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## Standard Guide for Use of Coal Combustion Products for Solidification/ Stabilization of Inorganic Wastes<sup>1</sup>

This standard is issued under the fixed designation E2060; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This guide covers methods for selection and application of coal combustion products (CCPs) for use in the chemical stabilization of trace elements in wastes and wastewater. These elements include, but are not limited to, arsenic, barium, boron, cadmium, chromium, cobalt, lead, molybdenum, nickel, selenium, vanadium, and zinc. Chemical stabilization may be accompanied by solidification of the waste treated. Solidification is not a requirement for the stabilization of many trace elements, but does offer advantages in waste handling and in reduced permeability of the stabilized waste.

1.1.1 Solidification is an important factor in treatment of wastes and especially wastewaters. Solidification/Stabilization (S/S) technology is often used to treat wastes containing free liquids. This guide addresses the use of CCPs as a stabilizing agent (with or without the addition of other materials; however, stabilization or chemical fixation may also materials. Stabilization may be achieved by using combinations of CCPs and other products such as lime, lime kiln dust, cement kiln dust, cement, and others. CCPs used alone or in combination with other reagents promote stabilization of many inorganic constituents through a variety of mechanisms. These mechanisms include precipitation as hydrates, carbonates, silicates, sulfates, and so forth; microencapsulation of the waste particles through pozzolanic reactions; formation of metal precipitates; and formation of hydrated phases (1-4).<sup>2</sup> Long-term performance of the stabilized waste is an issue that must be addressed in considering any S/S technology. In this guide, several tests are recommended to aid in evaluating the long-term performance of the stabilized wastes.

<https://standards.iteh.ai/catalog/standards/sist/6004ca7a-5462-437e-b2b2-66fce64e9ec/astm-e2060-22>

1.2 The CCPs that are suited ~~to~~for this application include fly ash, ~~spent dry scrubber sorbents, and certain advanced sulfur control by-products from processes such as duct injection dry flue gas desulfurization (FGD) material, and~~ fluidized-bed combustion (FBC)-(FBC) ash.

1.3 The wastes or wastewater, or both, containing the ~~problematic~~-inorganic species ~~will likely~~may be highly variable, so the chemical characteristics of the waste or wastewater to be treated must be determined and considered in the selection and application of any stabilizing agent, including CCPs. In any waste stabilization process, laboratory-scale tests for compatibility between the candidate waste or wastewater for stabilization with one or more selected CCPs and final waste stability are recommended prior to pilot-scale and full-scale application of the stabilizing agent.

1.4 This guide does not intend to recommend pilot-scale or full-scale processes or procedures for waste stabilization. Full-scale processes should be designed and carried out by qualified scientists, engineers, and environmental professionals. It is recommended that stabilized materials generated at the full-scale stabilization site be subjected to testing to verify laboratory test results.

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee E50 on Environmental Assessment, Risk Management and Corrective Action and is the direct responsibility of Subcommittee E50.03 on Beneficial Use.

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<sup>2</sup> The boldface numbers in parentheses refer to the list of references at the end of the text.

1.5 The utilization of CCPs under this guide is a component of a pollution prevention program; ~~Guide program. E1609 describes pollution prevention activities in more detail.~~ Utilization of CCPs in this manner conserves land, natural resources, and energy.

1.6 This guide applies only to CCPs produced primarily from the combustion of coal. It does not apply to ash or other combustion products derived from the burning of waste; coal coking byproducts; municipal, industrial, or commercial garbage; sewage sludge or other refuse, or both; derived fuels; wood waste products; rice hulls; agricultural waste; or other noncoal fuels.

1.7 Regulations governing the use of CCPs vary by ~~state~~ nation, state and locality. The user of this guide has the responsibility to determine and comply with applicable regulations.

1.8 It is recommended that work performed under this guide be designed and carried out by qualified scientists, engineers, and environmental professionals.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate ~~safety~~ safety, health, and health environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>3</sup>

- [C114 Test Methods for Chemical Analysis of Hydraulic Cement](#)
- [C311 Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete](#)
- [C400 Test Methods for Quicklime and Hydrated Lime for Neutralization of Waste Acid](#)
- [D75 Practice for Sampling Aggregates](#)
- ~~[D422 Test Method for Particle-Size Analysis of Soils \(Withdrawn 2016\)<sup>4</sup>](#)~~
- [D558 Test Methods for Moisture-Density \(Unit Weight\) Relations of Soil-Cement Mixtures](#)
- ~~[D653 Terminology Relating to Soil, Rock, and Contained Fluids](#)~~
- [D1556 Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method](#)
- [D1633 Test Methods for Compressive Strength of Molded Soil-Cement Cylinders](#)
- [D1635 Test Method for Flexural Strength of Soil-Cement Using Simple Beam with Third-Point Loading](#)
- [D2166 Test Method for Unconfined Compressive Strength of Cohesive Soil](#)
- [D2216 Test Methods for Laboratory Determination of Water \(Moisture\) Content of Soil and Rock by Mass](#)
- ~~[D2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods \(Shallow Depth\) \(Withdrawn 2007\)<sup>4</sup>](#)~~
- [D2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method](#)
- [D3441 Test Method for Mechanical Cone Penetration Testing of Soils](#)
- [D3877 Test Methods for One-Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures \(Withdrawn 2017\)<sup>4</sup>](#)
- [D3987 Practice for Shake Extraction of Solid Waste with Water](#)
- [D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils](#)
- ~~[D4842](#)~~[D4832 Test Method for Determining the Resistance of Solid Wastes to Freezing and Thawing Preparation and Testing of Controlled Low Strength Material \(CLSM\) Test Cylinders \(Withdrawn 2006\)](#)
- [D4843 Test Method for Wetting and Drying Test of Solid Wastes](#)
- [D4972 Test Methods for pH of Soils](#)
- [D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter](#)
- ~~[D5239](#)~~[D5907 Practice for Characterizing Fly Ash for Use in Soil Stabilization Test Methods for Filterable Matter \(Total Dissolved Solids\) and Nonfilterable Matter \(Total Suspended Solids\) in Water \(Withdrawn 2021\)](#)
- [D6913 Test Methods for Particle-Size Distribution \(Gradation\) of Soils Using Sieve Analysis](#)
- [D6938 Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods \(Shallow Depth\)](#)
- ~~[E1609](#)~~[D7928 Guide for Development and Implementation of a Pollution Prevention Program Test Method for Particle-Size Distribution \(Gradation\) of Fine-Grained Soils Using the Sedimentation \(Hydrometer\) Analysis \(Withdrawn 2010\)](#)

<sup>3</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>4</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

E2201 Terminology for Coal Combustion Products

**3. Terminology**

3.1 *Definitions:*

3.1.1 Definitions are in accordance with Terminology ~~D653~~E2201.

3.2 *Definitions of Terms Specific to This Standard:*

~~3.2.1 advanced sulfur control (ASC) products—by-products generated from advanced coal conversion technologies including FBC and gasification and by-products from advanced environmental emissions cleanup technologies such as duct injection and lime injection multiphase burners (LIMB).~~

~~3.2.2 baghouse—a facility constructed at some coal-fired power plants consisting of fabric filter bags that mechanically trap particulates (fly ash) carried in the flue gases.~~

~~3.2.3 beneficial use—projects promoting public health and environmental protection, offering equivalent success relative to other alternatives, and preserving natural resources.~~

~~3.2.4 BDAT—best demonstrated available technology.~~

~~3.2.5 boiler slag—a molten ash collected at the base of slag tap and cyclone boilers that is quenched in a water-filled hopper and shatters into black, angular particles having a smooth, glassy appearance.~~

~~3.2.1 bottom ash—BDAT—agglomerated ash particles formed in pulverized coal boilers that are too large to be carried in the flue gases and impinge on the boiler walls or fall through open grates to an ash hopper at the bottom of the boiler. Bottom ash is typically grey to black in color, is quite angular, and has a porous surface texture.~~best demonstrated available technology.

3.2.1.1 Discussion—

The treatment technology that best minimizes the mobility or toxicity (or both) of the hazardous constituents for a particular waste.

~~3.2.7 coal combustion products—fly ash, bottom ash, boiler ash, or flue gas desulfurization (FGD) material resulting from the combustion of coal.~~

~~3.2.8 DSC—differential scanning calorimetry.~~

~~3.2.9 DTA—differential thermal analysis.~~

~~3.2.10 DTG—differential thermal gravimetry.~~

~~3.2.11 electrostatic precipitator—a facility constructed at some coal-fired power plants to remove particulate matter (fly ash) from the flue gas by producing an electric charge on the particles to be collected and then propelling the charged particles by electrostatic forces to collecting curtains.~~

~~3.2.12 encapsulation—complete coating or enclosure of a toxic particle by an additive so as to sequester that particle from any environmental receptors that may otherwise have been negatively impacted by that particle.~~

3.2.2 *ettringite*—a mineral with the nominal composition  $\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \cdot 26\text{H}_2\text{O}$ . Ettringite is also the family name for a series of related compounds, known as a mineral group or family, which includes the following minerals O (1):

Ettringite  
Charlesite  
Sturmanite  
Thaumasite  
Jouravskite  
Bentorite

$\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \cdot 26\text{H}_2\text{O}$   
 $\text{Ca}_6(\text{Si},\text{Al})_2(\text{SO}_4)_2(\text{B}[\text{OH}]_4)(\text{OH})_{12} \cdot 26\text{H}_2\text{O}$   
 $\text{Ca}_6\text{Fe}_2(\text{SO}_4)_2(\text{B}[\text{OH}]_4)(\text{OH})_{12} \cdot 26\text{H}_2\text{O}$   
 $\text{Ca}_6\text{Si}_2(\text{SO}_4)_2(\text{CO}_3)_2(\text{OH})_{12} \cdot 24\text{H}_2\text{O}$   
 $\text{Ca}_6\text{Mn}_2(\text{SO}_4)_2(\text{CO}_3)_2(\text{OH})_{12} \cdot 24\text{H}_2\text{O}$   
 $\text{Ca}_6(\text{Cr},\text{Al})_2(\text{SO}_4)_3(\text{OH})_{12} \cdot 26\text{H}_2\text{O}$

3.2.14 *flue gas desulfurization material*—a by-product of the removal of the sulfur gases from the flue gases, typically using a high-calcium sorbent such as lime or limestone. Sodium-based sorbents are also used in some systems. The three primary types of FGD processes commonly used by utilities are wet scrubbers, dry scrubbers, and sorbent injection. The physical nature of these by-products varies from a wet, thixotropic sludge to a dry powdered material, depending on the process.

3.2.15 *fly ash*—coal ash that exits a combustion chamber in the flue gas. Coal fly ashes are typically pozzolans. Some coal fly ashes also exhibit self-hardening properties in the presence of moisture.

3.2.16 *pozzolans*—siliceous or siliceous and aluminous materials that in themselves possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxides at ordinary temperatures to form compounds possessing cementitious properties.

3.2.3 *S/S*—solidification/stabilization.

3.2.18 *stabilization or fixation*—immobilization of undesirable constituents to limit their introduction into the environment. Toxic components are immobilized by treating them chemically to form insoluble compounds.

3.2.19 *solidification*—the conversion of soils, liquids, or sludges into a solid, structurally sound material for disposal or use, typically referring to attainment of 50 psi or strength of surrounding soil.

3.2.4 *XRD*—x-ray diffraction.

#### 4. Significance and Use

4.1 *General*—CCPs can have chemical and mineralogical compositions that are conducive to use in the chemical stabilization of trace elements in wastes and wastewater. These elements include, but are not limited to, arsenic, barium, boron, cadmium, chromium, cobalt, lead, molybdenum, nickel, selenium, vanadium, and zinc. Chemical stabilization may be accompanied by solidification of the waste treated. Solidification is not a requirement for the stabilization of many trace elements, but does offer advantages in waste handling and in reduced permeability of the stabilized waste. This guide addresses the use of CCPs as a stabilizing agent with or without addition of other materials. *S/S*

NOTE 1—In the United States, *S/S* is considered the BDAT for the disposal of some wastes that contain metals since they cannot be destroyed by other means (2). is considered the BDAT for the disposal of some wastes that contain metals since they cannot be destroyed by other means (2).

4.1.1 *Advantages of Using CCPs*—Advantages of using CCPs for waste stabilization include their ready-availability in high volumes, and generally good product consistency from one source, and easy handling. CCPs a single source. In addition, in some instances certain CCPs can partly or entirely replace other expensive stabilization materials such as Portland cement. CCPs vary depending on the combustion or emission control process and the coal or sorbents used, or both, and CCPs contain trace elements, although usually at very low concentrations. CCPs are generally an environmentally suitable materials option for waste stabilization, but the compatibility of a specific CCP must be evaluated with individual wastes or wastewater through laboratory-scale tests followed by full-scale demonstration and field verification. CCPs suitable for thisthe chemical stabilization have the ability to incorporate large amounts of free water into hydration products, via hydration reactions. These same hydration reactions frequently result in the formation of mineral phases that stabilize or chemically immobilize the trace elements of concern. CCPs that exhibit high pHs (>11.5) offer advantages in stabilizing trace elements that exist as oxyanions in nature (such as arsenic, boron, chromium, molybdenum, selenium, and vanadium) and trace elements that form oxyhydroxides-oxyhydroxides, carbonates or other low-solubility precipitates at high pH (such as lead, cadmium, barium, and zinc). Additionally, CCPs that exhibit cementitious properties offer advantages in solidifying CCP-waste mixtures as a result of the hydration reactions of the CCP. These same hydration reactions frequently result in the formation of mineral phases that stabilize or chemically fix the trace elements of concern. nickel, and zinc).

4.2 *Chemical/Mineralogical Composition*—Since many CCPs are produced under conditions of high-generated at higher temperature, reactions with water during contact with water or-aqueous solutions can be expected. Mineral formation may contribute to the chemical fixationstabilization and/or solidification achieved in the waste stabilizationtreatment process. One example of this type of chemical fixationstabilization is achieved by ettringite formation. Reduced leachability of several trace

elements has been correlated with ettringite formation in hydrated high-calcium CCPs typically from U.S. lignite and subbituminous coal, FGD materials, and ASC by-products. These materials are the best general and dry FGD materials. These materials worthy candidates for use in this chemical fixation/stabilization process. Lower-calcium CCPs in presence of sulfate sources, may also be effective with the addition of a calcium source that maintains the pH above 11.5. Ettringite forms as a result of hydration of many high-calcium CCPs, CCPs in presence of sulfate sources, so adequate water must be available for the reaction to occur. The mineral and amorphous phases of CCPs contribute soluble elements required for ettringite formation, and the ettringite formation rate can vary based on the mineral and amorphous phase compositions.

### 4.3 *Environmental Considerations: Regulatory Framework:*

#### 4.3.1 *Regulatory Framework: Waste Management Framework—*

4.3.1.1 *Federal*—In 1999, EPA completed a two-phased study of CCPs for the U.S. Congress as required by the Bevill Amendment to RCRA. At the conclusion of the first phase in 1993, EPA issued a formal regulatory determination that the characteristics and management of the four large-volume fossil fuel combustion wastestreams (that is, fly ash, bottom ash, boiler slag, and flue gas emission control waste) do not warrant hazardous waste regulation under RCRA and that utilization practices for CCPs appear to be safe. In addition, EPA “encourage[d] the utilization of coal combustion byproducts and support[ed] State efforts to promote utilization in an environmentally beneficial manner.” In the second phase of the study, EPA focused on the byproducts generated from FBC boiler units and the use of CCPs from FBC and conventional boiler units for mine reclamation, among other things. Following completion of the study, EPA issued a regulatory determination in April 2000 that again concluded that hazardous waste regulation of these combustion residues was not warranted. There is currently no regulatory program at the federal level that addresses the utilization of CCPs. The wastes or wastewater requiring stabilization may fall under federal jurisdiction, so the final stabilized material may need to be evaluated and disposed of according to federal regulations. Potentially applicable federal regulations may include the Resource Conservation and Recovery Act (RCRA), Hazardous Solid Waste Act (HSWA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and Superfund Amendment and Reauthorization Act (SARA). A brief description of these regulations is included in the EPA document, entitled *Stabilization/Solidification of CERCLA and RCRA Wastes: Physical Tests, Chemical Testing Procedures, Technology Screening, and Field Activities* (2) and have been summarized by ACAA (5). The EPA document states “stabilization/solidification is a proven technology for the treatment of hazardous wastes and hazardous waste sites.” According to EPA (2), stabilization/solidification is the BDAT for the disposal of some metals since they cannot be destroyed by other means. Provisions in federal laws list requirements that land disposal of hazardous wastes is only acceptable if these wastes are treated with the BDAT or with technology that meets or exceeds the treatment level of BDAT. Wastes that contain free liquids are prohibited from land disposal by federal RCRA regulations or by equivalent state regulations, or both. The chemical binding of free liquids brought about by solidification allows wastes that fail the EPA Paint Filter Test (EPA Method 9095-SW846) (6) to be land-disposed after successful S/S treatment. Waste stabilization activities most often occur within a regulatory waste management framework. This regulatory framework will generally establish minimum waste sampling and characterization requirements as well as establish documentation, qualification, and performance criteria for waste management activities. The framework may also prescribe or prohibit certain waste management practices. The applicable requirements of the regulatory framework may be formalized in a permit. This guide is intended to be applied within the context of a regulatory waste management framework.

4.3.1.2 A summary of coal fly ash utilization in waste stabilization/solidification, including a discussion of environmental/regulatory issues, demonstrations, and commercial applications, has been prepared (5):

*NOTE 2*—The U. S. regulatory framework is briefly described in *Stabilization/Solidification of CERCLA and RCRA Wastes: Physical Tests, Chemical Testing Procedures, Technology Screening, and Field Activities* (2).

4.3.1.3 *State*—Some states do not have specific regulations addressing the use of CCPs, and requests for CCP use are handled on a case-by-case basis or under generic state recycling laws or regulations. Some states have adopted laws and regulations or issued policies and/or guidance regarding CCP use, but CCP use varies widely within these states (7). Waste or wastewater requiring stabilization and the final stabilized material may also be regulated by individual states, so these regulations need to be identified and followed. Many states are authorized to manage the hazardous waste management programs within their state. RCRA and HSWA statutes allowed the states to become authorized by EPA. It is therefore extremely likely that S/S-treated waste will be regulated by a state:

4.3.2 *Beneficial Use Framework*—Beneficial use activities often occur within a regulatory framework. In some locations, new beneficial uses require prior regulatory approval as part of a beneficial use determination. Beneficial use determinations may require specific characterization of the material and the beneficial use. Jurisdictions that require approval of beneficial use may also maintain exemptions or predeterminations for certain materials or beneficial uses.

## 5. CCP Characterization

~~5.1 General—Characterization of the CCP(s) under consideration for use as a stabilizing agent is needed to determine bulk chemical and mineralogical composition to form ettringite when hydrated and that sufficient alkalinity is available to maintain a high pH.~~

~~5.1 Sampling and Handling—General—Characterization of the CCP(s) under consideration for use as a stabilizing agent is required to determine bulk chemical and mineralogical composition. Sampling CCPs for testing purposes should conform to Practice D75 or Test Method C311 as appropriate. Proper laboratory protocols for handling fine material should be followed.~~

~~5.2 Chemical Composition—Test Method C311 is often used to determine the major chemical constituents of CCP samples. The most critical constituents requiring quantitation are calcium, aluminum, and sulfur.~~

~~5.3 pH—Test Method D4972 or Practice U. S. D5239 may Environmental Protection Agency (USEPA) Method SW-9045 (5) can be used to determine CCP pH. In assessing the test results, consideration should be given to the possibility that the pH of the CCP may differ with age, water content, and other conditions. EPA Method SW-9045 (8) is also applicable.~~

~~5.4 Buffer Capacity—The buffer capacity Test Method C400 of the CCP is important in maintaining the high pH that generally is a requirement for the stabilization mechanisms of interest when CCPs are used as stabilization agents. The CCP must have enough buffer capacity to maintain the pH of the stabilized waste in the appropriate range so the waste remains stable over time and under environmental stresses. Test Method can be applied to evaluate the buffer capacity of the CCP, and to determine the basicity factor for the CCP. It is important that the buffer capacity of the CCP is sufficient to maintain a high pH so that conditions are favorable to allow the stabilization mechanisms of interest to occur (for example, hydroxide formation, precipitation, etc.), and so that C400 can be applied to evaluate the buffer capacity of the CCP. Determine the basicity factor for the CCP as noted in Test Method B of Test Method the waste remains stable over time and under environmental stresses. C400.~~

~~5.5 Swelling—Test Method D3877 can be used to determine the swelling potential of self-hardening (high-calcium) CCPs and FGD material. The reactions producing the expansive properties generally do not commence for a period of more than begin to occur until at least 30 days after initial CCP hydration. The test procedure To address this delayed reaction the test method must address this delayed reaction. The procedure should be modified to extend the wetting and drying cycle to 60 days. Expansive reactions, including the formation of ettringite, may have an impact on the permeability of the stabilized waste. Following completion of hydration at 60 days, the mineral composition should be determined.~~

<https://standards.iteh.ai/catalog/standards/sist/6004ca7a-5462-437e-b2b2-66fce64e9ec/astm-e2060-22>

~~5.6 Mineral Composition (Optional)—Composition—XRD is can be used to determine the mineral content of CCPs. Fly ash, bottom ash, and boiler slag contain significant amorphous phases that cannot be identified through the use of XRD techniques. Many ASC by-products dry FGD materials have a higher calcium content compared to that of CCPs. XRD evaluation can be performed on the hydrated CCP collected from the swelling test, summarized in 5-65.5, to determine whether or not the CCP tested forms CCP(s) formed hydrated minerals.~~

## 6. Selection of CCP for Waste Stabilization/Solidification/Stabilization

~~6.1 General—Many CCPs have the potential to stabilize inorganic trace elements; however, those with the highest potential are finely divided powdered materials, including fly ash, spent dry scrubber sorbents, and certain ASC by-products. FGD materials, and FBC ashes. Specifically, CCPs that are known to undergo hydration reactions that result in the formation of certain minerals, including ettringite, carbonate minerals, and insoluble sulfates, have high potential to be useful serve as stabilizing agents for many trace elements that are not organically associated. A CCP exhibiting high pH also offers advantages in the stabilization of trace elements.~~

~~6.2 Chemical Properties—The chemical properties of CCPs used in waste stabilization applications may include a wide range of chemical compositions, pHs, buffering capacities, and reactivities.~~

~~6.2.1 Chemical Composition—CCPs of differing chemical composition can offer advantages for solidification/stabilization applications. Most coal fly ashes are pozzolanic; however, certain subbituminous and lignite coal ashes may contain higher amounts of calcium oxide and exhibit greater cementitious properties. Cementitious CCPs offer additional advantages in solidification/stabilization applications; the potential formation of monolithic structures of CCP-waste combinations without addition of cement or other additives; appropriate chemical components that allow the formation of ettringite for stabilization of~~

oxyanions (such as oxyanions of arsenic, boron, chromium, molybdenum, selenium, and vanadium), which is accomplished by substituting these oxyanionic species for  $\text{SO}_4^{2-}$  in the ettringite structure; and high pH, which facilitates ettringite formation and the precipitation of low-solubility metal carbonates. The presence of sulfate in CCPs being considered for solidification/stabilization applications can offer advantages in reducing hydroxides and carbonates. Sulfate containing CCPs can reduce the mobility of barium through barium sulfate formation. The presence of iron and/or manganese species can enhance the formation of low-solubility metal oxyhydroxides. oxyhydroxides and, through co-precipitation, can further reduce the soluble amounts of other metals.

6.2.2 *pH*—It is recommended that the pH of the CCP be determined using methods noted in [5.45.3](#). CCPs exhibiting high pH (>8) offer advantages in numerous solidification/stabilization mechanisms.

6.2.3 *Hydrated Mineral Formation*—The CCP selected for hydration purposes should be hydrated/evaluated using the procedure—Test Method [D3877](#) to determine swelling potential listed in potential. [5.6](#)—Thirty (30) days is recommended as the minimum hydration time; however, 60 days may provide more reliable results because ettringite formation is a slow reaction. As noted in [5.75.6](#), XRD is the best analytical tool to determine the presence of hydration products.

6.2.4 *Buffer Capacity*—The buffer capacity of the CCP should be determined as noted in [5.55.4](#). As an example of the use of the calculated basicity factor, to ensure that the CCP has the capability to neutralize significant acid while maintaining the pH above 11.5 for ettringite stability, a BF >0.1 would be appropriate. The limit for the BF of the CCP should be evaluated on the basis of the expected mechanism of solidification/stabilization, the candidate waste, and/or the site conditions expected for the stabilized material (see [7.5.2](#)).

6.3 *Final CCP Selection*—One or more CCP(s) that meet Section 6 criteria can be selected for the laboratory-scale demonstration of the stabilization process using the criteria listed in this section. ~~CCPs meeting the specified criteria should be subjected to the laboratory-scale demonstration using the candidate waste as noted in Section 8.~~

## 7. Waste Characterization and Stabilized Material Testing

7.1 *General*—Specific characteristics of the waste or wastewater requiring stabilization must be determined. The concentrations of the elements expected to participate in the chemical fixation/stabilization reactions are required to determine the quantity of stabilization agent or CCP to use. The pH and buffer capacity of the waste must be known. All waste characterization tests and procedures must be performed on representative samples of the specific waste to be treated. The final stabilized material form must also be evaluated for specific parameters to verify that the stabilization process has been effective.

7.2 *Physical Tests for Wastes*—Physical testing of the waste prior to treatment provides information on treatability, transport, storage, and mixing considerations. Physical testing of the stabilized material form provides information on the relative success of the stabilization process.

7.2.1 *Particle-Size Analysis*—The results of particle-size analysis provide information on the relative proportions of gravel, sand, silts, and clay-sized particles within the waste, uniformity, concavity, average grain size, and maximum and minimum particle sizes and can be determined using Test Method/Methods [D422D6913](#) and [D7928](#).

7.2.2 *Atterberg Limits*—The Atterberg Limits are a series of tests originally developed to determine the characteristics of clays used in ceramics. The recommended test procedure is Test Method [D4318](#), which is used to determine the liquid limit (the moisture content at which the material flows as a viscous liquid), plastic limit (the moisture content at the boundary between the plastic and brittle states), and plasticity index (the difference between the liquid and plastic limits).

7.2.3 *Moisture Content*—The moisture content of the waste can be determined using Test Method [D2216](#), which will indicate the amount of free water in the waste (waters of hydration are not included as part of the moisture content). Water may not be the only liquid phase in a waste requiring stabilization, so care must be taken to remove other liquids or otherwise account for them in determining the moisture content.

7.2.4 *Density*—The bulk density of a material is the ratio of the total weight of the material to the total volume and is frequently used to convert weight to volume for materials-handling calculations. Several methods are appropriate for determining the bulk density of the waste prior to stabilization. These include laboratory Test Methods [D2937](#) and [D1556](#) and an [D4832](#) and in situ measurement, situ, Test Method/Methods [D2922D2937](#) and [D6938](#).

7.2.5 *Suspended Solids*—In the case of stabilizing oxyanionic species in a wastewater or liquid waste, it is recommended to