided by using automated temperature controls and gas detectors as a backup. Molten SPC and SC adhere to the skin upon contact. Therefore, gloves, goggles or face shields, and protective clothing are essential where direct contact between operators and molten SC are planned. Normal precautions for handling hot fluid materials must be observed. These and other practices for safely handling both solid and liquid sulfur have been established by the National Safety Council.[7, 23]

SPC and SC will burn if held in a flame, but will self extinguish when the heat is withdrawn.[4, 5] The U.S. Department of Transportation (DOT) classifies materials for transportation and establishes flammability ratings for essentially all commodities. SPC and SC meet none of the criteria for classification as flammable materials.

As a sidelight safety consideration, SC vaults, barriers, radiation shielding, radon-gas barriers, floors, and sumps in nuclear, mixed, and hazardous waste facilities, hospitals, research centers, and universities offer greater potential for operator safety and environmental enhancement.

Continued SPC Testing

Irradiation tests were recently completed at Oregon State University (OSU). The original intent was to test the lead-ladened SC as a possible personnel shielding for high-radiation areas. Twelve SC specimens containing high loadings of lead oxide were subjected to 10E+8 Rad, as prescribed in the NRC irradiation test. The test specimens showed no visible signs of deterioration (no spalling, cracking, or other evidence of disintegration) and they exceeded NRC's requirement for 500 psi compressive strength.[24] In fact, the specimens actually gained significant compressive strength during the irradiation test, and were an order of magnitude better than NRC requirements. The physical and mechanical characteristics of the test material before and after the test will be released in the final report.*

* Test results confirmed in telecommunication with Mr. Bill McBee, the irradiation test manager, June 4, 1991

There were no radioactive wastes encapsulated in the SC for the OSU test; however, as discussed, it is the hazardous components (the chemical components) rather than the radioactive components that cause problems in solidification. Lead is a toxic metal, a problematic hazardous waste, so this test was important in the evaluation of SPC as a viable stabilization agent.

Since NRC requires only 500 psi compressive strength, and since the SC, which contained various wastes, averaged approximately 4000 psi, there is a large "window of opportunity" for experimentation to develop the optimum SC mixture for given waste forms. As more additives are combined with SPC, the molten SC becomes more viscous (harder to pour), the resultant solidified SC becomes more elastic and less brittle, and the compressive strength will decrease towards 500 psi. Unlike concrete, SC can be vibrated a large percentage of the time to settle the SC with only slight deterioration, so a more viscous mix could be tolerated.

The principal developer of SPC and SC says the construction-grade SPC being used in the EPA and NRC tests is not the best formulation. He is currently developing a "second generation SPC," which he believes will perform better as a LLW and MW stabilization agent.[g]
g. Confirmed in telecommunication with Mr. Bill McBee, the primary developer of SPC, February 28, 1991

Encouraged by the more recent experimentation, the Bureau of Mines, Division of Environmental Technology, plans to pursue more failure analysis and ultimately to seek solutions to hazardous waste disposal.[25] Considering SC's radon barrier assets in combination with radiation shielding, the tests being conducted and being planned may prove fruitful for the nuclear industry, factories, hospitals, research centers, and perhaps even homes and businesses.

With respect to waste vault and barrier construction, and hazardous, nuclear, and MW treatment and disposal programs, additional experimentation with SPC and SC by the private sector, the Bureau of Mines, and DOE is encouraging.

Plans for SPC in Waste Treatment and Disposal

Both the Scientific Ecology Group (SEG) and DOE's WERF at the INEL, are seriously contemplating installation of SPC and SC equipment for the solidification of LLW and MW.[f]
f. Mr. Tim Hallman, Engineer, SEG, confirmed their intentions by phone on April 30, 1991, and the author has been working on the INEL effort.
The contractors at DOE's Hanford Complex are exploring the use of SC for stabilization of LLW and MW.[21]

The Northern California Power Agency, Middletown, California, extracts considerable quantities of sulfur from its geothermal power Stretford H_2S Abatement Facility. They recover elemental sulfur in sulfur cake, which is a 50:50 mixture of sulfur and water with trace heavy metals, vanadium, mercury, and arsenic. Cost is high for its disposal in an EPA-approved disposal site. In a joint environmental-enhancement and cost-saving venture, they are designing a facility to produce high-quality SPC from the waste sulfur and its hazardous contents, thereby creating a delisted SPC. They plan start-up for the first quarter of 1992.

Summary

Prime threats to adequately solidified and stabilized LLW and MW are water, lack of leach resistance, excess permeability, inability to withstand chemical attack both from within the mass and from the disposal environment, and ultimately the inability of solidified waste to consistently meet EPA and NRC requirements for disposal. Tests to date show SPC to be excellent in these areas.

SPC is a thermoplastic that melts at 120°C (248°F) and, unlike hydraulic cements does not require activation agents to cause solidification. SC achieves a compressive strength upon cooling that concrete requires 28 days to achieve. With given quantities of four troublesome radioactive wastes combined with SC and PCC, it required up to 6.7 times less SC than PCC to achieve a solidified form that could pass the EPA and NRC tests. The average figure was 3.9.

SPC offers a cleaner mixing system to operate, with fewer disposal containers to handle, and fewer waste containers to dispose of. Cleanup of the SC mixer after a pouring campaign is not required. Chemical analysis of the waste prior to establishing additives and waste-to-cement ratios is less demanding. Involvement, and therefore radiation exposure, will be lessened for treatment operators, health physics technicians, and disposal operators.

SC ladened with 43wt% MW fly ash (which was chosen as a most troublesome waste) has passed all EPA and NRC lab tests, and is ready for the final full-scale test. There is nothing to suggest that SC will not pass that test, which will open the door to a promising new waste solidification agent.

Some unexpected bonuses developed during the research of SC for treatment and disposal; SPC exhibits superior strength and durability and excels when subjected to harsh chemical environments, microbe attack, etc. SC is also impervious to water and to radon gas. These facts may lead to safer nuclear facilities of all types and more environmentally sound disposal structures.

SPC is a promising solidification and stabilization agent for LLW, MW, Greater-than-Class-C, transuranic, and hazardous wastes. However, like all solidification and stabilization agents tested to date, it will not accommodate all wastes.

Conclusion

Federal, State, and local laws mandate ever increasing requirements for solidification and stabilization of LLW and MW. In many cases, solidification and stabilization agents used in the past for selected wastes are not passing the required tests for more troublesome wastes. SPC shows considerable promise in being able to accommodate a large percentage of those wastes. Current laws encourage full treatment of wastes. With incineration and/or vitrification of all candidate wastes, the potential for successful solidification and stabilization of many more waste streams using SPC is realistically high.

Sulfur is a stable element. Tests to date suggest that SPC is also stable. All indications are that SPC may well be the stabilization agent that will preserve the encapsulated waste for thousands of years.

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