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**FUNDAMENTAL MECHANISMS
IN FLUE GAS CONDITIONING**

QUARTERLY REPORT
January 1994 - March 1994

Prepared for

U.S. DEPARTMENT OF ENERGY
Pittsburgh Energy Technology Center
P.O. Box 10940
Pittsburgh, PA 15236

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Todd R. Snyder

SOUTHERN RESEARCH INSTITUTE
2000 NINTH AVENUE SOUTH
P.O. Box 55305
BIRMINGHAM, ALABAMA 35255-5305

Prepared for

Felixa Eskey, Project Manager
UNITED STATES DEPARTMENT OF ENERGY
Pittsburgh Energy Technology Center
Post Office Box 10940, MS 922-206
Pittsburgh, Pennsylvania 15236-0940

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INTRODUCTION

This project is divided into four tasks. We developed our Management Plan in Task 1. Task 2, Evaluation of Mechanisms in FGD Sorbent and Ash Interactions, focuses on characteristics of binary mixtures of these distinct powders. Task 3, Evaluation of Mechanisms in Conditioning Agents and Ash, is designed to examine effects of various conditioning agents on fine ash particles to determine mechanisms by which these agents alter physical properties of ash. We began Tasks 2 and 3 with an extensive literature search and assembly of existing theories. We completed this phase of the project with publication of two special Topical Reports. During the past several quarters we performed our analyses of the samples in our database. Pilot-scale evaluations have begun and will continue through the next quarter. We will include the results of laboratory and pilot-scale work performed under Tasks 2 and 3 in a Flue Gas Conditioning Model that we will issue under Task 4. The Final Report for the project will also be prepared under Task 4.

In our literature reviews reported in Topical Reports 1 and 2, we emphasized the roles adsorbed water can have in controlling bulk properties of powders. The experiments we performed were primarily designed to define the extent to which water affects key properties of ashes, powders, and mixtures of sorbents and ashes. We are currently performing a series of pilot-scale tests designed to determine the effects that adsorbed water has on fabric filtration and electrostatic precipitation of entrained fly ash particles in actual flue gas environments.

PILOT-SCALE TESTS TO VERIFY THE ROLES OF ADSORBED LIQUID

We are investigating two key phenomena in our pilot-scale tests. The first is the ability of flue gas humidification to increase ash cohesivity through the creation of liquid bridges between particles collected in a fabric filter. Increasing cohesivity through the development of liquid bridges was demonstrated in our laboratory measurements of tensile strength and uncompacted bulk porosity, and in filtration studies performed for DOE/PETC under an earlier contract. With the range of coals that will be fired in Southern Research Institute's Coal Combustion Facility (CCF), filtration tests should verify how different fly ashes react to water conditioning in actual flue gas environments. The CCF provides a valuable test location for our studies. We are drawing a slipstream of flue gas and entrained fly ash particles during several different CCF tests. During the next few months, the CCF will be burning (in fuel evaluation tests and corrosion tests) a number of different coals. The variety of coals that will be burned at the CCF represents a valuable opportunity to compare the effects of adsorbed water on the behavior of different types of fly ashes. One or two of these tests will be run on Powder River Basin coal. Since we evaluated ash from Powder River Basin coal in our laboratory studies, CCF tests of this coal will provide excellent opportunities for the comparison of the results of our pilot-scale tests to our laboratory results. Our laboratory studies indicated that the response of different types of fly ashes to water vapor conditioning varied greatly. The effects of actual flue gas, a variety of coal types, and true size distributions of entrained fly ash particles should provide rigorous verification of the effects of developing liquid bridges between particles. Any effects that adsorbed water has on the cohesivity of the ash collected on the dust cake should be apparent in the K_2 values measured during filtration cycles in a portable fabric filter.

The second phenomenon we plan to study is the electrostatic reentrainment of previously collected ash particles in an ESP. We have prepared a small ESP for use in our pilot-scale tests. Our laboratory

studies have shown the effects that relative humidity can have on the forces (resistivity, cohesivity, and tensile strength) that hold the collected ash on the grounded ESP plate. Our laboratory studies, literature review, and our review of field experiences indicated that severe reentrainment can occur when these three forces have been modified by changes in flue gas temperature and/or water content. Therefore we have been intentionally modifying these factors in order to induce this type of electrostatic reentrainment.

The first of our pilot-scale tests was conducted during December 1993, and is discussed in our most recent quarterly report. The second of our pilot-scale combustor tests was performed during January 1994. The primary objectives of this test were to assess the effects that humidification and cooling had on the characteristic gas flow resistance of a dust cake collected in a fabric filter, and on the reentrainment of particles from ash layers collected in an ESP. We used a fine spray of water droplets to moisten and cool the flue gas and condition the fly ash particles in the conditioning chamber.

Glass windows located at the inlet and outlet of the ESP were used to observe ash levels in the hopper and the effects of rapping on the ash layers accumulated on the ESPs grounded collection plates. During our first test, Method 17 mass measurements were made downstream of the ESP with the voltage on and off. (Time limitations precluded the performance of mass measurements during the second test.) Without the cooling induced by the water spray, the temperature at the inlet of the ESP was about 292 °F. Flue gas temperature dropped by about 8 to 10 °F through the length of the ESP.

Our continuous mass monitor served as a reliable indicator of relative changes in mass concentrations in the outlet duct. Our evaluations of the effectiveness of rapping the ESP collection plates indicated that we should rap the plates only after evaluating a particular combination of flue gas temperature and moisture. More frequent rapping would cause the buildup of ash on the plates to be too slow.

We operated the FFSS with a fabric temperature of 285 °F for the duration of our first test. For both tests, we used woven fiberglass fabric with a 25% exposed surface texturization for our filtration substrate. This is fabric commonly used at utility reverse-gas baghouses. Since one of the primary objectives of our first test was to establish the cleaning schedule that would provide the fastest, most accurate assessment of the pressure drop characteristics of the ash, we operated the FFSS with 1 and 2 hour filtering cycles during this test.

Because the calculation of K_2 requires knowledge of the rate of accumulation of ash on the fabric, we used the rate of pressure drop accumulation at a constant flowrate as our parameter for evaluation of ash filtration characteristics during our first test. For our second test, we measured the mass loading entering the FFSS by placing a thimble filter in parallel with the FFSS. This allowed us to normalize the rate of pressure drop increase by the mass concentration entering the FFSS. (The mass of ash reaching the filter cake cannot be directly measured because of the near-continuous operation of the FFSS, and effects that the geometry of the FFSS transform has on selective particle settling.)

During our second CCF test, the ESP was operated around 40 kV and 0.48 mA total current. This setting resulted in a current density of 30 nA/cm². (Periodically during our tests we measured V-I curves for the ESP. We maintained the applied voltage between 38 and 43 kV to build ash layers on the grounded plates. At these voltages, the current density ranged from 2.5 to 33 nA/cm².) Relatively stable operation was maintained for the FFSS and ESP at about 290 °F for about 6 hours. We collected a relatively thick ash layer on the ESP plates and then began injection of a water spray

into our conditioning chamber to cool the ESP inlet to around 168 °F. While the flue gas and slipstream ducting were cooling, we also lowered the set points on the FFSS ovens and probe heaters to around 165 °F. After temperatures stabilized at these lower values we operated the ESP and the FFSS for several hours. We then began to increase the temperature in the ESP by reducing the volume of water spray. (We discontinued FFSS operation during the period of transition in flue gas temperature.) Severe reentrainment from the ESP plates was observed at an ESP inlet temperature of about 193 °F. We reestablished stable ESP and FFSS operation at about 220 °F. Figure 1 presents a record of this and subsequent reentrainment events as observed by our P5-A optical monitor.

From an ESP operating temperature of around 220 °F, we gradually lowered the flue gas and ESP temperature to around 165 °F by increasing the water spray. However, during this drop in temperature, we were not able to reproduce the reentrainment phenomenon we observed during the temperature rise through 193 °F. We then cleaned the ESP plates and re-deposited an ash layer at an operating temperature of about 165 °F. The FFSS was also brought back on line at this temperature and allowed to operate for four hours. During this period, the filtering pressure drop across the fabric in the FFSS did not increase. Our experiences at other operating temperatures would tend to attribute much of this inability to build pressure drop to a decrease in the fundamental gas flow resistance (K_2) of the filter cake. However, even a much lower K_2 should still result in a gradual increase in filtering pressure drop. We also measured lower mass loadings at the inlet to the FFSS at this temperature, but we would still predict some increase in pressure loss through the fabric.

After an ash layer had been formed in the ESP at 165 °F, we isolated the FFSS and began a ramp up in temperature. Once again, we observed severe reentrainment at ESP inlet temperatures between 198 and 218 °F. After cleaning the ESP plates and reheating the system to around 260 °F, we maintained stable operation of the FFSS at this temperature. After operation at 260 °F, we once again attempted to induce reentrainment by gradually decreasing operating temperatures. We did observe an increase in emissions from the ESP at about 203 °F. Unfortunately, this event coincided with a soot blow in the CCF, and we cannot be certain the emissions we saw were due to reentrainment from the ESP. Visual observations through the ESP window did show significant amounts of ash falling off the plate during this period; however, similar reentrainment was often viewed through the window when no significant increases in outlet emissions were being measured by the P5-A.

We once again dropped the system temperature to about 165 °F and built a new ash layer on the ESP plates. After building the layer, we gradually increased the system temperature and once again observed highly active reentrainment of the collected ash. This time the reentrainment occurred at an ESP inlet temperature of about 182 to 187 °F. During this episode of reentrainment (shown in Figure 2) the relative humidity in the ESP was about 16 %. (This value of relative humidity has been adjusted to account for the difference in the temperatures of the ESP and the relative humidity monitor.) We continued to increase system temperature all the way up to about 220 °F, but we did not observe additional significant reentrainment. We then reheated the system to about 272 °F to obtain more FFSS operating data. We also rebuilt ash layers on the ESP plates at this temperature. As we had done before, we attempted to induce reentrainment of these ash layers by gradually dropping system temperature with water spray injection. No significant reentrainment was observed as we slowly lowered the system temperature to 150 °F. However, when we raised the temperature of the inlet to the ESP back up to around 203 °F, we again observed the reentrainment phenomenon.

Figure 1. Comparisons of ESP inlet temperature and P5-A outlet monitor output. Distinct reentrainment events correspond to periods when the ESP temperature was being increased.

Figure 2. Comparisons of ESP inlet temperature and P5-A outlet monitor output. Distinct reentrainment events correspond to periods when the ESP temperature was being increased. Actual values of relative humidity in the ESP were somewhat lower than the values presented on this graph due to differences in temperature.

Observations from FFSS Operation

In order to analyze the effects that duct humidification had on the filtration characteristics of the ash collected in the FFSS, we observed two main parameters: the rate of pressure drop increase across the filtering fabric, and the amount of ash entering the FFSS filtration cabinet. These data are summarized in Table 1. The final column in this table normalizes the rate of pressure drop increase by the mass loading we measured with the thimble filter we placed in parallel with the FFSS. This normalized value should provide a fair indication of relative changes in K_2 at different flue gas conditions. The relative humidity values presented in Table 1 were calculated from moisture determinations performed on samples taken from the ESP outlet duct during the corresponding FFSS test periods.

Table 1
Summary of FFSS Operation

FFSS orifice temperature, °F	approximate RH in FFSS, %	$\Delta(\Delta P)/hr$, in. H_2O/hr	FFSS inlet mass loading, gr/ft^3	$\Delta(\Delta P)/hr/FFSS$ inlet mass loading, (in. H_2O/hr)/ gr/ft^3
300	1.3	0.23	1.15	0.20
300	1.3	0.22	1.15	0.20
300	1.2	0.40	1.65	0.24
260	2.5	0.30	1.03	0.29
220	6.1	0.11	0.75	0.14
190	--	0.00	--	--
165	22	0.01	0.38	0.02
165	23	0.01	0.45	0.02

The values in Table 1 indicate that rate of pressure drop increase falls as humidity increases. (The data obtained at around 260 °F vary from this trend.) For a more definite assessment of this effect, we will obtain more FFSS data between 300 and 165 °F during our next test. Although we will be performing more evaluations of water vapor conditioning during subsequent CCF tests, we have shown that this type of conditioning was able to reduce filtering pressure drop.

Observations from ESP Operation

As in our first test, the total flow rate through the ESP was maintained at about 280 acfm. In order to evaluate the ability of flue gas humidity and temperature to affect the electrostatic reentrainment of deposited layers, we observed the ash layers and the performance of the ESP as we slowly increased or decreased the flue gas temperature. We altered temperature by varying the amount of water injected into the conditioning chamber. Several factors may have complicated our observations. Our visual observations of the ash layers deposited on the ESP plates indicated that the appearance of the layer depended on the relative humidity in the ESP during deposition. When ash layers were deposited at around 275 °F (1.2 % RH) the ash layer looked smooth, with many large craters in its surface. In contrast, the ash layers deposited under high humidity conditions (22 % RH at about 165 °F) appeared fluffy, and the surface of the layer seemed to be composed of small (1/32 inch diameter) agglomerates of ash particles. This appearance agrees with the kind of fluffy structures we observed in laboratory measurements of uncompacted bulk porosity at relatively high humidities. We would expect that these fluffy ash layers have a higher porosity and probably a different inherent tensile strength associated with the physical configuration of particles than the smooth layers formed at lower

relative humidities. Since the major reentrainment phenomena we observed were from these fluffy ash layers, the characteristics (porosity and tensile strength) of the layer may be key factors in inducing reentrainment.

Because the temperature and humidity of the flue gas were changing as we approached conditions where reentrainment was likely (around 190 °F and 18 % RH), the ash layers on the ESP plates were either drying out or adsorbing additional moisture as the ESP passed through the conditions most conducive to reentrainment. The actual water content of the ash layer may not have been the same during ascending and descending temperature conditions. It is also possible that, during periods of ascending flue gas temperature, the drying out of the fly ash layer generated a small degree of evaporative cooling of the layer. This might be sufficient to affect the rate of increase of the temperature of the ash.

Ash resistivity is a key factor in the reentrainment phenomenon. Resistivity is strongly influenced by adsorbed water on the ash, as well as by ash temperature. Therefore the same factors mentioned above that may have affected the porosity and tensile strength of the ash layer, also significantly influenced ash resistivity. We measured the resistivity of ash we obtained from the ESP plates after the conclusion of the second test. These data are presented in Figure 3.

The ash we saw being ejected from the ash layers on the plates usually came off as small (~1/8 inch) chunks. It was not possible to tell from visual observation what became of the chunks after they fell into the gas stream. Since the bulk cohesivities of the ash layers formed at high and low relative humidities are probably quite different, the chunks of ash that we observed reentering the flue gas stream from the ash layers may have behaved differently in the inter-electrode region. In the laboratory, we observed the decrepitation, or breaking up, of agglomerates of ash lofted into the inter-electrode space in the electrostatic tensiometer we used to measure tensile strength. If the degree of difference in cohesivity was sufficient to induce or prevent significant decrepitation of the chunks of ash entrained from the ash layer, then we may actually have been inducing reentrainment during our descending-temperature transitions. The reentrained chunks of ash may have been too cohesive to decrepitate, and therefore may have fallen rather quickly and directly into the ESP hopper. This type of reentrainment would have been visible through the ESP window, but would not have been detected by our continuous mass monitor. On the other hand, the fluffier chunks of ash formed at high humidities may have decrepitated more fully, and led to the large increases in outlet emissions sensed by our P5-A monitor.

Rather large deposits built up on the discharge electrodes during operation at low temperatures and high humidities. The deposits were about 1 inch wide transverse to flow and up to 4 1/2 inches long in the direction of gas flow. Deposits formed on the wires at higher temperatures and lower humidities were only about 1/8 inch thick and seemed to be more radially symmetrical. We are not sure what effects these buildups have on reentrainment (other than an alteration of the field strength required to obtain a given total current).

Figure 3. Resistivity of ash collected from the ESP plates following our second CCF test. Resistivity was measured with 9.5 % H₂O by volume.

PLANS FOR THE UPCOMING QUARTER

During our first two pilot-scale tests, current and voltage levels for the ESP power supply were recorded manually. We have modified our power supply and data acquisition system so these data will be recorded automatically in subsequent tests. We have obtained a more sensitive P5-A to use on the outlet duct, in place of the unit we have been using. This newer, more sensitive unit may help resolve the decrepitation issue discussed above. We have placed the other P5-A in the ducting leading to the ESP. We also plan to videotape the reentrainment phenomena we expect to see through the ESP window during subsequent tests. During our second test, we determined that the saturated steam we currently have available for flue gas conditioning is too wet for our needs. We have superheated the steam line to allow for the injection of dry steam. Additional coals scheduled to be tested at the CCF (in 70-hour runs) include Powder River Basin coal and a Venezuelan coal. The next pilot-scale test (currently scheduled for the middle of May) will be performed on the Venezuelan coal. We plan to participate in the next three or four CCF tests.

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Approved by

A handwritten signature in black ink, reading "P. Vann Bush", is written over a horizontal line.

P. Vann Bush Manager, Particulate Science and Engineering Group

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