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Dust Cake Behavior in Filters With High Surface Area to Volume Ratios

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INTRODUCTION

High-temperature particulate control devices are an integral part of advanced coal-fired power systems. By efficiently removing minute particles from high-temperature gas streams, environmentally clean and efficient power systems can be realized. In recent years, economic incentives have prompted developers of high-temperature and high-pressure (HTHP) particulate filtration systems to pursue filter element designs with more filter surface area for a given volume. Although higher surface-to-volume (SV) ratio filter designs are driven by economic incentives, physical constraints and the fundamental behavior of dust cake formation and removal will limit the maximum SV ratio.

In an attempt to improve the understanding of dust cake behavior in a well controlled environment, a two-dimensional cold flow filter module is being tested. This filter module can be used to investigate dust cake formation, removal, and re-entrainment over a range of operating conditions. Some of the operating conditions investigated include filter spacing (3.2 and 6.4 cm), filter length (51 and 102 cm), face velocity (160 to 460 cm/min), particle loading (10,000 to 40,000 ppm), and the physical properties of the particulate media.

Preliminary results suggest that the cohesive strength of the particulate media has a strong influence on how the dust cake is removed during reverse pulse cleaning. Furthermore, the properties of the particulate media play an important role in forming non-uniform dust cakes. In the following paragraphs, the experimental apparatus, preliminary results, and future plans will be discussed.

EXPERIMENTAL APPARATUS

In these tests, compressed air was used as a carrier gas for the particulate media studied. During the test, the air flow rate and pressure drop across the filter module were monitored by Rosemount (Model 3051) differential pressure transmitters. Flyash was injected using a K-Tron (Model #T20-90-048-F1) twin screw dust feeder. The filter surfaces were constructed from Grade 5 sintered stainless steel. This 1.6-mm thick filter slab had a pore size distribution in the 50 to 100 micrometer range. The air and particulate flow entered the filter plenum at the bottom of the filter module, and flowed upward into a rectangular channel formed by the two filter surfaces and two optically clear Lexan windows. (See Figure 1.)

In order to quantify dust cake thickness variations and determine dust cake permeabilities, an optical device was developed to measure the dust cake thickness in-situ. (See Figure 2.) This device monitored the cake thickness over the entire length of the filter.

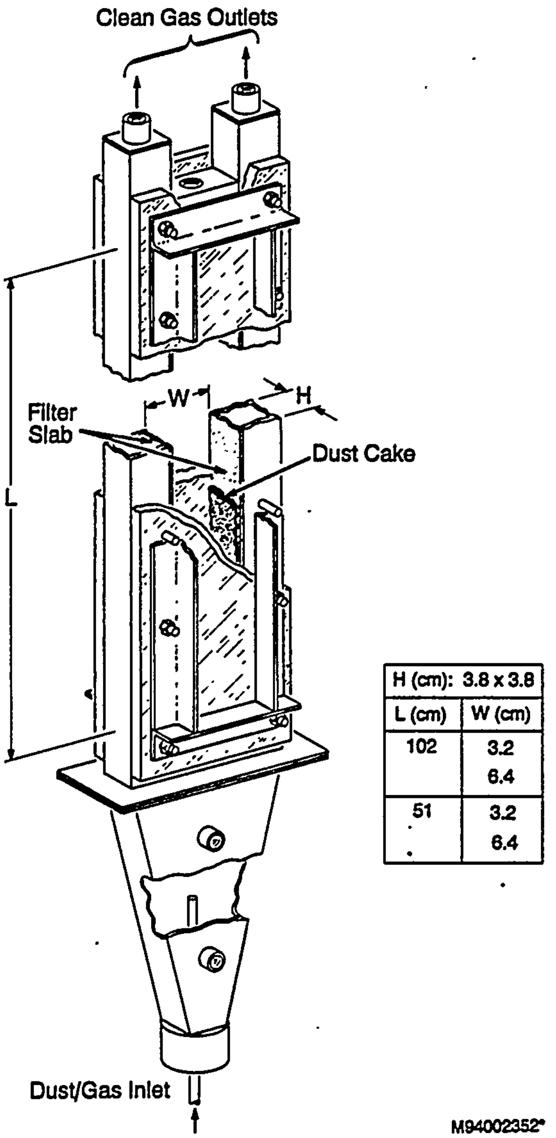

Figure 1. Schematic of the Filter Test Module

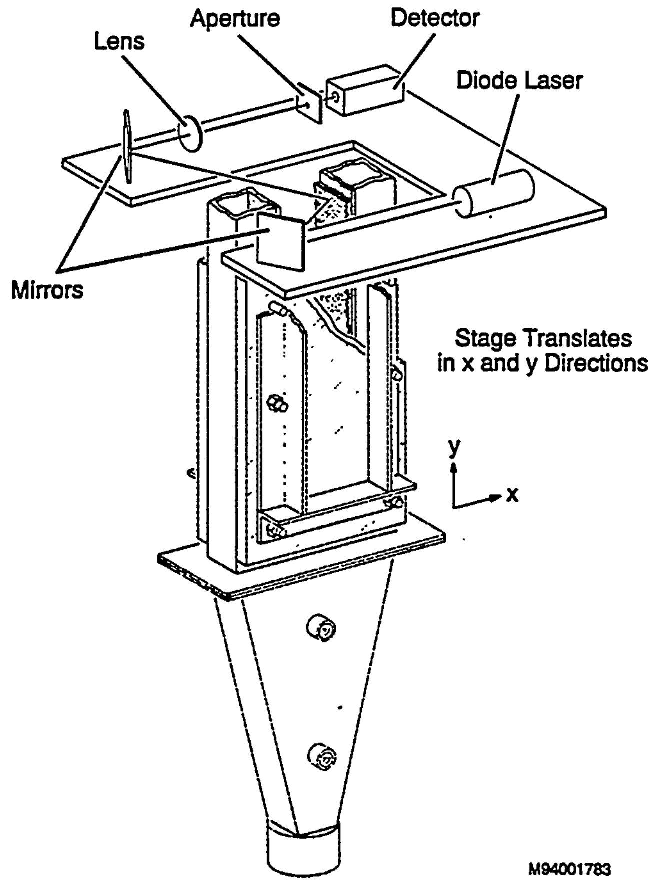

Figure 2. Schematic of the Dust Cake Measurement Device

The following three flyash materials have been proposed for study:

Sample 1: Pressurized Fluidized Bed Combustor (Tidd) flyash, sample taken December 1992

Sample 2: Pressurized Fluidized Bed Combustor (Tidd) flyash, sample taken February 1994

Sample 3: Pulverized Coal Boiler (Ft. Martin) flyash

The major differences between Sample 1 and Sample 2 are a result of process modifications made at the Pressurized Fluidized-Bed Combustor (PFBC) plant facility. These modifications included spoiling the efficiency of a cyclone located upstream of the filter vessel, and injecting tempering air to lower the operating temperature in the filter vessel. The preliminary results presented in this paper will concentrate on Samples 1 and 3. Testing of Sample 2 will be completed in the future.

RESULTS AND DISCUSSION

The following discussion will address the particulate media characterization, dust cake formation, and dust cake removal data that have been collected at this time.

Particulate Media Characterization

Prior to testing, the particle size distributions were characterized by a Coulter Scientific Multi-sizer II. The mean particle diameters on a volume and population basis are shown in Table 1. The particle density was characterized by a Micromeritics Accu-Pic 1330 helium pycnometer. These results are also shown in Table 1.

In addition to the standard particle size and density analyses, Samples 1 and 2 were analyzed in greater detail. The bulk uncompacted fracture strengths were measured for Samples 1 and 2 as a function of temperature. (See Figure 3.) These samples were heated in a nitrogen environment, and the voidages of both samples were maintained at 86 percent. The theoretical relationship between fracture strength of bulk powders and the properties of its constituent particles can be expressed as follows (Molerus 1975):

$$\sigma_t = \frac{(1-\varepsilon)}{\pi} K \frac{H}{d^2} , \qquad (1)$$

where

σ_t = Fracture strength, (Pa),
ε = Bulk powder porosity,
K = Co-ordination number (varies in the range of 6 to 16 for a uniform size distribution),
H = Isotropic contact force between particles, (N), and
d = Particle diameter, (m).

Although this expression has a strong dependence upon particle size, the Coulter Counter and the dry aerodynamic particle size analyses indicated that a factor of 30 difference in fracture strength could not be explained by differences in particle size alone. Thermogravimetric analyses were conducted to determine if these two samples exhibited significantly different chemical behavior. (See Figures 4 and 5.) Although these analyses showed similar trends, Sample 1 demonstrated a faster rate of weight loss around 900°C (1650°F). It is suspected that this weight loss is due to the decomposition of $CaMg_3(SO_4)_4$, and the faster rate observed for Sample 1 may be indicative of a higher concentration. At this time, it is not clear how $CaMg_3(SO_4)_4$ affects the fracture strength, but testing is planned to answer this question.

Table 1. Particulate Media Characteristics

Sample Number	Description	Mean Size: Volume % (micrometer)	Mean Size: Number % (micrometer)	Particle Density (g/cc)
1	PFBC Ash - Tidd (Sample taken 12/92)	4.63	2.50	2.84
2	PFBC Ash - Tidd (Sample taken 2/94)	5.63	2.55	2.78
3	PC Boiler Ash - Ft. Martin	67.53	20.81	2.74

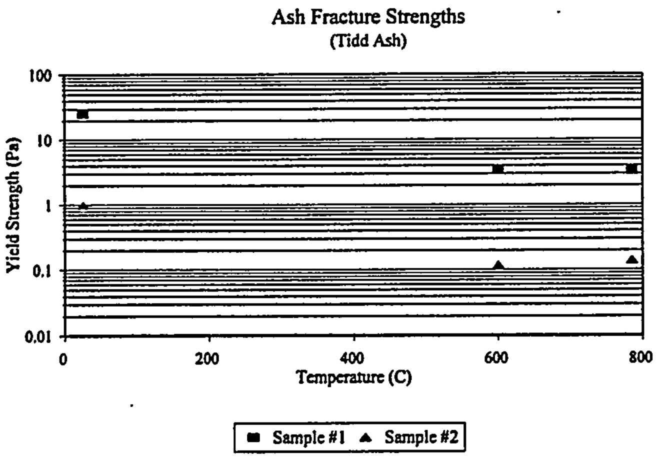

Figure 3. Fracture Strength of Two Pressurized Fluidized Bed Combustor Flyash Samples as a Function of Temperature

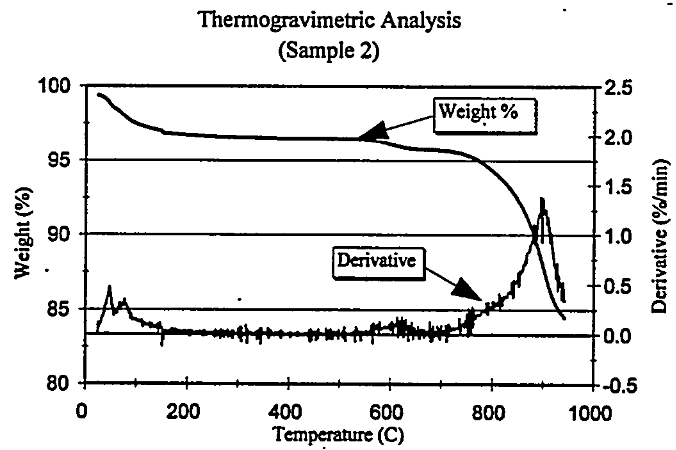

Figure 5. Thermogravimetric Analysis or Pressurized Fluidized Bed Combustor Flyash - Sample 2

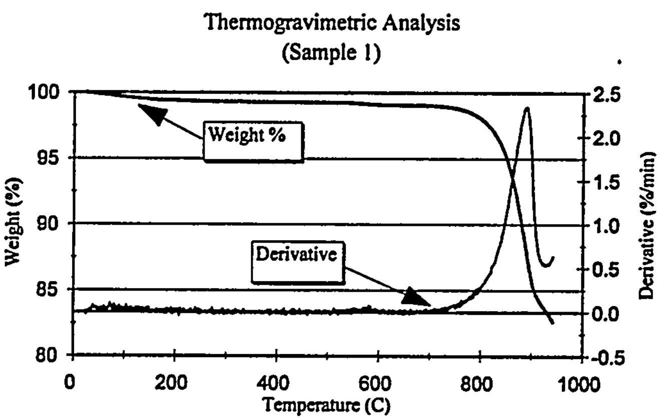

Figure 4. Thermogravimetric Analysis or Pressurized Fluidized Bed Combustor Flyash - Sample 1

Dust Cake Formation Behavior

The air and particulate were injected from the bottom of the plenum, upward toward the filter channel. The operating conditions investigated are shown in Table 2. It should be noted that the filter module with the 6.4-cm spacing was blinded at a face velocity of 458 cm/min. At this high face velocity, particles penetrated the surface of the porous metal surface and became trapped within the filter wall. As a result, the filter permeability decreased, and backflush cleaning was no longer effective. The filter module with the 6.4-cm spacing was blinded very early in the test plan, so the effect of filter aspect ratio has not been thoroughly investigated at this time.

For Sample 1, dust cake thicknesses were uniform for all of the operating conditions studied. However, when Sample 3 was investigated under the same operating conditions, distinct features formed along the top half of the filter surfaces. The length of these irregularly shaped mounds ranged from a few millimeters to roughly 50 mm. The thicknesses and the widths were in the 1 to 7 mm range. Along one filter surface, these features were periodically spaced every 35 to 40 mm. This filter surface had a small depression (roughly 25 to 40 mm in diameter and roughly 5 mm deep) located near the middle of the filter surface length. This depression was formed during assembly of the filter module, and may have been introducing turbulent effects into the flow. The mound-like features seemed to be more distinct at higher face velocities which also suggests that these features are dependent upon turbulent effects.

Table 2: Operating Conditions Investigated

Filter Aspect Ratio (length/filter spacing)	Face Velocity (cm/min)	Particle Loading (ppm)
32	168	10,000
32	168	40,000
32	229	10,000
32	229	40,000
16	229	10,000
8	458†	10,000

† This face velocity blinded the filter module with a 6.4 cm spacing.

These irregular formations were observed with Sample 3, and not with Sample 1. A potential explanation for this difference may be due to the significantly larger particle size distribution for Sample 3, and the fact that the gas momentum in the vertical direction is depleted along the length of the filter. Noting that the largest particles in Sample 3 are in the 100 to 200 micrometer range, at some point along the length of the filter, the velocity falls below the terminal velocity for these particles. Since the body forces on these large particles are more dominant than the drag forces pulling them to the filter surface, the particles fall toward the inlet of the filter module. At some point near the inlet, the vertical velocity component is large enough to re-entrain these particles. This behavior causes the particles to circulate, and is readily observed over an area of 35 to 50 cm of the filter length. This particle motion introduces more turbulence toward the top of the filter module, where the irregular dust cake features are observed. It is important to note that these features are easily removed during reverse pulse cleaning.

Dust Cake Removal Behavior

The behavior of Sample 1 and Sample 3 during pulse cleaning was significantly different. Under the same operating conditions, Sample 1 exhibited "patchy" or incomplete cleaning, whereas Sample 3 cleaned uniformly. The tensile strength of Sample 3 has not been measured, but Sample 1 seems significantly more cohesive.

When the dust cake removal is incomplete, it has been observed that subsequent cleaning pulse cycles do not remove the dust cake from the areas which were previously not cleaned. Although these "patches" have significantly lower permeabilities than the clean areas, the dust cake continues to form on these patches at a slow rate. Over time, these "patches" may lead to significant ash build-up and become nucleation sites for ash bridges. Qualitatively speaking, these "patches" seem to be more prominant near the top of the filter surface, but more data is necessary to substantiate this observation.

Although these results are preliminary, they emphasize the importance of dust cake properties on cleaning behavior, as well as behavior during dust cake formation. A thorough understanding of the relationship between particluate media properties and cleaning behavior of a particular media will lead to improved filter element designs and cleaning techniques.

FUTURE WORK

Plans for this project are as follows:

- Complete testing for Sample 2.
- Measure fracture strength of Sample 1 and Sample 3 at 925°C, to determine if the weight loss observed in the thermogravimetric analyses is responsible for increasing the ash cohesive strength. If these fracture strength measurements are significantly different than the measurements made at a slightly lower temperature, a thorough chemical analysis will be conducted.
- Utilize fast response instrumentation to characterize cleaning parameters.
- Improve existing module design to allow better quantification of incomplete cleaning.
- Investigate the feasibility of new filter designs and cleaning techniques.

ACKNOWLEDGEMENTS

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