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**CHARACTERIZATION AND MODIFICATION
OF PARTICULATE PROPERTIES
TO ENHANCE FILTRATION PERFORMANCE**

**QUARTERLY TECHNICAL PROGRESS REPORT.
March, 1989 - May, 1989**

Prepared for
U.S. DEPARTMENT OF ENERGY
Pittsburgh Energy Technology Center
Post Office Box 10940, MS 920-L
Pittsburgh, Pennsylvania 15236

Southern Research Institute

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June 22, 1989

Todd R. Snyder
Michael S. Robinson
P. Vann Bush

SOUTHERN RESEARCH INSTITUTE
Post Office Box 55305
2000 Ninth Avenue South
Birmingham, Alabama 35255-5305

Prepared for

U.S. DEPARTMENT OF ENERGY
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Post Office Box 10940, MS 920-L
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Perry D. Bergman, Project Manager

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SUMMARY

This report describes the results of project activities that occurred during the period from March 1 through May 31, 1989. The organization of this report generally follows the outline of work presented in the Project Work Plan. Work performed during this period included tests under Task 2 - Parametric Tests of Ashes and Fabrics, and Task 3 - Survey of Methods to Modify Particle Filtration Properties. Discussion of the Task 2 work has been organized topically, rather than adhering to the Activities specified in the Work Plan.

Cohesive ash from the Tennessee Valley Authority's 160 MW Atmospheric Fluidized-Bed Combustor at the Shawnee Plant in Paducah, Kentucky was obtained during this quarter and has been analyzed in the laboratory.

The second phase of the abstract search and review of pertinent articles included in activity 3.1 is nearly complete. A summary of this phase of the literature search is included in this report. A variety of potential conditioning agents have been evaluated during this reporting period. These agents include sodium bicarbonate, hydrated lime, various grades of fine silica powder, gasifier char, glass beads and glass fibers. The three source ashes have been mixed with these agents in different concentrations and using various mixing techniques. These tests are continuing, and this report contains a summary of the combinations evaluated during this past quarter.

DISCUSSION OF TECHNICAL PROGRESS

TASK 2. PARAMETRIC TESTS OF ASHES AND FABRICS

The test plan for Task II calls for parametric testing with the SRI Fabric Filtering Sampling System (FFSS) of the filtration performance of three ashes. The three sources of ash are:

- Monticello Station (Texas Utilities Electric Co.) - Texas lignite coal ash
- Scholz Station (Gulf Power Co) - eastern, bituminous high sulfur coal ash
- Shawnee Steam Plant (Tennessee Valley Authority) - 160-MW Atmospheric Fluidized Bed Combustor (AFBC) - ash and limestone sorbent

The second parameter in the filtration tests is the size distribution of the ash entering the FFSS (inlet ash). Three size fractions of each of the source ashes are to be filtered: unmodified source, $< 5 \mu\text{m}$ mass median diameter (MMD), and $\leq 2.5 \mu\text{m}$ MMD. Inertial separators placed in the sampling line are used to generate these latter two truncated size fractions of inlet ash. An Acurex Source Assessment Sampling System (SASS) cyclone (inlet cyclone #2) has been used to generate the smallest of these size fractions. The final parameter in the filtration tests is the fabric design. Two extremes in design of woven fiberglass filtering fabric are to be used: double-crowfoot weave with 100% exposed surface texturization (EST) and a four-harness satin weave with 0% EST. As of the end of this reporting quarter the following ash, fabric, and size fraction combinations have been tested.

Table 1
TASK II PARAMETRIC FILTRATION TESTS COMPLETED AS OF MAY 31, 1989

ASH SOURCE	FABRIC DESIGN	INLET ASH SIZE FRACTION
Scholz	0% EST	Unmodified
Scholz	100% EST	Unmodified
Scholz	0% EST	$\leq 2.5 \mu\text{m}$
Scholz	100% EST	$\leq 2.5 \mu\text{m}$
Monticello	0% EST	Unmodified
Monticello	100% EST	Unmodified

Characterization of Inlet Ash

The methods used to characterize the inlet ash are described in Appendix A. The concentration and size distribution data for the inlet ashes are summarized in table 2. Figure 1 graphically summarizes the impactor data. The mass probability distributions of both unmodified source ashes are similar for particle diameters less than $10 \mu\text{m}$, but the Monticello ash is coarser, with a substantially larger MMD. Inlet cyclone #2 reduces the unmodified source Scholz ash entering the sampling probe to a size fraction with an MMD of $2.2 \mu\text{m}$ prior to the entry of the ash into the FFSS.

Table 2
INLET ASH CHARACTERISTICS

SOURCE ASH	CYCLONE USED	METHOD 17 INLET LOADING gr/ft^3	FFSS INLET LOADING gr/ft^3	MMD* μm
Monticello	None	6.76	6.88	34
Scholz	None	7.06	6.80	19
Scholz	# 2	0.54	0.62	2.2

* measured with University of Washington Mark V Cascade Impactor

Characterization of Dustcake Ash

Ash samples taken from dustcakes collected by the FFSS were analyzed with a Coulter Counter, which provides a measurement of the distribution of particle sizes based on their equivalent volumetric diameter. (This volumetric distribution can be considered to be equivalent to a mass distribution, provided all particles in a sample are assumed to have the same true density.) The Coulter Counter data are summarized in the table 3 and in figure 2.

Figure 2. Mass probability distributions of dustcake ashes collected from unmodified Monticello and Scholz inlet ashes.

The values of MMD for the unmodified dustcake ashes are in the range of typical values for dustcake ashes from baghouses on utility pulverized-coal-fired boilers (approximately 5 - 8 μm).

Table 3
MEDIAN DIAMETERS OF DUSTCAKE ASHES COLLECTED IN THE FFSS

ASH	FABRIC EST* (%)	INLET ASH SIZE	MMD (μm)
Monticello	0	Unmodified	7.1
Monticello	0	Unmodified	6.7
Monticello	100	Unmodified	5.6
Scholz	100	Unmodified	5.4
Scholz	100	$\leq 2.5 \mu\text{m}$	2.6

* exposed surface texturization

The difference between the inlet ash and the dustcake ash is a result of the settling out of large particles into the FFSS hopper before they reach the filtering fabric. This settling tends to effectively reduce the differences between the size distributions of the Scholz and Monticello ashes. Figure 3 shows the mass probability distributions of two samples of Scholz ash. The inlet ash sample data was obtained with the cascade impactor located immediately downstream of inlet cyclone #2. The dustcake ash sample was collected by the FFSS downstream of inlet cyclone #2 and analyzed with the Coulter Counter. The differences in the distributions plotted in figure 3 are probably due to differences in the measurement techniques.

The mass probability distributions of two samples of Monticello dustcake ash collected on fabric with 0% EST from an unmodified inlet ash were also measured using the Coulter Counter. The analyses performed on these two samples obtained from two different tests verified the reproducibility of the parametric tests. The results presented in figure 4 show that the size distributions of the two dustcake ashes are similar. The size distribution of unmodified Monticello ash collected on fabric with 100% EST is included in figure 4 for comparison with unmodified Monticello ash collected on fabric with 0% EST. It was expected that the ash comprising the dustcake would be independent of fabric type; however figure 4 suggests this may not be the case. This apparent difference will be examined in future tests.

Analyses of Filtration Test Results

The standard way to compare filtering data is to normalize the pressure drop by the filtering face velocity (or air-to-cloth ratio), yielding the quantity called drag. Drag is then presented as a function of the dust loading (or dustcake areal density) on the filtering fabric throughout the filtration test.

One of the two principle characteristics of the drag-area density relationship is the specific drag coefficient, K_2 , which is defined as the slope of the curve after ash particles have filled the pores in the fabric or dustcake. The relationship is expected to become linear after these pores have been filled, and theoretically does for idealized porous beds. The other principle

Figure 3. Mass probability distributions of Scholz ash collected downstream of inlet cyclone #2. The inlet ash size distribution was characterized with the University of Washington Mark V impactor and the dustcake ash was characterized with the Coulter Counter.

Figure 4. Mass probability distributions of Monticello dustcake ash collected on each of the two test fabrics. Analyses of samples from two separate filtration tests performed on the 0% EST fabric are shown.

characteristic of the drag-areal density relationship is the effective residual drag, Se , which is the Y intercept of the linear part of the curve. These two characteristics are shown graphically on figure 5, an idealized data set. Often, actual data taken with the FFSS has been fitted more precisely with a second-order equation rather than a straight line. This second-order fit acknowledges the fact that the $K2$ value increases as a function of areal density. When a second-order fit is used, Se is the Y intercept of the second-order curve. The equations of fit to the data were calculated by the method of least squares for all data points whose areal density value was greater than 0.01 lbs/ft^2 . This minimum value, 0.01 lbs/ft^2 , was chosen to exclude all data taken while the fabric pores were filling in with ash particles.

Sudden increases in fabric pressure drop, as described in quarterly report number 1, have also been observed in more recent tests. It is believed that these increases are due to dustcake compaction resulting in a decrease in porosity, but that these are perturbations that can be factored out of the data for the purposes of our analyses. Adjustments have been made to the data to allow comparisons between different tests. In some tests a sudden increase in pressure drop occurred only during the last few minutes of the test, in which case only the data collected prior to the event is reported. Where many increases in pressure drop occurred throughout the test, the effects were removed by subtracting the magnitude of the increase from all data after each increase. These adjustments have the effect of filtering out the perturbations just as curve-fitting does.

Effects of Size Distribution

Figure 6 presents one mass probability distribution of Scholz dustcake ash collected with no inlet cyclone in line and another distribution obtained with inlet cyclone #2 in line. Use of the cyclone induces a dustcake comprising much smaller particles. This difference affects the filtration performance of the ashes. Figures 7 and 8 present drag versus areal density relationships comparing the two size fractions of Scholz ash collected on each of the test fabrics. The specific drag coefficient of the ash, $K2$, which is the rate of increase of drag per unit areal density increase, is significantly greater for the dustcake comprising the smaller ash particles regardless of fabric. The filtration performance of these ashes and corresponding data for the test with unmodified Monticello ash are summarized in table 4 below.

Table 4
MATHEMATICAL CHARACTERISTICS OF THE SCHOLZ AND MONTICELLO
FILTRATION DATA

ASH	FABRIC	SIZE	Se^{**}	$K2^*$	r^*	r^{**}
Scholz	0%	Unmodified	0.471	6.885	.99923	.99990
Scholz	100%	Unmodified	0.085	7.103	.99492	.99985
Scholz	0%	$\leq 2.5 \mu\text{m}$	1.219	41.743	.99943	.99955
Scholz	100%	$\leq 2.5 \mu\text{m}$	0.144	23.124	.99982	.99982
Monticello	0%	Unmodified	0.997	5.840	.99633	.99854
Monticello	100%	Unmodified	0.100	5.164	.99813	.99972

* Values derived from a linear fit to the data.

** Values derived from a second-order fit to the data.

Figure 5. Idealized plot of drag as a function of areal density showing the phase of filtration when fabric pores are filled and the definitions of K_2 and S_e .

Figure 6. Mass probability distributions measured with the Coulter Counter of Scholz dustcake ashes.

Figure 7. Drag as a function of areal density for filtration tests of the Scholz ash collected on 100% EST fabric.

Figure 8. Drag as a function of areal density for filtration tests of the Scholz ash collected on 0% EST fabric.

Some of the relationships between drag and areal density appear distinctly concave, so second-order fits to the data were calculated. The second-order fit is definitely an improvement for the tests with no inlet cyclone, based upon the r values for the regression lines. This means that the drag increases at an increasing rate as the areal density increases, possibly indicating dustcake compaction as described by Rudnick (1978). A second-order fit provides no improvement for tests run with the inlet cyclone which modifies the size distribution to ≤ 2.5 microns. The correlation coefficients r are presented as indicators of the quality of the linear and second-order fits used in the data reduction.

The increase in K_2 when cyclone #2 is used is primarily due to the larger total surface area of particles in a given mass of dustcake ash for the cakes comprising the smaller ash particles. Deviations from this effect would be expected only when the morphology of the smaller particles significantly differ from the morphology of the larger particles.

Effects of Ash Source

Figure 9 is a comparison of Scholz and Monticello ashes collected on each fabric type. The data in Figure 9 and Table 4 indicate that the K_2 values for the unmodified Scholz and Monticello ashes are relatively similar. Observations of the dustcakes formed during these tests, as well as characteristics of the source hopper ashes and dustcake ashes obtained from full-scale operating baghouses at these two plants, indicate that the dustcakes formed by these two ashes are quite different. The porosity of dustcakes formed in the FFSS tests were estimated to be 73.4% for the Scholz dustcakes and 61.0% for the Monticello dustcakes. (These estimates were derived from dustcake height and areal density determinations made at the end of the filtration tests, and are in good agreement with data from baghouses at these plants.) Since filtering drag is highly dependent on dustcake porosity, the difference in drag induced by these differing porosities must be compensated for by another factor. This factor is the particle morphology. Photographs of the two source hopper ashes presented in previous quarterly reports show the smaller particles (those preferentially collected on the dustcake) to be smoother and more spherical for the Monticello ash than for the Scholz ash. This trend agrees with observations of dustcake ash from the baghouses at these two plants. Laboratory measurements of the drag-equivalent diameter, specific surface area and morphology factor of these FFSS dustcake ashes are planned to verify this observation.

The data in Figure 9 also indicate a distinctly greater Se for the Monticello ash collected on the 0% EST fabric than for the Scholz ash collected on the 0% EST fabric. We believe this difference is a result of the infiltration of the low cohesivity Monticello ash particles into the pores of the 0% EST fabric. In contrast, the Scholz ash particles, because of their relatively higher cohesivity, do not infiltrate the pores of the 0% EST fabric to the extent of the Monticello ash particles, but tend to bridge over the pores.

Effects of Fabric Design

Figures 7, 8 and 9 show the effects of fabric on the drag-area density relationship developed during filtration. In all cases Se is larger for a dustcake collected on fabric with 0% EST. This is due to the size and distribution of pores in the fabric structure. All of the sample air passing through the FFSS must pass through the pores in the fabric after passing through the dustcake supported on the fabric. Although the 0% EST fabric contains larger, more distinct pores than the 100% EST fabric, the total area of porous fabric is less than in the 100% EST fabric. The pores through the 0% EST fabric are rapidly filled in and/or

Figure 9. Drag as a function of areal density for filtration tests of the unmodified Scholz and Monticello ashes.

bridged over with dustcake ash particles. If these pores become loaded with dustcake ash particles, the movement of the air through them can generate a significant amount of drag.

K2 is generally dependent only on ash characteristics (cohesivity, shape and size) and independent of fabric type. However, in the case of the smaller size Scholz ash, the data in Table 4 show K2 to be twice as great on the fabric with 0% EST as on the fabric with 100% EST. This influence of fabric design on K2 will be studied further in later tests.

Activity 2.2.3: Very cohesive ash (Shawnee AFBC)

Approximately 2000 lbs of ash were collected from baghouse compartment 6 - west hopper, at the 160 MW Atmospheric Fluidized-Bed Combustor (AFBC) located at the Tennessee Valley Authority Shawnee Plant in Paducah, Kentucky. This ash was brought to the laboratories at Southern Research Institute for use in activity 2.2.3 and conditioning studies performed under Task 3. Measured characteristics of this ash are presented in the discussion of activity 3.3.

TASK 3. SURVEY OF METHODS TO MODIFY PARTICLE FILTRATION PROPERTIES

Activity 3.1: Literature Search to Identify Trial Conditioning Agents

A search of abstracts contained in the National Technical Information Service (NTIS), COMPENDEX PLUS, and Searchable Physics Information Notices (SPIN) databases was performed through the DIALOG Information Services. The NTIS database consists of unclassified government-sponsored research, development and engineering reports, and other analyses prepared by government agencies. The COMPENDEX PLUS database provides coverage of the world's significant engineering and technical literature. This database corresponds to the printed publication, "Engineering Index", plus additional conference records from the Engineering Meetings file. The SPIN database provides the most current indexing and abstracting of the major American, Russian, and Chinese physics and astronomy journals.

More than 5600 abstracts located through the literature search were reviewed. 57 articles and reports were selected in this review and ordered. As of the end of this reporting period, all but seven of the reports or articles had been received. Each article or report received has been examined thoroughly for information applicable to this research project. In addition to the material obtained through the DIALOG search, several other articles and brochures have been examined for useful information. Appendix B contains a summary of each of the sources examined which contained information useful to the objectives of this project. (This appendix begins at the point where a corresponding appendix, Appendix A, ended in the last quarterly report.) The most useful sources found during this quarter are identified as articles number 74, 91, 101, 107, 117, 131, 132, 133, and 134.

In general, the literature reviewed indicated that the primary particle attraction mechanisms that determine the cohesiveness of powders are electrostatic attraction, van der Waals forces, and adsorbed surface films. The particle characteristics that are of primary importance are particle size and particle shape. The predominant attractive force determining the cohesivity of fly ashes is the van der Waals force, which is heavily influenced by particle size and shape, particle closeness, and contact area. These factors can in turn be influenced by the introduction of relatively small amounts of submicron particles on the surfaces of the host fly ash particles. These small additive particles can increase the separation distances between the host particles, decreasing the van der Waals

force. They may also act as lubricants between the larger host particles, allowing the conditioned mixture to flow more freely than the original host powder. More detailed discussions of these mechanisms are included in Appendix B.

Activity 3.3: Laboratory Analyses of Unconditioned Ashes

The hopper ash obtained from the 160 MW AFBC was characterized with the range of laboratory tests described in the first Quarterly Technical Progress Report. The results of these tests are presented in Table 5 along with corresponding results for the Monticello and Scholz ashes, analyzed earlier. (Table 5 contains the corrected value of specific surface area of the Monticello hopper ash, which was incorrectly reported in earlier reports.) The compacted bulk porosity, uncompacted bulk porosity, and shear tests performed on the AFBC ash indicate that it is significantly more cohesive than the Monticello or Scholz ashes and therefore meets the qualifications called for in the Project Work Plan. The AFBC ash has a smaller mass median diameter as measured with the Bahco aerodynamic classifier than the other two ashes (figure 10). The volumetric size distribution of the AFBC ash measured with the Coulter Counter is presented in figure 11. SEM photographs of the AFBC hopper ash are presented in figure 12 and show the irregular particle shapes of the AFBC ash particles, which are also indicated by the relatively high morphology factor measured for this ash.

Activity 3.4: Selection and Acquisition of Conditioning Agents

The search for conditioning agent candidates is continuing. Most of the agents acquired and tested so far are relatively fine powders. Information obtained through the literature search indicates that the effectiveness of fine powders used to alter the properties of a host powder are strongly dependent on the size, shape and concentration of the additive particles. Very fine additive particles can be introduced between host powder particles, thereby strongly influencing interparticle forces of attraction. If the size of these additive particles is less than the asperities normally found on the surfaces of the host particles, the additive particles will be obscured by the asperities, and their conditioning effectiveness will be reduced. When fine additive particles are basically spherical they can act as rolling ball bearings between the host particles, decreasing the cohesivity of the conditioned ash. Additive particles having more irregular shapes are less likely to be able to act in this manner. In order for conditioning additives to be effective, their concentration must be high enough to influence the geometry of a significant percentage of contact points between host particles, but low enough to prevent excessive interaction between conditioning particles. (These considerations are discussed in more detail in Appendix B.)

Conditioning agents selected so far include gaseous NH_3 (in the presence of SO_3), several grades of fine silica powders, three types of fly ashes, gasifier char, sodium bicarbonate, chemical hydrated lime, glass beads, and glass fibers. Table 6 lists these conditioning agents and some of their pertinent characteristics.

Activity 3.5: Evaluation of Conditioning Agents

Three main sets of conditioning experiments were performed during this reporting period. The first two sets were performed in the mixing and conditioning chamber described in previous reports. The first set consisted of additional tests designed to examine in greater detail some of the test results presented in the last quarterly report. As with the earlier tests, mixtures of Monticello hopper ash and Scholz ash samples combined in the mixing and

Table 5
RESULTS OF THE ANALYSES OF ASH SAMPLES

	Bahco MMD Coulter MMD Drag-Equivalent	Monticello Hopper Ash	AFBC Hopper Ash	Scholz Hopper Ash
Particle Diameters (μm)		52.29 -- 8.50	5.7 5.5 1.02	14.15 -- 5.14
Particle Density (g/cm^3)		2.13	2.80	2.35
Specific Surface Area (m^2/g)		9.2	13.5	7.4
Morphology Factor		--	34.2	--
Effective Angle of Internal Friction (degrees)		33.5	50.8	42.3
Uncompacted Bulk Porosity		0.502	0.856	0.751
Compacted Bulk Porosity		0.389	0.645	0.636
Relative Gas Flow Resistance (in. $\text{H}_2\text{O}\cdot\text{min}\cdot\text{ft}/\text{lb}$)		3.4	4.2	0.6
Chemical Composition (wt. %)				
Li ₂ O		0.02	0.01	0.02
Na ₂ O		0.30	0.22	0.66
K ₂ O		0.90	1.2	2.6
MgO		1.8	2.1	0.91
CaO		5.9	37.5	4.3
Fe ₂ O ₃		3.1	11.6	20.7
Al ₂ O ₃		19.7	9.7	19.5
SiO ₂		66.1	21.0	49.9
TiO ₂		0.83	0.50	1.1
P ₂ O ₅		0.05	0.14	0.18
SO ₃		0.11	14.4	1.0
Soluble Sulfate		0.16	14.0	1.4
Loss on Ignition		0.11	12.4	20.5
Equilibrium pH		9.2	11.8	10.4

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Figure 10. Aerodynamic size distributions of the Monticello, Scholz, and AFBC hopper ashes measured with the Bahco classifier.

Figure 11. Volumetric size distribution of the AFBC hopper ash measured with the Coulter Counter.

(a)

(b)

(c)

(d)

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Figure 12. SEM photographs of AFBC hopper ash at magnifications of a) 100x b) 500x c) 1000x d) 5000x.

Table 6
CHARACTERISTICS OF CONDITIONING AGENTS EVALUATED IN TASK 3

CONDITIONING AGENT	PRIMARY CHARACTERISTICS
Cab-O-Sil silica L90	100 m ² /g; low bulk density; white powder; 99.8% SiO ₂ ; hydrophilic amorphous aggregates
Cab-O-Sil silica M5	200 m ² /g; low bulk density; white powder; 99+% SiO ₂ ; very hydrophilic amorphous aggregates
Cab-O-Sil silica EH5	380 m ² /g; low bulk density; white powder; 99+% SiO ₂ ; extremely hydrophilic amorphous aggregates
AGSCO Novaculite silica	1.7 m ² /g; 4.0 µm MMD; 99.5% SiO ₂ ; well-rounded crystalline discs
NaHCO ₃	6.7 m ² /g; low-medium bulk density; soluble white powder
High-Calcium Dolomitic Lime	13.0 m ² /g; medium bulk density; soluble white powder; Ca(OH) ₂ + Mg(OH) ₂
Gasifier Char	278 m ² /g; low bulk density; black powder; very irregular particle shapes; high Carbon content
Glass Fibers	< 5 µm diameter by < 20 µm long strands of fiberglass insulation
Monticello hopper ash	low cohesivity ash (see Table 5)
Scholz hopper ash	medium cohesivity ash (see Table 5)
AFBC hopper ash	high cohesivity ash (see Table 5)

conditioning chamber were collected passively on the inner walls of the chamber. (Details of the test parameters maintained in the mixing and conditioning chamber during these tests are provided in the last quarterly report.) Figures 13 and 14 present the uncompacted and compacted bulk porosities, respectively, of the mixtures of the two ashes as a function of the percentage by weight of Scholz ash added to the Monticello ash prior to the test. Although the cohesivities of the two fly ashes tested were modified by the addition of specific amounts of the other ash, the amounts of additive ash required to significantly modify the host ash cohesivity are probably too high to warrant large-scale application of this type of ash conditioning. However, other types of fly ash (AFBC, etc.) may serve as effective conditioning agents at reasonably low concentrations.

The second set of tests was intended to deposit the fine silica powder Cab-O-Sil M5 on the surfaces of the source hopper ashes. These tests were performed at 300° F, with a 0.2% weight/weight ratio of silica to hopper ash, and the mixed product was collected on the inner walls of the mixing and conditioning chamber. The details of the test procedures used for these tests are provided in Appendix C. Using this mixing method, the addition of the Cab-O-Sil M5 silica to the Scholz hopper ash caused no significant change in the cohesivity of the wall ash. The addition of the silica to the Monticello hopper ash increased the compacted and uncompacted bulk porosities of the wall ash, indicating an increase in ash cohesivity with the addition of the fine silica.

To allow mixing tests to be performed more rapidly, and to eliminate the uncertainty of collection of consistent ash samples from the inner wall of the mixing and conditioning chamber, an alternative mixing method was developed. This method was used for all of the mixing trials in the third set of tests. The basic procedure for this method consisted of combining 400 g of source ash with the desired amount of additive powder (usually between 0.02 and 8.0 g) in a 1-quart jar. This mixture was then shaken by hand for approximately 3 minutes, and then blended at medium speed in a Waring blender for 3 additional minutes. (More precise details of this method are provided in Appendix D.)

Many different combinations of hopper ashes and additives were produced as part of the third set of tests. Monticello and Scholz hopper ashes were combined with Cab-O-Sil M5, Cab-O-Sil EH5, Cab-O-Sil L90, sodium bicarbonate, chemical hydrated lime, gasifier char, glass beads, glass fibers, and Novaculite (silica powder approximately 4 μ m mean diameter). Table 7 presents the mixture ratios and the compacted and uncompacted bulk porosities for the various mixtures produced. Selections of this data are shown graphically in Figures 15, 16, and 17.

The various additive products tried as part of the third set of tests were intended to physically alter the contact points between the host hopper ash particles. Alteration of the contact points should change the cohesivity of the hopper ash. Altered cohesivity would then be reflected in changes in the uncompacted and compacted bulk porosities of the conditioned hopper ash. Results indicated that blending the hopper ashes without any additives lowered the uncompacted and compacted bulk porosity of the hopper ashes. The mechanism responsible for this effect is presently unknown. Tests are planned to determine if a less energetic mixing technique can still be effective for homogeneously mixing the additive with the ash without inducing cohesivity changes in the absence of any additive.

None of the additives blended with the Scholz ash appeared to have a significant effect on the ash cohesivity. When the uncompacted bulk porosity of the conditioned ash is used as the primary indicator of cohesivity, several additives apparently decreased the cohesivity of the Monticello ash. These additives were the three Cab-O-Sil fine silica powders, the chemical hydrated lime, and the gasifier char. We believe the mechanism responsible for

Figure 13. Uncompacted bulk porosity of the wall ash samples as a function of the Scholz ash content of the ash mixture loaded into the chamber.

Figure 14. Compacted bulk porosity of the wall ash samples as a function of the Scholz ash content of the ash mixture loaded into the chamber.

Table 7
SUMMARY OF ANALYSES OF MIXTURES PRODUCED IN BLENDER

Base Ash	Additive in Mixture	% wt. of Additive	Uncompacted Bulk Porosity, %	Compacted Bulk Porosity, %
Scholz	M5 silica	0	70.2	53.0
Scholz	M5 silica	0.05	68.1	53.4
Scholz	M5 silica	0.1	68.8	53.6
Scholz	M5 silica	0.2	68.7	53.5
Scholz	M5 silica	0.5	68.5	54.1
Scholz	M5 silica	1	69.4	53.6
Monticello	M5 silica	0	56.5	34.7
Monticello	M5 silica	0.05	51.7	34.0
Monticello	M5 silica	0.1	49.6	34.2
Monticello	M5 silica	0.2	46.7	34.1
Monticello	M5 silica	0.5	47.2	34.9
Scholz	L90 silica	0	70.2	53.0
Scholz	L90 silica	0.1	69.2	53.2
Scholz	L90 silica	0.5	69.8	53.6
Scholz	L90 silica	1	70.8	53.8
Monticello	L90 silica	0	56.5	34.7
Monticello	L90 silica	0.1	48.7	35.5
Monticello	L90 silica	1	51.3	36.1
Scholz	EH5 silica	0	70.2	53.0
Scholz	EH5 silica	0.1	69.6	53.0
Scholz	EH5 silica	1	70.3	54.0
Monticello	EH5 silica	0	56.5	34.7
Monticello	EH5 silica	0.1	47.6	38.0
Monticello	EH5 silica	1	47.9	36.1
Scholz	Novaculite	0	70.2	53.0
Scholz	Novaculite	0.05	68.7	53.4
Scholz	Novaculite	0.2	69.6	52.7
Scholz	Novaculite	0.5	69.8	52.7
Scholz	Novaculite	1	69.9	52.1
Scholz	sodium bicarbonate	0	70.2	53.0
Scholz	sodium bicarbonate	0.05	70.6	53.3
Scholz	sodium bicarbonate	1	70.2	53.5

Table 7. (continued)

Base Ash	Additive in Mixture	% wt. of Additive	Uncompacted Bulk Porosity, %	Compacted Bulk Porosity, %
Monticello	sodium bicarbonate	0	56.5	34.7
Monticello	sodium bicarbonate	0.1	54.7	34.6
Monticello	sodium bicarbonate	0.5	58.2	35.6
Monticello	sodium bicarbonate	1	59.4	38.6
Monticello	sodium bicarbonate	2	58.0	38.9
Monticello	sodium bicarbonate	5	56.2	38.0
Scholz	chemical hydrated lime	0	70.2	53.0
Scholz	chemical hydrated lime	0.1	70.2	53.6
Scholz	chemical hydrated lime	1	69.8	53.5
Monticello	chemical hydrated lime	0	56.5	34.7
Monticello	chemical hydrated lime	0.1	50.6	35.3
Monticello	chemical hydrated lime	1	49.5	35.5
Scholz	gasifier char	0	70.2	53.0
Scholz	gasifier char	0.1	69.8	53.4
Scholz	gasifier char	1	69.4	52.7
Monticello	gasifier char	0	56.5	34.7
Monticello	gasifier char	0.1	47.9	33.5
Monticello	gasifier char	1	48.6	33.0
Scholz	glass beads	0.05	70.6	52.8
Scholz	glass beads	1	70.4	52.8
Monticello	glass fibers	0	56.5	34.7
Monticello	glass fibers	13	54.5	34.2

Table 7. (continued)

Base Ash	Additive in Mixture	% wt. of Additive	Uncompacted Bulk Porosity, %	Compacted Bulk Porosity, %
Monticello	AFBC hopper ash	0	56.5	34.7
Monticello	AFBC hopper ash	0.05	52.9	35.8
Monticello	AFBC hopper ash	0.1	51.5	35.1
Monticello	AFBC hopper ash	0.5	53.0	35.8
Monticello	AFBC hopper ash	1	50.2	35.0
Monticello	AFBC hopper ash	5	52.7	35.9
Monticello	AFBC hopper ash	20	62.1	39.3
Monticello	AFBC hopper ash	50	73.8	48.5
Monticello	AFBC hopper ash	80	81.3	57.5
Monticello	AFBC hopper ash	95	83.7	61.6
Monticello	AFBC hopper ash	99	84.7	62.9
Monticello	AFBC hopper ash	99.5	84.5	62.9
Monticello	AFBC hopper ash	99.9	84.6	63.0
Monticello	AFBC hopper ash	99.95	84.2	63.2
Monticello	AFBC hopper	100	84.9	63.1

Figure 15. Results of uncompacted bulk porosity measurements of selected mixtures produced in the Waring blender™ of Monticello ash and conditioning agents.

Figure 16. Results of compacted bulk porosity measurements of selected mixtures produced in the Waring blender™ of Monticello ash and conditioning agents.

Figure 17. Results of uncompacted bulk porosity measurements of mixtures produced in the Waring blender™ of Monticello ash and sodium bicarbonate.

the decrease in cohesivity of the Monticello ash when mixed with these additives is the reduction in van der Waals forces due to an increase in the ash particle separation distance. The Monticello ash particles basically resemble smooth spheres. The smaller Monticello ash particles, for which van der Waals forces definitely predominate, more closely resemble smooth spheres than the larger particles. When small additive particles are mixed with the host ash particles, they become deposited on the surfaces of the host particles, preventing close interparticle contact. In the case of the Scholz ash, however, the surfaces of the host ash particles are relatively rough spheres. In this application the small concentration of small additive particles present in conditioned Scholz ash are unable to increase the particle separation distance. Instead, they become effectively obscured among the irregular asperities already present on the surfaces of the Scholz ash particles.

In most cases, the compacted bulk porosity values measured for the conditioned ashes did not show significant changes in ash cohesivity due to the addition of the conditioning powders. This may be due to the high degree of stress placed on the bonds between the ash particles during the compaction process. This stress may overcome the effects of van der Waals forces, and become primarily dependent on host ash particle morphology and size distribution.

The results of the compacted and uncompact bulk porosity tests of the Monticello ash conditioned with sodium bicarbonate indicate that an increase in cohesivity may have been induced. The uncompact bulk porosity tests indicate that the optimum concentration of sodium bicarbonate is approximately 1.0% by weight. The compacted bulk porosity test results indicate an optimum value of approximately 2.0% by weight. Some increase in the compacted bulk porosity value was also noted for the Monticello ash in combination with EH5 fine silica, although this trend was not verified by uncompact bulk porosity measurements.

APPENDIX A

Inlet Ash Characterization Techniques

APPENDIX A

Inlet Ash Characterization Techniques

The smaller size fraction ($\leq 2.5 \mu\text{m}$) was produced by placing the #2 cyclone from an Acurex SASS train cyclone set upstream of the FFSS. This cyclone has a cut point of $2 \mu\text{m}$ with a flow rate of 1.32 acfm. When an inlet cyclone is used a pre-collecting container is also put in line upstream of the cyclone as an auxiliary inertial separator to insure that the collection cup of the cyclone is not overburdened. The inertial separator is an air-tight cylinder 12.5-inch tall by 3-inch diameter. During the tests run with the inertial separator, both using Scholz ash, the cyclone cup collected 40% by weight of the ash accumulated by the inertial separator and cyclone combined. This is a significant portion of the total, indicating that the inertial separator has a cut point greater than $2.5 \mu\text{m}$. Figure A-1 is a photograph showing the arrangement of inertial separator, inlet cyclone, and entry into the FFSS.

Several EPA Method 17 mass measurements were made on each ash source/size fraction condition measured. Mass measurements were run at isokinetic conditions for 3 min to 1 hour using either a 63 mm filter or a 19x90 mm thimble. The exact sampling conditions were chosen so as to run for as long as possible without overloading the filter. The results of the mass trains were consistently reproducible. Two University of Washington Mark V impactor runs were made for each of the three ash source/size fraction conditions. The impactor data were also accurately reproduced. The total mass collected in the Method 17 tests were used to calculate an inlet mass loading as a check on the accuracy of the impactors. The impactor mass loadings agreed with the mass measurement results and are included in the reported mass concentration which is an average of all measured mass concentrations.

A specialized plumbing arrangement was required to run the impactor downstream of the inlet cyclone. Because the cut point of the cyclone depends on its flow rate, it was necessary to pull 1.32 acfm through the cyclone to measure the size distribution entering the FFSS. The impactor however, is not accurate at flow rates greater than 0.75 acfm. The solution was to split the flow exiting the cyclone into two legs using a Y-shaped tube. One leg of the Y went through the impactor to a pump pulling 0.66 acfm, the other leg went through a mass filter to a pump pulling 0.66 acfm, for a total flow through the cyclone of 1.32 acfm. The results of both impactor runs were nearly identical, and good agreement was observed between the inlet mass loading measured by the Method 17 tests and by the impactor. As a further check the leg of the Y from which the impactor sampled was switched with the mass measurement for the second run. The results of this arrangement agreed with the first configuration.

Figure A-1. Photograph of the sampling train arrangement used to modify the inlet ash size distribution. The dust-laden sample air moves through the inertial separator, inlet cyclone #2, and finally into the FFSS.

APPENDIX B
Summary of Literature Review
Part II

74. Johansen, S.T. Fouling of walls in systems where hot, dusty gases are transported. Selskapet for Industriell og Teknisk Forskning, Trondheim (Norway) (1988).

This report discusses the mechanisms (electrostatic attraction, van der Waals forces, adsorbed surface films) of adhesion that determine the degree of adhesion between fly ash particles. Though the report deals primarily with the fouling of tubes in hotter environments than fabric filters experience, some of the discussions are useful. The author states that particles can pick up electrostatic charge easily, and that individual particles can carry significant charges. These factors can lead to rapid agglomeration. Increased humidity in the gas can reduce the charging of the particles. The author references Rumpf's discussions of chemical and physical properties of particles, microstructure of particles, temperature, humidity, electrical charges, adsorbed gases, and particle size.

The author notes that some references indicate that van der Waals forces are 100 times stronger than electrostatic forces, while other references state they may be of the same magnitude. Young's statement that the adhesion of silica is due to water vapor adsorption on silanol sites of the silica surface. A brief discussion is provided on physical and chemical adsorption of gases on particle interfaces. Chemisorbed layers are often monolayers which are very hard to remove. Adsorbed layers increase the distance between interacting bodies, and thus decrease van der Waals forces. However, some experimenters have demonstrated that the adsorption of water increases adhesive forces by up to a factor of 5.

Contamination of particle surfaces with submicron particles can decrease particle adhesion by decreasing contact area and closeness of approach. Contact area can be increased with softening of particles. Adhesive forces increase proportionally with contact area. Surface roughness also influences adhesion. Some investigators have shown that submicron irregularities sticking to specific sites can increase adhesion. Others have found decreased adhesion. The important factors seem to be primary particle shape and size, and the size and distribution of submicron irregularities. Adhesion depends on particle closeness and contact area.

76. Ahluwalia, R.K., Im, K.H., Hajduk, J.C. Mechanism of particulate adhesion in coal-fired gas turbine systems. CONF-8609154-3 (1986).

The authors state that the primary sources of adhesive energy between particles arise from van der Waals forces and electrostatic attraction. The presence of moisture negates the contribution of electrostatic attraction. The rest of this report is not applicable to this research project.

77. Royal, T.A. Gravity flow of solids engineering handbook. Volume 1. Analysis of pressurization of lock hoppers and typical measured flow properties of coal. Final technical report phase 2. DOE/MC/14101-2054-V.1 (1986).

This report contains extensive information on the interpretation of shear measurements made on cohesive powders. No other information useful to this research project is contained in this report.

78. Miller, S.J., Laudal, D.L. Particulate characterization. Final report for the period ending March 31, 1986. DOE/FE/60181-2089 (1986).

This report covers similar information as reference 71. The aspects of this work most applicable to this research project are discussed under reference 71.

83. Miller, B., Lamb, G., Constanza, P., Saville, D., Oak, M. Studies of dustcake formation and structure in fabric filtration. EPA-600/9-81-023 (1983).

This report covers early work on the feasibility of electrically stimulated fabric filtration (ESFF). The data indicated that the effect of electrically charged dust on dust deposition was more pronounced for more texturized, or nappier fabrics.

85. Powder coatings and their applications. January 1976 - August 1981 (Citations from the paper and board, printing, and packaging industries research associations data base) NTIS (1981).

Only one article in this bibliography may be of interest. This article mentions the use of Cab-O-Grip 11 as an anti-slip agent. This is another silicon dioxide product from the Cabot corporation.

88. Ranade, M.B., Goyal, A. Research on coatings or surface treatment of metal powders (Final report June 1, 1975 - May 31, 1976). RADC-TR-76-355 (1976).

The authors provide some discussion of the theoretical mechanisms that are thought to govern interparticle attraction, however, they stress the need for experimental verification of the effects of additives on powder properties. They added Cab-O-Sil and a similar product, Silanox, to aluminum powder and tested the tensile strength, flowability, and general characteristics of the resultant mix. Addition of up to 2% Cab-O-Sil and Silanox noticeably improved flow properties but did not decrease the effect of the interparticle forces. The authors speculate that these additives act as spacers and ball bearings under shear conditions. This report also describes some techniques for assessing the strength of the interparticle forces.

89. Hedley, W.H., Fearheller, W.R., Richardson, G.A., Zanders, D.L. Studies of surface chemistry of solids in dissemination (Quarterly progress report no. 2, Nov 67 - Jan 68). (1968).

Although most of this report is not applicable to this research project, The authors do estimate that a temperature of approximately 400 C would be required to completely remove tightly-bound water from Cab-O-Sil.

91. Berg, T., Hunkins, M., Stansbury, M. Investigation of the force of adhesion between powder particles. AGC-0395-04(04)SP (1963).

This early report discusses the force of adhesion between solid particles in contact with one another with emphasis on the effect of humidity. The researchers found that water was instrumental in adhesion. For monomolecular layers of water on particles and surfaces, the hydrogen bonds between the water and the solids were responsible for the observed adhesion. The authors did not detect the influence of van der Waals forces. They determined that the force of adhesion is proportional to the surface area of the particles. The authors stated that below 3% humidity, electrostatic forces caused the observed adhesion. From 3 to 8% humidity, hydrogen bonds were responsible for adhesion. Above 20% humidity, water coverage of the particles or solids was approximately 100%.

94. Kendall, K. Agglomerate strength. Powder Metallurgy 31:1 (1988).

Kendall states that Rumpf's theory of agglomerate cohesion is in error and that real agglomerates are imperfect and weak because they contain small internal agglomerates that act as defects. When these small agglomerates are broken apart, powder compact strength increases substantially. Compaction can breakdown small agglomerates.

96. Coury, J.R., Thambimuthu, K.V., Clift, R. Capture and rebound of dust in granular bed gas filters. Powder Technology 50:3 (1987).

The authors show how electrostatic effects can aid adhesive forces. They also indicate that the adhesive forces responsible for the bonding of dry dust and the filter are dominated by van der Waals forces. The rest of this article deal with methods by which particles are captured and retained in granular bed filters.

99. Hsieh, H.P. Effect of particle size distribution and shape on bulk properties of calcined alumina. Journal of Powder and Bulk Solids Technology 10:2 (1986).

The author provides a simple formula for the compressibility of a powder in terms of the packed and loose bulk densities. The semi-empirical model described by the author is of no real value for this research project.

101. Steeneken, P., Woortman, A., Gerritsen, A., Poort, H. Influence of flow conditioners on some mechanical properties of potato starch powder. Powder Technology 47:3 (1986).

The authors modified the cohesivity of potato starch powder with the addition of small (.01 - .10 wt.%) amounts of fine silica. The presence of fine silica on the surfaces of the much larger starch particles causes the starch powder to pack more tightly and flow more freely. This effect is due to the extra space between the larger particles caused by the introduction of the smaller conditioning particles. Some of the wording used in this article is ambiguous, however the experimental information contained may provide some basis for setting initial concentrations of fine silica for use in conditioning experiments for this project.

103. Cottaar, E., Rietema, K. Theoretical study on the influence of gas adsorption on interparticle forces in powders. Journal of Colloid and Interface Science 109:1 (1986).

The authors conclude that gas adsorption can quite heavily influence the interparticle forces and cohesion (increase up to a factor of three). Cohesion is stated to be practically independent of the hardness of the particles involved.

104. Takahashi, M., Suzuki, S., Kosakai, M. Dependence of intergranular fracture strength of a compact of pressed granules on their deformation characteristics. Journal of American Ceramic Society 69:1 (1986).

This article states that the cohesive force between compacted granules can be assumed to be proportional to the corresponding contact area. The authors develop an equation that predicts how the tensile strength of a compact is affected by the compaction pressure, intergranular porosity, and granule size. The authors also state that the tensile strength depends not only on the porosity of a compact but also on the compacting pressure.

106. Nikolakakis, I., Pilpel, N. Effect of particle shape on the tensile strengths of powders. *Powder Technology* 42:3 (1985).

Tensile strength depends on packing fraction, moisture content, temperature, length of period of consolidation, and particle size and shape. Tensile strength increases with more irregular particle shape. The effect of shape on tensile strength is increased for smaller particles.

107. Hartley, P.A., Parfitt, G.D., Pollack, L.B. Role of van der Waals force in the agglomeration of powders containing submicron particles. *Powder Technology* 42:1 (1985).

Van der Waals force is dominant for some agglomerates tested in this work (carbon black) while adsorbed water or liquid bridges provide the dominant force for titanium dioxide. The authors state that as particle size decreases, the cohesivity of the powder increases. Mechanical forces resulting from the interlocking of irregularly shaped particles can also influence cohesion. More tightly packed powders exhibit greater tensile strength.

109. Molerus, O., Nywelt, M. Influence of the fine particle content on the flow behavior of bulk materials. *Powder Technology* 37 (1983).

The authors reference earlier work by Kurz and Munz that indicates that small changes in the fine particle content give measurable changes in cohesiveness. The author's work described in this paper deals with mixtures of particle types (coarse and fine) that contain a much greater fine particle content than would be used to condition fly ashes. This article does contain some useful discussions of the techniques for reducing shear data.

112. Nosker, R.W., DiMarco, L.A., Williams, R. Deliquescence as the mechanism for strong dust adhesion. *Applied Physics Letters* 38:12 (1981).

Water soluble salts were seen to serve as adhesives, causing dust particles to strongly adhere to a substrate. This strong adherence was generated by storage of the dust-laden substrate above 80% humidity for several hours.

113. Chudleigh, P.W. Fabric filter performance: effect of dust charge and cleaning efficiency. *Filtration and Separation* 19:5 (1982).

The author achieved a reduction in filtering pressure drop in a laboratory-scale fabric filter device by increasing the residual charge on the particles prior to their deposition on the filter cake. The more highly charged particles form a more porous dustcake. Cake cleanability was not adversely affected. The author attributes this to the relatively rapid dissipation of charge in the dustcake structure. (Corona charging of dusts prior to filter collection has been investigated at SRI under other projects. This approach was deemed too expensive for the pressure drop savings.)

114. Harnby, N., Jackson, I. Effect of moisture on powder mixing processes. Presented at the fourth European Conference on Mixing, Noordwijkerhout, Netherlands (1982).

Though the work described in this paper concerns particles with larger mean size than fly ash collected on fabric filters, the authors provide an observation on the effectiveness of impeller mixing. When interparticle forces are strong, segregation will be inhibited. If the interparticle forces are relatively weak, segregation will be enhanced as mixing progresses. For all mixes, an equilibrium segregation will be obtained after a sufficient amount of mixing.

115. ter Borg, L. Evaluation of shear test results on bulk solids in chemical industry. German Chemical Engineering 5:1 (1982).

The author added flow additives (zinc stearate, sodium mersolate) to various bulk samples of chemicals. Flowability was seen to increase with additive contents between 2 and 5% for some combinations. (These values are somewhat higher than have been reported by others.)

117. Castle, G.S.P. Mechanisms involved in fly ash precipitation in the presence of conditioning agents - a review. IEEE Transactions on Industry Applications IA-16:2 (1980).

This article reviews the use of water vapor, SO_3 , NH_3 , and triethylamine as fly ash conditioning agents. NH_3 is stated to increase ash cohesivity and thereby aid ash agglomeration. The effects of ammonia on ash cohesivity are believed to be due to the ammonium sulfate produced in the conditioning application. Mechanisms for cohesivity modification are not discussed in detail in this article; however, several references are listed that may provide more useful information.

118. Alince, B., Lepoutre, P. Plastic pigments in paper coatings - the effect of particle size on porosity and optical properties. Tappi 63:5 (1980).

The authors report that blends of 0.5 and 0.2 μm synthetic particles with platelike clay resulted in increased porosity, and that similar mixtures of the clay with 0.1 and 0.03 μm particles caused decreased porosity. In blends with spherical calcium carbonate, a decrease in porosity was noted.

121. Cheremisinoff, P.N. Advanced flyash conditioning technology. Power Engineering 81:11 (1977).

This article reviews some of the methods by which fly ash has been conditioned for improved ESP performance. SO_3 and NH_3 are briefly discussed, and their potential for increasing ash cohesivity is mentioned. No further details are included.

123. Chattopadhyay, A.K., Whittemore, O.J.Jr. Powder compaction in systems of bimodal distribution. American Ceramic Society Bulletin 52:7 (1973).

The compacting forces used in the experiments described in the article are far too great to apply to dustcake formation. The particle sizes used are significantly larger than the size of dustcake ashes. Consequently, no useful information was obtained from the article.

128. Dalmon, J., Tidy, D. The cohesive properties of fly ash in electrostatic precipitation. Atmospheric Environment 6 (1972).

The authors applied ammonium sulfate, sulfuric acid, SO_3 , SO_2 and HCl in liquid or gaseous forms to two types of fly ash. Although relative cohesivity was assessed with tensile strength measurements, most of the article deals with ESP operation. No information is provided on the effects of differing amounts of conditioning agents, or on the details of cohesivity modification.

129. Dalmon, J., Tidy, D. Effect of ammonium sulfate and related compounds on the performance of an experimental electrostatic precipitator. Central Electricity Generating Board (internal publication) 1968.

The authors injected ammonium sulfate as a aqueous solution with some success for their objectives. Injection of solid ammonium sulfate was required to be as a fine particulate.

130. Dalmon, J., Tidy, D. A comparison of chemical additives as aids to the electrostatic precipitation of fly ash. Atmospheric Environment 6 (1972).

The additives included ammonium sulfate, sulfuric acid, SO_3 , and NH_3 . (Other additives were ineffective.) The discussions and evaluations are heavily weighted to ESP operation, and do not impact directly on this project.

131. Hollenbach, A., Peleg, M., Rufner, R. Interparticle surface affinity and the bulk properties of conditioned powders. Powder Technology 35 (1983).

The authors assess the effect of four conditioning powders on three substrate powders. In most cases, the achievement of scattered adherence of the conditioner on the surfaces of the larger particles reduces cohesivity and bulk porosity. The nature of the adherence between conditioner and substrate depends on the particular species involved. For some conditioner/substrate combinations, the conditioner tended to aggregate with its own species, rather than disperse on the substrate. The authors used Cab-O-Sil EH5 silica (which we also plan to try) and obtained some results which may prove promising for application to this project. A 2 % w/w mixture of Cab-O-Sil EH5 with fine sodium chloride exhibited an increased bulk porosity over the pure sodium chloride substrate. The authors tried conditioner concentrations of 0.1, 0.5, 1.0, and 2.0 % w/w. Mixing was performed in a laboratory mixer. The authors state in their conclusions: "The results of this work demonstrate that the bulk properties of conditioned powders are strongly influenced by the kind of surface interaction between the host powder and the conditioner particles. It appears there are at least three degrees of surfaces affinity in such systems expressed by complete adherence, partial adherence and no adherence at all. The magnitude of the change in the bulk properties also appears to be associated with the degree of surface coverage. This is evident from the relationship between the magnitude of the change and the conditioner concentration. Where surface affinity is strong, large effects are noticeable already at concentrations of 0.1 - 0.5 %. Where there is little affinity, the effects become appreciable only at higher concentrations, i.e. at about 1 - 2 %."

132. Cab-O-Sil fumed silica properties and functions. Cabot Corporation (1987).

This brochure describes the uses and properties of Cab-O-Sil. Cab-O-Sil fumed silica is produced by the hydrolysis of silicon tetrachloride vapor in a flame of hydrogen and oxygen. The following reaction occurs at 1800 C: $\text{SiCl}_4 + 2\text{H}_2 + \text{O}_2 \longrightarrow \text{SiO}_2 + 4\text{HCl}$. Molten spheres of silica are formed in the combustion process. The diameters of the silica spheres are varied through process parameters from .007 to .030 μm . (These sizes are estimated from measurements of specific surface area, which range from 400 to 100 m^2/g .) The molten spheres collide and fuse with one another to form branched, three dimensional aggregates. As these aggregates cool, reversible mechanical entanglement and agglomeration take place.

The bulk properties of the final product are quite unique. The bulk porosity of the uncompacted fumed silica is near 98% (approximately 2 lbs/ft^3), and the silica is highly hydrophilic. The brochure describes in great detail the chemical reactions that occur between the fumed silica and water vapor. Uses of Cab-O-Sil in liquid systems are discussed, as well as uses in dry systems. The Cabot Corporation emphasizes the ability of the fumed silica to cause powders to flow more freely. The silica aggregates probably form a coating on the larger host particles, and act as mobile "ball bearings" for the free movement of the large particles. The fumed silica reportedly neutralizes the electrostatic charge on the host particles, and can make caked powders free flowing by adsorbing the moisture from the surfaces of the host particles.

133. Visser, J. An invited review: Van der Waals and other cohesive forces affecting powder fluidization. Powder Technology 58 (1989).

This article includes discussion of cohesive forces present in powders between 1 and 100 μm diameter. The author identifies the van der Waals forces as the dominant forces influencing powder cohesivity. The van der Waals forces are only noticeable at separation distances of less than 1 nm. For particles greater than a few microns in diameter, the van der Waals forces become insignificant compared to the gravitational force. Gravitational force is proportional to the cube of the diameter while the van der Waals forces are proportional to the diameter. The author states that results of tests on one class of powder (A, B, C, or D, according to Geldart) cannot be extrapolated to other classes of powders. Also powder behavior can vary significantly as temperature and pressure are varied. The author also mentions the importance of other forces, including capillary, magnetic and electrostatic, and particle characteristics such as surface asperities, hardness, humidity, conductivity and magnetic susceptibility. If asperities found on the particle surfaces are of the order of 1 μm , then the separation distance between particles becomes too great for the action of van der Waals forces. Particles can be irregularly shaped in such a way as to allow the particles to come closer together, increasing the van der Waals attraction. This author also notes the ability of the addition of fine particles to increase particle separation, and reduce cohesivity.

The author states that the results of small-scale experiments should not be extrapolated to large-scale industrial operations because of the effects of pressure and temperature on powder behavior. Visser notes that the dimensions (size, shape) of fine particles used as spacers are critical to their success. Visser references the work of Piepers, et al., who note that physically adsorbed gases increase the cohesion of powders. The type of gas used has a large influence on the results. Gas adsorption can also alter the separation distance between particles. Visser also references Bailey, who states that electrostatic charging of powder particles invariably occurs during powder-handling operations due to tribo-electrification. This useful article concludes with the statement

that a basic understanding of the underlying mechanisms of powder cohesivity is still lacking; however, theories for the various mechanisms are available.

134. Kono, H.O., Huang, C.C. Fundamental principles of flow conditioners for very fine powders. paper presented at Powder and Bulk Solids Conference at Rosemont, IL 1989.

This paper was intended to define the flowability of fine, bulk powder under low loading pressure. The particle structures formed under this level of stress (compacting force) is relatively delicate, and should correspond relatively well to dustcake structure. The authors tested calcium stearate and polysaccharide as flow conditioning agents for type C powders (according to Geldart). The calcium stearate used had a mean diameter around 4 μm . When mixed with coal powder, a relative minimum of flowability was achieved at .5 % by weight concentration of calcium stearate. At concentrations greater than this critical point, the flowability of the coal powder/additive mix increased. These tensile measurements were performed with a device developed by Hartley. The authors reported that uncompacted bulk powder density measurements were not sensitive to different additive concentrations.

APPENDIX C

Procedures Used for Producing Conditioned Mixtures of Ash and Fine Silica in the Mixing Chamber

APPENDIX C

Test Procedures For the Conditioning of Fly Ash with Cab-O-Sil Silica in the Mixing and Conditioning Chamber

Time h:mm:ss	Action
Pre-test	Load and install 47 mm filter holder
Pre-test	Load 400 g of ash into removable collection reservoir
Pre-test	Load silica storage cell with 0.8 g of silica
Pre-test	Seal chamber
Pre-test	Pre-heat oven to 155 C overnight
0:00:00	Initiate dry air flow into chamber at 4 liter/min
1:00:00	Turn off dry air flow
1:00:30	Turn on fan at 75% power
1:01:00	Turn off fan
1:01:30	Blow silica from storage cell into mixing and conditioning chamber with brief blast of dry air
1:02:00	Begin agitation of fan slowly (moving belt back and forth by hand)
1:12:00	Cease agitation of fan
1:12:00	Turn on fan at 75% power
1:12:30	Turn off fan
1:12:30	Initiate dry air flow into chamber at 4 liter/min
1:12:45	Switch outlet flow through 47 mm filter
1:16:00	Bypass outlet flow around filter
1:16:00	Turn off dry air flow
1:36:00	Initiate moist air flow into chamber at 4 liter/min
2:36:00	Turn off moist air flow
2:36:00	Turn on fan at 75% power
2:44:30	Turn off fan
2:45:00	Shut off oven heaters
3:45:00	Collect 47 mm filter with conditioned ash sample
Post-test	Collect wall ash sample

APPENDIX D

Procedures Used for Producing Conditioned Mixtures of Ash and Various Powders in the Waring Blender

APPENDIX D

Test Procedures For the Conditioning of Base Fly Ash with Fine Powders in the Waring Blender

Time h:mm:ss	Action
Pre-test	Load 400 g of base ash into 1-quart jar
Pre-test	Load desired amount of conditioning powder into same 1-quart jar
0:00:00	Place lid on jar and hand mix contents by shaking jar
0:03:00	Cease hand-mixing of contents of jar
0:04:00	Load contents of jar into Waring Blender
0:10:00	Turn on blender at 50% power
0:13:00	Turn off blender
0:17:00	Remove sample from blender

END

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