Characteristics and Performance of Fly Ash from Sodium Sorbent Scrubbing of SO_3 Emissions from Coal-Based Power Plants

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ABSTRACT

Sodium-based reagents are effective in reacting with sulfur trioxide (SO_3) and are used to capture SO_3 from flue gas at coal-based power plants. In using sodium-based reagents to remove SO_3 from the flue gas, sodium sulfite and sulfate are formed and these solid reaction products are incorporated into the particulate stream and collected with the fly ash in the primary particulate control device (PCD). There is also potential for the sodium-based reagent to react with other components of the gas phase and with ash particulates in the flue gas and in the PCD. All of the products of these reactions have the potential to impact the resulting fly ash and its performance in both disposal and utilization settings. Anecdotal evidence has shown that the fly ash that contains the sodium-based components may have different physical and chemical characteristics than fly ash generated without the addition of a sodium-based sorbent.

Laboratory evaluations are under way at the Energy & Environmental Research Center to characterize the chemical composition, physical and engineering performance, and environmental performance of a variety of samples collected from full-scale facilities utilizing sodium-based sorbents to remove SO_3. Preliminary results indicated that the composition of the fly ash collected from systems utilizing sodium sorbents to remove SO_3 from flue gas varies from baseline fly ash without sodium sorbent but that its utilization in concrete can continue to be a viable utilization option.

INTRODUCTION

Sulfur trioxide (SO_3) is a component of flue gas at coal-based electric generating facilities, and may need to be controlled in order to meet regulatory emission limits. Sodium-based reagents, such as trona (sodium sesquicarbonate), are effective in reacting with SO_3 and are used to capture it from flue gas at coal-based power plants. When sodium-based sorbents are used to capture SO_3, the resulting product becomes part of the fly ash stream. In using sodium-based reagents to remove SO_3 from the flue gas, sodium sulfite and sodium sulfate are formed and are present in the fly ash. There is also the potential for the sodium-based reagent to react with other components of the flue gas and with ash particulate in the flue gas and in the collection device. The sodium-based SO_3 control products collected with fly ash have the potential to impact the composition and characteristics of the resulting fly ash in both disposal and utilization settings.

In order to understand the properties and performance of sodium-based SO_3 control material, a laboratory evaluation was initiated by the Energy & Environmental Research Center with funding from the Electric Power Research Institute (EPRI). The development of the fundamental characterization data from laboratory tests will facilitate the effective use of sodium-based sorbents for SO_3 controls and the continued appropriate utilization and disposal of the resulting fly ash.

Emission regulations in the United States have resulted in changes to coal-based electric generating units through the addition of emission controls. Figure 1 shows a time line of existing and projected emission control requirements for pulverized coal (pc) boilers in the United States. Some coal-based electric generating units have noted increased levels of SO_3 in flue gas and an associated “blue plume” as a result of the implementation of NO_x control strategies. SO_3 has also been shown to reduce the efficiency of some mercury emission control strategies, so dry sodium sorbent injection is being evaluated to improve mercury removal efficiencies.[1–3]

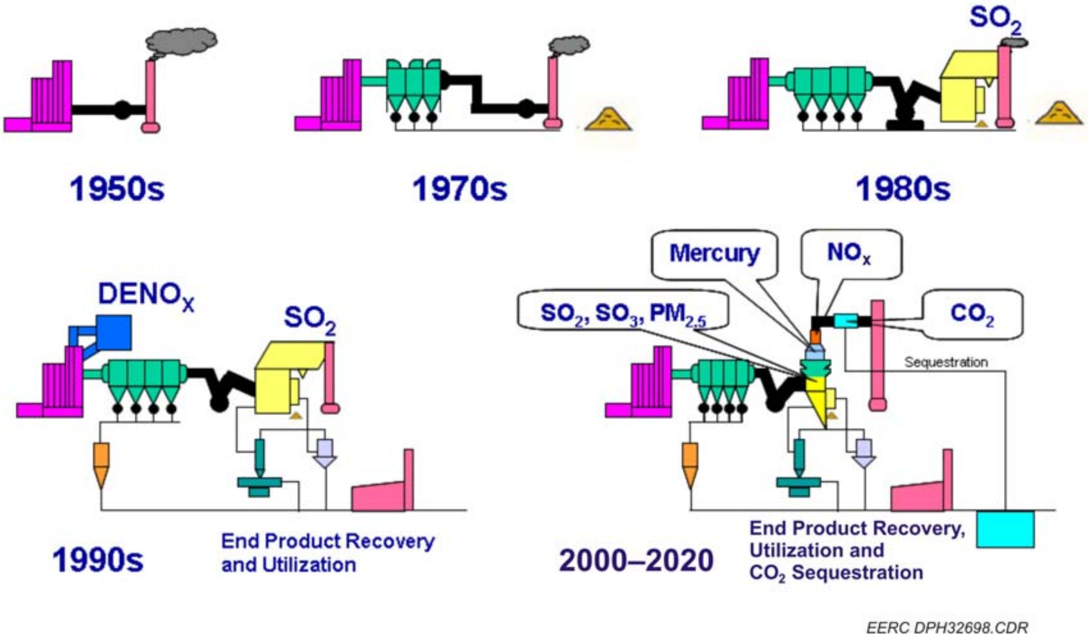

Figure 1. Evolution of air pollution control equipment on pc boilers (source: Institute of Clean Air Companies [ICAC]).

It has been observed that there is increased production of SO_3 at power plants that have implemented selective catalytic reduction (SCR) to reduce NO_x emissions. It has also been noted that the presence of SO_3 in flue gas can limit the effectiveness of activated carbon (AC) for mercury capture. As a result, strategies for removal of SO_3 are being implemented at some coal-based power plants. The most common strategy for reduction of SO_3 to mitigate blue plume is the addition of a sorbent to react with the SO_3. Common sorbents used are hydrated lime, a magnesium hydroxide slurry, sodium bisulfite, sodium carbonate, or trona. The technologies used for SO_3 control were described by EPRI[4] and are summarized in Table 1. The summary of SO_3 control technologies includes the use of sodium sorbents, both through dry injection or introduction in solution. These are currently being evaluated and, in some cases, implemented to remove SO_3 from the flue gas. The use of sodium sorbents is accomplished through dry sorbent injection (DSI) systems or through

Table 1. Summary of SO_3 Control Technologies

Technology Type	Reagent or Sorbent	Injection Type	Injection Location(s)	Additional Information
Magnesium Oxide Injection	Magnesium oxide or hydroxide	Slurry injection	Upstream of air heater	
	Magnesium oxide	Dry powder injection	Upstream of air preheater	
	Magnesium hydroxide	Slurry injection	Upstream of air heater	Fuel Tech trademarked technology called Targeted Duct Injection (TDI™)
Sodium Based Sorbent (SBS) Injection	Sodium bisulfite Sodium sulfite Sodium carbonate By-product sodium bisulfite–sulfite solution	Slurry injection	Upstream of air heater Downstream of air heater Upstream of SCR (under investigation)	
Dry Sorbent Injection (DSI)	Hydrated lime trona	Dry injection	Downstream of air heater Upstream of air heater may also be used for hydrated lime injection	

introduction of sodium solutions into the flue gas stream in various locations in the duct typically referred to as SBS injection. The sodium sorbents currently used in these technologies include trona (sodium sesquicarbonate; $Na_2CO_3 \times NaHCO_3 \times 2H_2O$), sodium carbonate ($Na_2CO_3$), sodium bisulfite ($NaHSO_3$), and sodium sulfite ($Na_2SO_3$). In SBS, a by-product solution of sodium bisulfite and sodium sulfite may also be used. Sodium-based sorbents have been shown to be more efficient than calcium-based sorbents, especially when higher removal rates are required.[4, 5]

Sodium sorbent injection offers efficient removal of sulfur gases including SO_3 and is already being used to reduce SO_3 in flue gas streams. Sodium sorbents can be injected dry or in solution and are used to reduce SO_3 emissions. These are generally injected in very low amounts before the pollution control device (PCD), usually an electrostatic precipitator or a baghouse that uses a fabric filter (FF). The sorbent–SO_3 reactants become part of the fly ash stream and are collected in the PCD with the fly ash. This injection and collection scenario has implications for the resulting fly ash, specifically; the injection of sodium-based sorbents for SO_3 control may be problematic for the use of fly ash in concrete. Anecdotal evidence has suggested that the sodium addition from this type of SO_3 control causes variability and slightly elevated sodium, which may impact the performance of the fly ash in concrete, although some users report no impacts. These reports indicate that the issue is likely a combination of the alkali content of the coal and resulting baseline fly ash and the added sorbent. It has also been indicated that some facilities may have a variable injection schedule, resulting in variable sodium content in the final fly ash product. The added sodium from the sodium sorbent will increase the sodium content of the fly ash and may impact the performance of the fly ash in typical pozzolanic applications such as concrete production.

Research is currently under way to determine the impact of sodium-based reagents on the characteristics and performance of the resulting fly ash.

EXPERIMENTAL

Samples of fly ash were collected from full-scale coal-based power plants using sodium-based reagent injection for SO_3 control. Baseline samples of fly ash without sodium sorbent added were also collected where available. The same laboratory protocols were applied to all samples.

Chemical characterization focused on analyses to determine bulk chemical composition (total major, minor, and trace elements). Physical characteristics of the collected samples include evaluation by use of standard research techniques, including particle size, specific gravity, and morphology. Results from tests completed to date are included in Section 3. Complete results and analysis will be provided in the final report.

Total Bulk Chemical Composition

The major bulk composition, reported as percent oxides, was determined using x-ray fluorescence spectrometry. ASTM International (ASTM) D 4326-04 “Standard Test

Method for Major and Minor Elements in Coal and Coke Ash by X-Ray Fluorescence" was used.[5] The elements noted in Table 2 were included in the bulk composition analyses.

The total concentrations of the trace elements noted in Table 2 were determined using standard methods. Acid digestion by U.S. Environmental Protection Agency (EPA) Method 3052[6] was used on the coal combustion products (CCPs) followed by detection using inductively coupled plasma–mass spectroscopy (ICP–MS), EPA Method 6020,[7] with the exception of total mercury. The total mercury content of solid samples was determined using a direct mercury analyzer (DMA) or digestion followed by cold-vapor atomic absorption spectrometry (CVAAS).

Table 2. Elements Included in the Bulk Composition Analyses

Components	List of Elements	Type of Analysis Anticipated
Major Components	Silicon, aluminum, iron, calcium, magnesium, sodium, potassium, sulfur	XRFA[a]
Minor Components	Barium, manganese, phosphorus, titanium	XRFA
Trace Components	Antimony, arsenic, boron, beryllium, cadmium, chromium, lead, mercury, molybdenum, nickel, selenium, strontium, thallium, vanadium	Acid digestion/atomic absorption or ICP–MS, DMA

[a] X-ray fluorescence analysis.

Moisture, LOI, and pH

The moisture content, loss on ignition (LOI), particle size, specific gravity, and pH were determined on all samples. ASTM C 311-04 "Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete"[8] was used to measure moisture content and LOI.

The bulk pH of the samples was determined in slurry using distilled water. The pH was initially measured after 10–15 minutes of stirring. The sample slurry was then covered, and stirring continued. A final pH value was obtained after 24 hours of stirring.

Environmental Performance

Evaluation of the environmental performance will focus on trace constituents typically found in coal combustion fly ash, such as arsenic, selenium, mercury, and other air toxic elements, because these elements are relatively volatile and have the potential to be present in the flue gas to react with injected reagents. The environmental performance will be evaluated through laboratory leaching tests and associated quantitative analysis of the parameters identified.

Engineering Performance

Engineering performance focused on use in concrete for the fly ash samples collected from systems utilizing sodium sorbents for SO_3 control. The use of fly ash for or as a supplementary cementitious material in concrete production is the most common use of fly ash in the United States, and many coal-based electric generators market fly ash into this application. The addition of sodium or other sorbents to capture SO_3 in the flue gas may change the chemistry and potentially the resulting performance of the fly ash for use in concrete.

Concrete Testing

ASTM C618

Fly ash being sold for admixture with portland cement in concrete typically must meet the specifications contained in ASTM C618 "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete."[9] The ASTM C618 specification is the most widely used because it covers the use of fly ash as a pozzolan or mineral admixture in concrete. The three classes of pozzolans are Class N, Class F, and Class C. Class N is raw or calcined natural pozzolan, such as some diatomaceous earths, opaline cherts, and shales; tuffs, volcanic ashes, and pumicites; and calcined clays and shales. Class F is pozzolanic fly ash normally produced from burning anthracite or bituminous coal. Class C is pozzolanic and cementitious fly ash normally produced from burning lignite or subbituminous coal. For characterization of the SO_3 control materials for use as a mineral admixture in concrete, standard ASTM C618 tests as noted in Table 3 were applied. Omitted from Table 3 is the specification for water-soluble available alkalies. The old limit of 1.50%, expressed as total Na, was dropped several years ago, but the procedure is still often specified. Since the impact of sodium sorbent addition on characteristics and performance is the focus of this work, the available alkali test was included in the test protocol.

RESULTS AND DISCUSSION

Sample Collection

Nine SO_3 control samples from seven units (Table 4) were collected in order to evaluate the impact of the addition of sodium sorbents on the fly ash characteristics and performance. Multiple samples were received from two plants, and each of these sample sets included a baseline fly ash sample representing typical operating conditions without sodium sorbent addition. All samples were collected from utilities burning eastern bituminous coals.

Table 3. ASTM Specification C618-08 Chemical and Physical Specifications

	Mineral Admixture (Class)		
	N	F	C
Chemical Requirements	70	70	50
Silicon Dioxide, Aluminum Oxide, Iron Oxide (SiO_2 + Al_2O_3 + Fe_2O_3), min. %			
Sulfur Trioxide (SO_3), max. %	4.0	5.0	5.0
Moisture Content, max. %	3.0	3.0	3.0
LOI, max. %	10.0	6.0	6.0
Physical Requirements	34	34	34
Fineness, max. % retained on 325-mesh sieve			
Strength Activity Index (SAI) with Portland Cement			
7 day, min. % of control	75	75	75
28 day, min. % of control	75	75	75
Water Requirement, max. % of control	115	105	105
Autoclave Expansion, Soundness, max. %	0.8	0.8	0.8

Table 4. SO_3 Control Sample Identification

Plant ID	EERC Sample ID	Sample Type	SO_3 Control Additive	Coal Rank
35086	08-020	Fly ash	Trona and magnesium hydroxide	Eastern bituminous
35086	08-021	Fly ash – baseline	Magnesium hydroxide	Eastern bituminous
49022	08-022	Fly ash	Trona	Eastern bituminous
17149	08-023	Fly ash	Trona	Eastern bituminous
14090	08-024	Fly ash	Sodium carbonate	Eastern bituminous
17084	08-026	Fly ash	Trona	Eastern bituminous
49005	08-027	Fly ash	Trona	Eastern bituminous
14603	08-034	Fly ash	Sodium carbonate	Eastern bituminous
14603	08-035	Fly ash – baseline	None	Eastern bituminous

Chemical and Physical Characterization

Total Bulk Chemical Composition

Table 5 contains the major and minor bulk chemical composition results for the samples evaluated. For all plants with baseline and sodium addition samples, the addition of the sodium reagent increased the sodium content, reported as Na_2O, and the total sulfur content, reported as SO_3. The most significant change noted was for the sample with sodium carbonate addition for Plant 7. The total concentration of sodium and sulfur were significantly elevated above the associated control sample.

Table 6 shows the total trace element concentrations for the project samples. The following observations can be made regarding the sample sets that contain a baseline fly ash and a fly ash that has been collected when sodium sorbent was injected.

- Concentrations of most trace elements analyzed were similar for the baseline fly ash and fly ash with sodium addition. These included antimony, arsenic, barium, cadmium, chromium, lead, molybdenum, nickel, thallium, and vanadium.

- Differences in total concentrations of boron and selenium were noted in the sample set for Plant 14603. For selenium, the baseline sample exhibited a lower concentration than the fly ash with sodium carbonate addition. For boron, the baseline fly ash had elevated boron compared to the fly ash with sodium carbonate added.

Moisture, LOI, and pH

The moisture content and LOI results as determined by ASTM C311 are given in Table 7. Within the plants with multiple samples, the following observations were made:

- For samples from Plant 35086, the fly ash + magnesium sample was the baseline. When lime was added with the magnesium to the fly ash, the moisture content and LOI values decreased slightly from the control samples, whereas the addition of trona increased the moisture content and LOI values slightly.

- For samples from Plant 14603, the sample with sodium carbonate exhibited a higher moisture content and LOI value.

The bulk pH values are shown in Table 8. All samples exhibited an increase in pH from the initial measurement at 10–15 minutes to the final measurement at 24 hours.

Table 5. Major and Minor Bulk Chemical Composition Results of SO_3 Control Samples, reported as % oxides

Plant ID	EERC Sample ID	Sample Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO_2	P_2O_5	SrO	BaO	SO_3
35086	08-020	Fly ash + trona and magnesium hydroxide	40.45	20.02	19.13	3.76	6.63	1.49	1.80	0.98	0.04	0.11	0.06	0.04	3.19
35086	08-021	Fly ash + magnesium hydroxide	39.91	19.45	23.08	3.96	5.53	0.44	2.01	0.93	0.04	0.10	0.04	0.05	2.61
49022	08-022	Fly ash + trona	48.96	25.86	12.08	1.51	0.75	0.84	2.15	1.40	0.02	0.21	0.08	0.07	0.27
17149	08-023	Fly ash + trona	43.91	20.76	20.80	3.68	0.86	1.19	2.23	1.02	0.05	0.18	0.05	0.07	1.13
14090	08-024	Fly ash + sodium carbonate	47.54	20.79	18.82	2.22	0.98	1.37	2.56	1.08	0.04	0.16	0.03	0.05	0.67
17084	08-026	Fly ash + trona	41.86	19.08	28.20	3.17	0.98	1.62	1.85	0.97	0.04	0.19	0.06	0.06	1.45
49005	08-027	Fly ash + trona	40.19	20.41	26.30	4.25	1.04	1.72	1.49	1.05	0.04	0.31	0.09	0.11	1.65
14603	08-034	Fly ash + sodium carbonate	48.05	18.98	17.15	1.59	0.79	3.22	2.38	0.97	0.02	0.05	0.02	0.03	2.25
14603	08-035	Fly ash	48.05	19.76	20.11	2.97	0.89	0.56	2.39	1.02	0.05	0.13	0.04	0.05	0.44

Table 6. Trace Elemental Concentrations of SO_3 Control Samples, µg/g

Plant ID	EERC Sample ID	Sample Type	Sb	As	Be	B	Cd	Cr	Pb	Mo	Ni	Se	Tl	V
35086	08-020	Fly ash + trona and magnesium hydroxide	3.5	58	1.4	456	0.84	19	7.1	19	6.8	8.2	3.0	47
35086	08-021	Fly ash + magnesium hydroxide	3.4	54	1.9	461	0.96	23	8.9	21	9.7	6.7	3.0	50
49022	08-022	Fly ash + trona	1.4	32	1.3	69	0.25	19	9.1	7.8	6.1	9.0	1.0	39
17149	08-023	Fly ash + trona	1.8	59	2.0	409	1.0	16	9.2	26	9.2	0.32	1.3	49
14090	08-024	Fly ash + sodium carbonate	2.4	110	2.1	346	1.3	19	21	27	14	8.1	2.7	49
17084	08-026	Fly ash + trona	1.8	74	0.9	184	0.93	12	7.7	19	3.8	0.86	0.72	36
49005	08-027	Fly ash + trona	1.1	54	1.8	233	0.44	20	11	10.2	5.4	7.7	3.6	48
14603	08-034	Fly ash + sodium carbonate	2.0	24	1.0	264	2.1	9.7	4.6	27	3.6	8.2	1.4	38
14603	08-035	Fly ash	2.3	38	1.7	458	1.8	13	4.5	38	4.7	2.2	1.8	55

Table 7. Moisture Content and LOI Results of SO_3 Control Samples, wt%

Plant ID	EERC Sample ID	Sample Type	Moisture Content	LOI
35086	08-020	Fly ash + trona and magnesium hydroxide	0.18	2.35
35086	08-021	Fly ash + magnesium hydroxide	0.16	1.93
49022	08-022	Fly ash + trona	0.19	5.55
17149	08-023	Fly ash + trona	0.02	3.84
14090	08-024	Fly ash + sodium carbonate	0.09	3.33
17084	08-026	Fly ash + trona	0.08	0.51
49005	08-027	Fly ash + trona	0.11	1.32
14603	08-034	Fly ash + sodium carbonate	0.35	4.70
14603	08-035	Fly ash	0.08	3.45

Table 8. Bulk pH Results of SO_3 Control Samples

Plant ID	EERC Sample ID	Sample Type	10–15-min pH	24-hour pH
35086	08-020	Fly ash + trona and magnesium hydroxide	9.82	10.42
35086	08-021	Fly ash + magnesium hydroxide	10.19	11.80
49022	08-022	Fly ash + trona	9.12	9.75
17149	08-023	Fly ash + trona	11.75	12.38
14090	08-024	Fly ash + sodium carbonate	6.91	11.76
17084	08-026	Fly ash + trona	11.51	12.23
49005	08-027	Fly ash + trona	8.52	9.90
14603	08-034	Fly ash + sodium carbonate	9.67	10.21
14603	08-035	Fly ash	10.64	11.93

Within the plants with multiple samples, the following observations were made:

- For Plant 35086 for both the 10–15-minute and 24-hour readings. The sample with trona addition exhibited lower pH values compared to the baseline sample for both the 10–15-minute and 24-hour readings.

- In Plant 14603, the use of sodium carbonate injection resulted in a decrease in the pH value, with the 24-hour pH actually lower than the initial 10–15-minute pH value of the baseline fly ash sample.

Engineering Performance

The standard ASTM C618 testing was performed on the fly ash samples collected from units using sodium sorbents for SO_3 control. Two baseline or control samples were also available and tested to provide comparative data. The levels of sodium sorbent required to control SO_3 is relatively low, but anecdotal evidence suggests that the presence of additional sodium and/or sulfite and sulfate may impact the performance of the SO_3 control fly ash when used in concrete.

ASTM C618 Chemical Requirement Results

The purpose of the chemical requirements contained in the C618 specifications is to ensure that the fly ash possesses sufficient chemical reactivity to perform properly when added to concrete and to ensure that it does not contain significant amounts of other deleterious materials which could interfere with the performance of the concrete. Many of the C618 chemical requirements were reported in previous sections of this report, but are summarized in Table 9. The SO_3 control samples available for this study were all collected at facilities combusting bituminous coal.

The purpose of the total oxides requirement of silica, alumina, and iron is to ensure that the fly ash contains sufficient amounts of the necessary constituents to react with available lime. The lower total oxides requirement for Class C materials recognizes that these will contain significant amounts of CaO, so the amounts of the other oxides will necessarily be lower for this particular class. All samples evaluated had total oxide (%SiO_2 + Al_2O_3 + Fe_2O_3) content above the minimum 70% required for a fly ash sample to meet Class F requirements, and all samples had total sulfur content (reported as %SO_3) below the maximum level of 5%. For sample sets where a baseline control sample was available and tested, the %SO_3 was higher in test samples with sodium sorbent added as compared to the associated baseline sample. A maximum limit on SO_3 content is specified to avoid an excess of this constituent in the hardened concrete that could contribute to a disruptive mineral transformation such as the formation of excessive amounts of ettringite. Moisture and LOI results were described previously. The level of available alkali in the fly ash must be limited where aggregates subject to disruptive alkali–aggregate reactions are present. These reactions can cause swelling or cracking of the aggregate, resulting in damage to the concrete. As shown in Table 9, the results for available alkali (reported as total available alkali as %Na_2O); the results vary significantly among the samples tested. Most samples exhibited available alkali content below the maximum of 1.50% as Na_2O. In both cases for sample sets where a baseline control sample was tested, the sample with sodium sorbent had a higher available alkali content compared to the baseline control.

ASTM C618 Physical Requirement Results

The purpose of the physical requirements contained in C618 is to ensure that the fly ash will perform properly when added to concrete and that the supply of fly ash remains sufficiently uniform over time. All SO_3 control samples were subjected to the physical tests designated in C618. Results of the tests are shown in Table 10.

Fineness

In addition to containing a high percentage of total silica, aluminum, and iron oxides, fly ash particles must be in a finely divided form to properly react with available lime. Fly

Table 9. ASTM C618 Chemical Requirement Results of SO_3 Control Samples

Plant ID	EERC Sample ID	Sample Type	Total Oxides, %	SO_3, %	Moisture Content, %	LOI, %	Available Alkali, %
–	Class F	Specification	70 (min.)	5.0 (max.)	3.0 (max.)	6.0 (max.)	1.50 (max.)
–	Class C	Specification	50 (min.)	5.0 (max.)	3.0 (max.)	6.0 (max.)	1.50 (max.)
35086	08-020	Fly ash + trona and magnesium hydroxide	79.60	3.19	0.11	2.31	1.50
35086	08-021	Fly ash + magnesium Hydroxide	82.44	2.61	0.10	1.86	0.67
49022	08-022	Fly ash + trona	86.89	0.27	0.13	5.82	0.92
17149	08-023	Fly ash + trona	85.47	1.13	0.05	4.12	1.05
14090	08-024	Fly ash + sodium carbonate	87.15	0.67	0.07	3.68	1.28
17084	08-026	Fly ash + trona	89.14	1.45	0.04	0.48	1.68
49005	08-027	Fly ash + trona	86.90	1.65	0.08	1.37	1.67
14603	08-034	Fly ash + sodium carbonate	84.18	2.25	0.33	4.50	3.21
14603	08-035	Fly ash	87.92	0.44	0.05	3.55	0.79

ash fineness is determined by measuring the amount of material retained after wet sieving through a No. 325 sieve. In addition to the fineness requirement, C618 contains a uniformity requirement which states that the fineness of a sample shall not vary from the average of the ten previous samples from the same source by more than 5 percentage points. All samples evaluated met the fineness requirement.

SAI

ASTM C618 contains strength activity requirements, which relate to its mixture with portland cement. The purpose of the pozzolanic activity tests is to measure the ability of the fly ash to develop strength through chemical reactions with cement. A preliminary review of the strength values indicates that six samples do not meet the minimum requirement at 7 days, and three of those do not meet the requirement for 28 days. It is typical for strength to increase between 7- and 28-day tests, but for one sample with trona addition (08-022), a decrease in strength was noted. The sample sets where baseline control samples were available showed that the baseline samples also did not

Table 10. ASTM C618 Physical Requirment Results of SO_3 Control Samples

Plant ID	EERC Sample ID	Sample Type	Fineness, %	SAI at 7 days, %	SAI at 28 days, %	Water Req., %	Autoclave Exp., %	Specific Gravity
–	Class F and C	Specification	34 (max.)	75 (min.)	75 (min.)	105 (max.)	0.8 (max.)	
35086	08-020	Fly ash + trona and magnesium hydroxide	13.95	68	70	95	−0.09	2.49
35086	08-021	Fly ash + magnesium hydroxide	15.43	54	61	97	−0.08	2.52
49022	08-022	Fly ash + trona	26.05	77	61	97	−0.12	2.27
17149	08-023	Fly ash + trona	23.51	77	76	98	−0.12	2.45
14090	08-024	Fly ash + sodium carbonate	14.32	94	98	95	−0.09	2.46
17084	08-026	Fly ash + trona	22.46	58	67	95	−0.10	2.63
49005	08-027	Fly ash + trona	27.85	79	83	97	−0.10	2.58
14603	08-034	Fly ash + sodium carbonate	26.09	71	81	97	−0.13	2.23
14603	08-035	Fly ash	11.09	60	74	98	−0.13	2.32

meet the strength requirements and that the associated test samples with sodium sorbent added actually exhibited higher strengths than the controls.

Autoclave Soundness

The autoclave soundness requirement relates to the tendency of mortar bars containing fly ash to either expand or contract during curing. For example, the test protects against the occurrence of the type of delayed expansion which could occur in concrete if sufficient amounts of MgO are present as periclase, which expands as it hydrates. All samples met the requirement for autoclave soundness.

Specific Gravity

The specific gravity of the fly ash is measured as a uniformity check. The specification states that the specific gravity of a sample should not vary from the average of the ten previous samples from the same source by more than 5 percentage points. The range of specific gravity results was typical for fly ash.

Summary of C618 Physical Test Results

Overall, the ASTM C618 results indicate that several of the coal combustion products do meet specifications for use as a partial cement replacement in concrete. A sample only needs to pass either the 7-day or 28-day SAI requirement of 75% to be considered passing. This was the case for most of the samples evaluated. Sample 08-024 (fly ash + sodium carbonate) passed all the specifications and performed quite well for strength activity. Several other samples that had sodium sorbent additions also met all specifications and performed well in at least one of the strength tests. Results of the physical tests for C618 will be fully evaluated in the final report.

SUMMARY

This research was designed to develop information on the characteristics and performance of materials produced at coal-based power plants using sodium-based sorbents to control SO_3 emissions.

Fly ash samples that resulted from the use of sodium sorbents to control SO_3 emissions were collected from several different coal-based electric generating facilities, and for two sample sets, baseline fly ash samples were collected and evaluated for comparative purposes. The compositional data on the comparative sample sets evaluated allowed the following observations to be made:

- Sodium and sulfur content was higher in the fly ash with added sodium sorbent than the baseline in both sample sets.
- LOI was higher for the fly ash with added sodium sorbent than the baseline in both sample sets.
- For the samples set with sodium carbonate addition, the moisture content was higher in the fly ash with sodium carbonate than in the baseline fly ash.
- For the sample set with sodium carbonate addition, the total selenium content was higher in the fly ash with sodium carbonate than in the baseline fly ash.

The leaching data on the comparative sample sets evaluated resulted in the following observations:

- For both sample sets with baseline fly ash and a sodium-treated sample, the sodium and sulfate leachate concentrations increased in the sample with the sodium sorbent addition.

- For the sample set with trona addition, an increase was noted for both arsenic and selenium from the baseline fly ash to the fly ash with trona added.

- For the sample set with sodium carbonate addition, an increase in leachate concentration from the baseline to the fly ash with sodium carbonate added was noted for arsenic, selenium, and vanadium.

Performance of the fly ash samples as a replacement for cement was evaluated using ASTM tests, and results were compared with the ASTM C618 “Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.” The bulk chemical composition of the samples evaluated is consistent with the requirements for ASTM Standard C618 Class F requirements, with all samples having a total of silicon, aluminum, and iron oxide contents >70%. Total sulfur (as $\%SO_3$), moisture, and LOI also were within the C618 limits. Most samples exhibited available alkali content below the maximum of 1.50% as Na_2O. One sample exhibited available alkali content greater than 3%. In both cases for sample sets where a baseline control sample was tested, the sample with sodium sorbent had a higher available alkali content compared to the baseline control consistent with the total sodium content. The ASTM Standard C618 results indicate that several of the CCPs do meet specifications for use as a partial cement replacement in concrete. In order to pass the strength activity requirement, a sample must pass either the 7-day or 28-day SAI requirement of 75%. Most of the samples tested passed this requirement.

CONTINUING WORK

The investigation of these samples is currently ongoing with laboratory evaluations and interpretation of results. The final characterization of these materials will include the following:

- Long-term leaching and analysis for the analytes noted.

- Sulfate–sulfite ratios in the bulk samples.

- Determination of the expansion potential of the samples.

- Determination of the crystallinity and morphology of the bulk samples and selected samples recovered from the long-term leaching and expansion tests.

- Evaluation of performance in concrete potentially for resistance to sulfate, alkali–silica reactivity, alkali–carbonate reactivity, deicing salts, and freeze–thaw durability.

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