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Project Summary

Development and Evaluation of Improved Fine Particulate Filter Systems

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The filterability of fly ashes emitted by coal-burning power stations is described, including that of several ashes generated by low sulfur western U.S. coal combustion that are best controlled by fabric filtration. Chemical and mineralogical analyses of the coals were examined to determine possible relationships between coal and ash properties and filtration behavior. Both fly ash size and coal ash content correlated strongly with the fly ash specific resistance coefficient, K_2. Weaker, but discernible, correlations were shown for electrical charge behavior and method of coal firing. Coal sulfur content, ash fusion properties, and chemical structures originally expected to influence particle size showed no clear-cut effects on filtration characteristics. The relevant literature on pulse jet filter theory and applications was assessed to develop coherent guidelines for designing predictive filter models. The effects of jet size and location, jet air volume, and the intensity and duration of the jet pulses were related to pressure loss. Energy transfer from the jet pulse to the fabric was explored in terms of jet pressure, solenoid valve action, the ratio of pulse volume to bag volume, and the kinetic properties of the felt bags. Finally, predictive equations were developed for estimating pressure loss over a broad range of collector design and operating parameters.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The primary objective of the research summarized in this report was to investigate possible relationships between coal and ash properties and fly ash filtration characteristics. It was postulated that certain chemical and physical properties of coals might have some predictive value in determining the specific resistance coefficients, K_2, of their resultant fly ashes. Since this parameter has a significant impact on filter system performance, a reliable estimation method would facilitate the design and evaluation of reverse-air and/or mechanical-shake-cleaned fabric filter systems. Additionally, it was expected that some coal and ash properties (e.g., particle size, surface, and adhesion characteristics) would determine how well a fabric might be cleaned. In some modeling equations, dust removal is defined by a cleaning parameter, a_c, that indicates the fraction of the filter surface from which the dust cake is removed by the cleaning action.

A second study objective was to extend the capabilities of the existing EPA/GCA filtration model to include pulse jet collectors or, alternatively, to develop a new model if the former model could not be modified practically. The proposed bases for developing a modeling protocol were the results of past and present GCA studies as well as those of other researchers. Additional information sources were correlations deriving from the present investigations of coal and ash properties and their impact on filter performance.

Background

Coal and Fly Ash Properties

Reliable prediction of fabric filter performance depends on accurate estimation of two major variables: K_2, the specific resistance coefficient for the dust, and a_c, a cleaning parameter that indicates the fraction of the fabric superficial dust loading removed during the cleaning process. K_2, which defines the gas permeability of a deposited dust layer, is especially important in determining the pressure loss for fabric filter systems cleaned by reverse-air and/or mechanical shaking. Although theoretical relationships exist for calculating K_2, the predicted results may be very inaccurate because of difficulties in measuring the parameters contributing to K_2 variability. Complications may also arise in field practice when non-steady state conditions, moisture condensation, or chemical reactions increase adhesion to the fabric.

Many coal and/or fly ash properties have been identified that may exert first, if not second, order effects on K_2; e.g., particle size, shape, hardness, surface roughness, and the chemical, hygroscopic, and hydration characteristics of the ash constituents. The above factors provided the guidelines for selecting the coal types and classes that were evaluated in this study.

Regional distributions for U.S. production of bituminous, subbituminous, and lignitic coals, Table 1, show that western coals account for only 25 percent of the annual tonnage. Recent indications of proportionately greater production of low-sulfur western coals (whose fly ash emissions are better controlled by fabric filtration than by electrostatic precipitation) suggested, however, that western coals be given a strong weighting in this study. Analyses of the physical and chemical properties of eastern coals also indicated that Regions 1, 2, and 3 coals could be treated as a single group to facilitate final sample selections.

Pulse Jet Filtration

Assessment of the relevant literature pertaining to the theory and application of pulse jet filters revealed no general modeling procedures for predicting filter system performance, although models have been proposed for filter systems utilizing combinations of bag collapse and reverse flow or mechanical shaking for periodic fabric cleaning. Extensive EPA sponsored studies and the findings of several independent groups have shown that very distinct differences in the overall operation of pulse jet filters preclude any direct adoption of the mathematical models developed for the other cleaning methods. It has also been established that particle removal is caused principally by the mechanical projection of dust from the pulsed fabric and not by air flushing. Additionally, most researchers now recognize that only a small fraction (~1 to 5 percent) of the dust dislodged from a bag ever reaches the dust hopper, regardless of the nearly 100 percent removal attainable with proper equipment design and operation (and under conditions where the dust is not subsequently compacted or cemented to fabric surfaces by adverse condensation effects). The very brief pulse durations, ~0.1 s, explain the rapid redeposition of dislodged dust and hence the presence of a semipermanent surface dust cake, W_c, referred to as a cycling layer. Preliminary studies have shown that the total pressure loss across a conventional pulse jet filter bag should be represented by three rather than two components; i.e., the contribution from the cleaned fabric with its residual dust holding that remains with the fabric, the loss associated with the cycling or reposited layer, and finally the contribution from the fresh layer of dust that is captured during the interval between each pulse. The object of the present study was to determine, by whatever combination of theoretical and empirical approaches that appeared feasible, how the available data and that derived from measurements performed during this study might be adapted to design a practical predictive model for estimating pressure loss.

Technical Approach

Selection of Coals and Fly Ashes

The classification of the fly ashes investigated in this program is shown in Table 2. Restriction of the number of

Table 1. *Estimated 1980 Coal Production by Coal Producing Region*[a]

Region	States	Production 10^6 tons/yr
1 Northern Appalachian	PA, WV(n)[b], OH, MD, MI	189 (22.7)[c]
2 Southern Appalachian	WV(s), VA, KY(e), TN(n)	192 (23.1)
3 Alabama	AL, GA, TN(s)	32 (3.8)
4 Eastern Midwest	KY(w), IN, IL	171 (20.6)
5 Western Midwest	AR, IA, OK, KS, MO,TX	39 (4.7)
6 Western	CO, WY, MT, SD, ND, UT, NM, AZ, ID, WA, AK	209 (25.1)

[a]Includes bituminous, subbituminous, and lignitic coals.
[b]Letters in parentheses refer to north, south, east, and west.
[c]Numbers in parentheses refer to percent of total production.

Table 2. *Classification of Fly Ash Samples by Selection Criteria*

Characteristic:						
• Coal producing region:[a]	1	2	3	4	5	6
No. of samples	3	1	1	0	1	8
• Boiler firing method:	Pulverized coal				Stoker-fired	
No. of samples	10				4	
• Sulfur content:[b]	Low (< 1%)		Medium (1-3%)		High (>3%)	
No. of samples	9		4		1	
• Ash content:	Low (<5%)		Medium (5-15%)		High (> 15%)	
No. of samples	3		9		2	
• Base/acid ratio:	Low (<0.17%)		Medium (0.17-0.33)		High (>0.33%)	
No. of samples	4		6		4	

[a]Arabic numerals refer to coal regions.
[b]When a range of values is used to characterize a specific coal or ash property, the midpoint of that range is used to categorize the sample.

samples to 14 was necessitated by the program scope, and the preponderance of western coals reflects best estimates of the future gas volumes to be controlled by fabric filters. Because high sulfur contents accentuate fly ash hygroscopicity while low sulfur contents enhance electrical charge effects, coal sulfur contents of 0.35 to 3.5 percent were surveyed. Total ash contents of 3.3 to 23 percent were investigated because it was believed that higher ash contents, in conjunction with a fixed heating rate, would reduce heat transfer to individual particles, such that large, irregularly shaped mineral particles would be less likely to melt. Among the many characterizing ratios for the mineral constituents of fly ash used to predict ash slagging and fouling properties, the base-to-acid (B/A) ratio appeared to have some predictive value through its impact on melting temperatures. Thus, several B/A levels were included in the samplings listed in Table 2. The distribution of fly ash samples was generally representative with respect to the principal coal firing methods. Pulverized coal combustion, far more common than stoker-firing on the basis of tonnage consumed, was the source of 10 of the fly ash samples while only 4 fly ashes were generated by stoker firing.

Determination of Coal Properties and Chemical Constituents of Fly Ashes

Fly ash suppliers provided most of the information on coal properties and fly ash chemical compositions summarized in Table 3. In general, coal data describing proximate analyses and sulfur contents were more complete than those for the chemical composition of the resultant fly ashes. When sample information was missing, source data specified by the fly ash suppliers for their coals (including state of origin, region, seam, and—where possible—mine) were used as a supplemental source.

Laboratory Measurements of K_2 and Fly Ash Size Properties

Fly ash K_2 values (Table 3) were determined with a bench scale filtration system using all glass (twill weave) fabric panels and resuspended fly ashes at a nominal filtering velocity, V, of 0.61 m/min (2 fpm). Increases in uniformly distributed fly ash loadings, W, (300 to 700 g/m^2) coupled with the corresponding increases in pressure loss, P, for filtration at a constant velocity, V, permitted estimation of K_2 for the resuspended fly ashes; i.e., $K_2 = P/VW$. The same test system was also used, with minor modifications, to determine the relationship between pulse jet pressure and dust dislodgement from Dacron felts.

Particle size parameters were determined by Andersen Mark III cascade impactor wherein samples were extracted by a short probe from the central section of the inlet manifold. This technique provides the best possible description of the dust that actually deposits on the filter surface. Cumulative size distributions were plotted on log-probability paper for the two impactor sizings performed for each fly ash. The aerodynamic mass median diameter, aMMD, and the geometric standard deviation, δg, estimated for each pair of curves showed excellent agreement in most cases.

Results

Coal Properties Versus Fly Ash Filterability

Relevant coal and fly ash properties for each sample are listed in Table 3 along with boiler type. Laboratory derived K_2 values, particle size properties, and qualitative estimates of the electrostatic behavior of the fly ash in the test system are also presented. In Table 4, correlation coefficients are listed for the relationships between K_2 and various coal and fly ash properties, including the particle specific surface parameter, S_o^2.

K_2 and Particle Size

As stated earlier, K_2 values were determined by experimental measurements because of limitations of the classical theory. One theoretical concept, however, proved useful in the present study: the relationship between K_2 and the specific surface parameter where K_2 is predicted to be proportional to S_o^2. The term S_o, which characterizes the surface/volume ratio for the polydisperse particle size system constituting the dust cake, is readily computed from the size parameters determined by cascade impactor measurements, the mass median diameter, MMD, and the geometric standard deviation, δg: $S_o = (6/MMD)\,(10^{1.151 \log^2 \delta g})$. The regression line generated from the data shown in Table 3 supports the K_2-S_o^2 relationship with the r^2 value statistically significant at the $p = 0.003$ level. Unfortunately, the data point scatter shown in Figure 1 precludes use of these data as a predictive tool because the 95 percent confidence interval embraces a range of 0.85 to 5.2 for a predicted mean K_2 value of 3.0 N•min/g•m.

Effect of Coal Firing Method on K_2

The method of coal firing usually influences fly ash size properties, with stoker-fired boilers producing coarser fly ashes than pulverized-fired or cyclone boilers. Unfortunately, only semiquantitative relationships could be inferred from the present observations: (1) because of limited data, and (2) because size properties can also be affected by additional factors not defined in this study (e.g., air/fuel ratio, boiler load level, system geometry, gas residence time, and settlement losses). Therefore, although the average K_2 value determined for stoker fired ashes was 3.6 N•min/g•m versus 2.2 N•min/g•m for the pulverized firing method (the expected result), the difference was not statistically significant based upon the limited number of observations.

Effect of Electrical Charge on K_2

In the absence of charge leakoff (that is enhanced by the electrical conductivity of ionizable materials in the dust layer), the accumulation of particles bearing similar charges is expected to expand the dust layer due to mutual repulsion. Consequently, a lower K_2 value is anticipated because of increased dust cake porosity as suggested by the circled points in Figure 1. Note, however, that stoker firing may also have contributed to lower K_2 values associated with the charged deposits.

Effect of Sulfur Content on K_2

The manner in which coal sulfur content affects fly ash filtration properties is not clearly understood, although it has been established that sulfur in various forms can affect ash fluid properties. If the viscosity of the molten ash is lowered sufficiently, it appears reasonable that gas stream turbulence and shearing action might lead to droplet shatter. On the other hand, particles that have melted, because of their viscous nature, may serve as irreversible collision sites for small particles undergoing Brownian diffusion. When the coal sulfur fraction is due mainly to its iron pyrite content, significant separation of FeS_2 during coal upgrading will lower the basic phase of the ash (i.e., the Fe_2O_3 contribution) and hence reduce the base/acid ratio. The expected results, as discussed in the following paragraphs, are fewer particles due to fusion and shatter, and diminished particle adhesion. Limited comparisons during the present survey showed no definitive relationship between coal sulfur content and K_2 values (see Table 4).

Effect of Coal Ash Content on K_2

It appeared that an increase in coal ash content should result in less heat transfer to individual mineral particles for a fixed energy input, thus slowing particle transition to the viscous and fluid states. Consequently, generally coarser and more irregularly shaped particles are expected. Comparison of K_2 values for 14 fly ashes on the basis of coal ash content appeared to confirm the presence of coarser particles (and reduced specific surface) because a statistically significant decrease in K_2 was noted as the ash content increased, see Table 4. Unfortunately, confidence limits for the predictive equation are too broad for any practical application.

Table 3. *Coal Properties and Fly Ash Filtration Parameters*

Fly ash source	Sample I.D.	Boiler type,[b] rate, MW_e	Coal properties: % sulfur	Coal properties: % moisture	Coal properties: % volatiles	Coal properties: % ash	Fly ash base/acid ratio	Fly ash charge effects	Measured values[a]: K_2 N•min/g•m	Measured values[a]: aMMD µm	Measured values[a]: MMD µm	Measured values[a]: δ_g	Measured values[a]: $S_0^2 \times 10^{-6}$, cm^{-2}
Southwestern Public Service, Amarillo, TX	SPS	(2) Pulverized total 700	0.3-0.4	25-28	32-36	5-7	0.48	No	2.82	7.3	5.2	2.8	3.90
Texas Utilities, Mt. Pleasant, TX	TU	(2) Pulverized total 1150	0.8-1.3	31	30	16-28	0.28	Yes	0.89	9.7	6.9	2.3	1.53
Kramer Station, NPPD, Omaha, NE	NPPD	(4) Pulverized total 113	0.5	19	36	3.3	0.22	No	3.79	5.9	4.2	2.3	4.14
Crisp County, Cordelle, GA	CC	Pulverized, 10	0.9	6.2	38	9.5	0.17-0.33	Yes	1.61	7.5	5.3	2.5	2.96
Amalgamated Sugar "A", Nampa, ID	AM A[c]	Pulverized, 29	0.5	14	40	4.0	0.22	Yes	1.49	7.7	5.4	2.5	2.81
Amalgamated Sugar "B", Nampa, ID	AM B[c]	Pulverized, 28	0.5	14	40	4.0	0.22	No	4.63	6.7	4.7	2.8	4.63
Pennsylvania Power & Light, Holtwood, PA	PPL	Pulverized, 79	1.9	14	7.6	23	0.07-0.5	No	0.98	9.6	6.8	2.2	1.45
Westinghouse, Hanford, WA	WH	Stoker, 7	0.5	8.3	38	9.2	0.35	Yes	4.55	8.2	5.8	3.7	5.93
Case Medical Center, Cleveland, OH	MCC	Stoker	1.8-2.7	6	38	7-9	0.25-0.50	Yes	4.52	6.5	4.6	3.8	10.1
Republic Steel, Warren, OH	RS	Pulverized, 35	3.5	3.2	37	14	0.5-1.0	No	2.12	9.6	6.8	2.3	1.56
Colorado Ute Electric Assoc., Nucla, CO (hopper sample)	N(H)	(3) Stoker, total 39	0.7	6.0	31	12	0.08	Yes	3.40	7.4	5.2	3.2	5.08
Colorado Ute Electric Assoc., Nucla, CO (bag shakedown)	N(S)	(3) Stoker, total 39	0.7	6.0	31	12	0.08	Yes	1.93	8.2	5.8	3.0	3.58
DuPont, Waynesboro, VA	D	Pulverized, 76	1.1	6.7	29	13	0.28	Yes	1.86	4.7	3.3	2.2	6.07
U.S. Steel, Provo, UT	USS	(3) Pulverized, total 90	0.7	5.6	39	6.4	0.13	No	1.73	8.6	6.1	2.3	1.95

[a] MMD and S_0^2 are derived values obtained by the following relationships:

$MMD = aMMD/\sqrt{\sigma_p}$ where σ_p is assumed to be 2 g/cm^3 for coal fly ash $S_o = (6/MMD)(10^{1.151 \log^2 \sigma g})$

[b] Number in parentheses is number of boilers.

[c] The same coal is processed by two different pulverizing/firing systems.

Table 4. Correlation Coefficients for K_2 with Various Coal and Fly Ash Properties

Variable	Correlation Coefficient (r)
Specific surface parameter, S_o^2 (cm^{-2})	0.733[a]
Sulfur in coal, %	−0.146
Ash in coal, %	−0.575[a]
Moisture in coal, %	−0.148
Volatile matter in coal, %	0.450
Base/acid ratio	−0.050

[a]Indicates that correlation coefficient is statistically significantly different from zero ($p < 0.05$).

K_2 Versus Base/Acid Ratios

Although a number of characterizing ratios derived from the chemical constituents of fly ash were investigated initially, only the base/acid (B/A) ratio appeared to offer any predictive capabilities. The basic components of the ash are Fe_2O_3, CaO, MgO, Na_2O, and K_2O while the acidic components are SiO_2, Al_2O_3, and TiO_2. Minimal ash melting points and fluid temperatures accompanied by a more rapid transition from the solid to the liquid phase are observed with a 1:1 mix (weight basis) of basic and acidic components. As B/A ratios become larger or smaller than 1, melting points and fluid temperatures rise. Comparison of B/A ratios for 93 ash samples with their corresponding fusion temperatures showed a high correlation coefficient ($r = 0.81$, $p < 0.001$). On the other hand, correlation coefficients based on observed relationships between B/A and K_2 or S_o^2 were roughly −0.2, well below the level of significance for the sample size. Hence, the B/A parameter does not appear to be a useful predictive tool at this time.

Pulse Jet Filtration Studies

Fundamental Concepts

The relevant literature on pulse jet filter theory and applications was assessed to develop coherent guidelines for designing predictive filter models. Observations of several foreign and U.S. researchers not previously subjected to rigorous comparisons showed that there is a considerable unanimity in technical perspectives when data and theories are viewed from a common baseline. Common misconceptions were clarified: (a) the air bubble that descends through the bag during pulsing, (b) dust removal by air flushing rather than by mechanical projection from a rapidly decelerating fabric, and (c) failure to recognize that only a small (1-5 percent) fraction of dust dislodged by pulse action actually reaches the hopper. Data from several sources suggest that not only the compressed air pressure, but also the rate of pressure rise within a bag and the fabric mobility, determine dust removal effectiveness.

Experiment and theory also indicate that the pressure loss across a dust-laden fabric at the initiation of cleaning is the summation of the losses across: (a) the cleaned fabric (whose irreversibly held dust loading contributes a base resistance considerably greater than that for the unused medium), (b) the redeposited recycling layer, and (c) the freshly deposited dust that arrives during the filtration interval. Thus, three contributions, rather than the customary two, are associated with fabrics cleaned by collapse or shaking where all dislodged dust descends to the hopper instead of redepositing (95 to 99 percent) on the fabric.

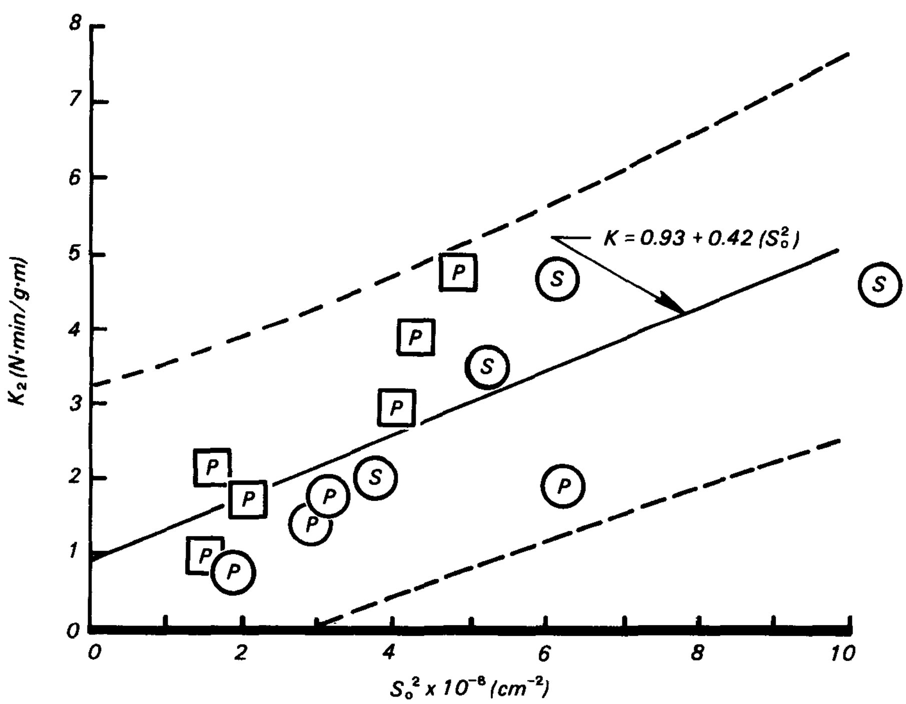

Figure 1. Specific resistance coefficient (K_2) vs. specific surface parameter (S_o^2) with 95 percent confidence interval indicated by dotted lines. (P) and (S) refer to pulverized and stoker firing. Circles delineate charge effects.

Recycled Dust Loading

The transient character of the flow interruption during pulse jet cleaning, about 0.1 sec, permits only a small fraction (~1 to 5 percent) of the dislodged dust to reach the hopper, with the remainder immediately redepositing on the pulsed or adjacent bags in the form of fairly coarse (~50 to 100 μm) agglomerates. Under typical operating conditions, the redepositing or recycled dust loading may range from 400 to 1,000 g/m^2. Because of its relatively porous nature, the recycled loading does not offer a high resistance to air flow although it does provide much higher collection efficiencies than the cleaned fabric alone.

Cleaning Characteristics

If a dust undergoes no changes upon standing (e.g., moisture absorption or chemical reactions with various materials that greatly increase adhesive properties), proper nozzle design and location will lead to nearly 100 percent separation of the surface dust layer from a pulsed fabric. As stated previously, however, 95 to 99 percent of the dislodged material will immediately return to the fabric. For a specified dust/fabric combination, a unique fabric loading is associated with complete dust dislodgement, the latter occurring when adhesion forces are balanced or just overcome by the separation forces determined by pulse intensity (pressure) and other factors. Therefore, once the pulse cleaning parameters are set, the recycling loading is essentially constant and independent of filtration velocity and inlet dust concentration. This facet of pulse jet collector performance lends itself to nearly constant gas flow and pressure loss as well as low effluent loadings, all distinct advantages when coupled to industrial processes or power plant operations.

Approach to Modeling

It was decided that the current absence of reliable methods for predicting dust cake adhesion and gas permeability properties would require semi-empirical modeling equations for predicting pressure losses for pulse jet collectors. For this reason, the terms representing the pressure loss at the cessation of the pulse for (a) the cleaned fabric and (b) the recycling layer were combined. The new descriptor, $(P_E)_{\Delta W}$, designated as the effective residual pressure loss, is uniquely defined by the dust/fabric combination of interest, the filtration velocity, and the parameters describing the pulse jet cleaning system. In turn, $(P_E)_{\Delta W}$ can be related to the rate of pressure increase within a pulsed bag, $d(\Delta p)/dt$, the latter a function of the pulse air volume, bag volume, and the rate at which compressed and extrained air is ejected into a bag. With respect to a single bag, the following equation allows computation of total pressure loss, P:

$$P = (P_E)_{\Delta W} + k\,CK_2\,V^2\Delta t \qquad (1)$$

where k is a constant that depends on the choice of units, C is the inlet dust concentration, K_2 is the specific resistance coefficient for the freshly deposited dust layer that arrives over the time interval, Δt, and V is the face velocity or air/cloth ratio for a group of bags being cleaned sequentially (one at a time). The pressure loss normalized with respect to velocity (otherwise referred to as the filter drag) may be calculated by the general relationship:

$$\bar{S} = \left(\sum_{i=1}^{n_b} \frac{a_i}{S_i} \right)^{-1} A \qquad (2)$$

where $\bar{S}$ is the average system drag, n_b is the total number of bags, A is the total cloth area, $a_i = A/n_b$, and S_i ranges from $S = (P_E)_{\Delta W}/V$ to $(P_E)_{\Delta W}/V + CK_2V\Delta t$.

Conclusions

Coal and Fly Ash Properties Versus Fly Ash Filterability

Coal fly ashes bearing an appreciable net electrostatic charge form a more porous dust layer on the fabric surface.

The method of coal-firing, through its impact on the size properties of the fuel entering the combustion zone, is expected to produce a discernible change in K_2, with the coarser coals charged to stoker-fired boilers leading to lower K_2 values and hence more permeable dust cakes. The limited samplings examined in the present study, however, showed no statistically significant differences between K_2 values of fly ashes generated by stoker-fired and pulverized coal fired boilers.

A statistically significant decrease in K_2 was observed with increasing coal ash contents, but not at a level where the data could be used for predictive applications.

A strong correlation was observed between fly ash size properties (i.e., particle specific surface) and K_2, as predicted by theory. However, note that, with concurrent variations in fuel preparation methods, size reduction processes, and air/fuel ratios, the relationships between fly ash size parameters and parent coal properties may be obscured.

A number of factors mitigate against accurate prediction of fly ash filterability from coal properties alone. First, several as yet unidentified coal properties probably exert secondary effects on fly ash filterability that are masked by strong first order parameters such as particle size. Second, large variations in coal properties with respect to seam location with the composition and quantity of overburden, parting, and floor materials also contribute to the variability. Finally, the design and operating parameters for the combustion system add a third and difficult-to-predict level of variability in K_2.

The problems noted above suggest strongly that direct field determination of coal filterability by a combination of stack sampling measurements and small scale pilot tests is the only realistic way to define and evaluate fly ash parameters that determine baghouse pressure loss and particle collection efficiency.

Mathematical Model for Pulse Jet Filtration

The conclusions presented here are based largely on the results of several GCA filtration studies with an extensive infusion of experimental data reported by independent researchers.

Single bag tests show that, with sufficient energy and the proper introduction of pulse air to a bag, most of the surface dust layer is momentarily dislodged.

Because pulse durations are very brief, ~0.1 s, most of the dislodged dust (95 to 99 percent) is returned immediately to the same or adjacent bags. The amount that descends to the hopper at steady state filtration must equal the dust quantity deposited during the previous filtration interval (~1 to 3 min).

Although the amount of dust redepositing (here referred to as W_c, the cycling layer) may range from 400 to 1,000 g/m², its highly agglomerated state significantly increases its permeability to air flow (about 7 times more than that for the freshly deposited dust). Thus, the W_c layer does not present a serious pressure loss penalty, although it does provide the uniform cake thickness essential for efficient particle capture and stable operating pressure loss.

The presence of the cycling layer, W_c, implies that three factors contribute to the overall bag pressure loss: the pressure loss due to the fabric and interstitial dust, the contribution from the cycling layer, and finally, the pressure loss caused by the fresh dust that arrives during the filtration interval.

The present inability to measure accurately the areal density of the cycling layer along with its unique permeability requires a semi-empirical approach to modeling. A parameter, defined as the effective residual pressure loss, $(P_E)_{\Delta W}$, must be determined for a specific dust/fabric combination and one set of filtration and cleaning parameters. Given only *one* pressure loss vs. time (or fabric loading) curve from which $(P_E)_{\Delta W}$ can be estimated, the filter designer or user can estimate bag pressure loss for any set of operating conditions, including variations in inlet dust concentration, filtration velocity, frequency of cleaning, intensity of cleaning as defined by reservoir compressed air pressure, compressed air orifice dimensions, solenoid valve opening time, bag volume, and the temperature, barometric pressure, and density of the filtered air. All predictions, however, apply only to the dust/fabric combination used in the single test.

The modeling equations may be extended to typical multibag, sequentially pulsed field units by iteration processes similar to those used with reverse air or mechanically shaken systems.

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The complete report, entitled "Development and Evaluation of Improved Fine Particulate Filter Systems," (Order No. PB 85-177 244/AS; Cost: $16.00, subject to change) will be available only from:
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