United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

Research and Development

EPA-600/S7-81-105 Dec. 1981

EPA

Project Summary

Control of Particulate Emissions from Atmospheric Fluidized-Bed Combustion With Fabric Filters and Electrostatic Precipitators

David V. Bubenick, Robert R. Hall, and John A. Dirgo

Fabric filters are being installed on many new atmospheric fluidized-bed combustion (AFBC) units, despite the lack of test or demonstration data. For this reason, the present study focuses on assessing fundamental chemical and physical characteristics affecting the performance of particulate control equipment based on five fly ash samples from full- and pilot-scale AFBC units. These results were used in conjunction with fabric filter (FF) and electrostatic precipitator (ESP) mathematical models to illustrate how control device performance may be affected by AFBC fly ash properties. Laboratory measurements of the specific resistance coefficient (K_2), a measure of the pressure loss through a dust deposit on a fabric, ranged from 1.9 to 5.3 N-min/g-m for the AFBC fly ashes, compared to values near 2.0 N-min/g-m for conventional fly ash. Mathematical simulation of an operating FF indicated that an increase in K_2 from 2 to 5 N-min/g-m could result in a 30 percent increase in penetration and a doubling of pressure loss. Low electrical resistivity values (10^5 to 10^7 ohm-cm) of two fly ash samples containing high carbon (34 to 46 percent) would be expected to cause poor ESP performance. The remaining three samples exhibited resistivities falling within the range of conventional combustion design experience with ESPs as shown by model simulation. Efficient operation of the mechanical precollectors or combustion efficiency improvements may reduce the impact of high carbon carryover and thereby minimize possible fabric blinding for FFs and sparkover resulting in poor ESP performance. The ultimate choice of a particulate control device must take into account all of the above factors as well as case-by-case and transient AFBC operating conditions.

This Project Summary was developed by EPA's Industrial Environmental 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

As part of an engineering assessment of control technology for atmospheric fluidized-bed combustion (AFBC), EPA's Industrial Environmental Research Laboratory at Research Triangle Park, NC, is investigating the suitability of fabric filters and electrostatic precipitators (ESPs) as final particulate collectors. Initial efforts were directed at examining selected planned and operating fabric filters and ESPs applied to AFBC boilers. This survey led to the conclusion that fabric filters are being installed on many new AFBC units despite the lack of comprehensive test or demonstration data. ESPs, on the other hand, have been applied on a rather limited basis. With this lack of a working data base, a more fundamental approach was elected to assess particulate control device suitability. This consisted of first making basic measurements on selected fly ash samples obtained from operating pilot- and full-scale AFBCs in the U.S. Basic relationships between key design and performance parameters for fabric filters and ESPs were examined using analytical mathematical performance models. The results of measurements and relationships are presented in this report, along with an assessment of additional data needs.

Approach

Five fly ash samples were obtained from fabric filter hoppers at four AFBC sites ranging in size from pilot- to full-scale units. A series of fundamental laboratory measurements were performed on each sample to characterize particle size distribution, specific resistance coefficient (a measure of fly ash filterability), electrical resistivity, chemical composition, carbon content, and morphology, as shown in Table 1. Test results were then used in conjunction with fabric filter and ESP mathematical models to illustrate how control device performance may be affected by AFBC fly ash properties.

The fabric filter mathematical computer model, developed by GCA/Technology Division for EPA, can be used to predict the field performance of fabric filter systems applied to coal-fired utility boilers.[1,2,3] The model applies to specific collector types using woven glass fabrics and simulates fabric cleaning by a collapse and reverse flow process and/or shake assist. Required operating parameters include flue gas temperature, inlet dust concentration, and gross filtration velocity (air-to-cloth ratio). Among the important dust properties to be considered is the specific resistance coefficient of the dust, K_2. This parameter describes the linear increase in resistance to air flow that occurs when dust deposition on the fabric filter bags is uniform over time. In addition, an estimate of the effectiveness of the fabric cleaning process is required. This estimate is provided by a_c, the ratio of the mass of dust removed from a bag during the cleaning cycle to the mass of dust on the bag prior to cleaning. In this study, the effects of K_2 on pressure drop and penetration, for different levels of filter face velocity and a_c, were examined.

The ESP computer model, developed by Southern Research Institute (SoRI) for EPA, simulates ESP operation and performance characteristics by incorporating fundamental theoretical relationships that describe the physical, chemical, and electrostatic mechanisms interacting in the ESP process.[4,5] Nonideal effects such as nonuniform gas velocity distribution, gas bypassage of electrified regions, and particle reentrainment due to rapping and other causes are accounted for by empirical correction factors. The SoRI/EPA model was used in this study to investigate the relationship between specific collection area (SCA) and overall mass collection efficiency using laboratory measured resistivity and particle size distribution data.

Results/Discussion

Table 2 shows the results of resistivity, particle chemical composition, particle size distribution, and filtration measurements of the five fly ash samples.

The specific resistance coefficient, K_2, of the FBC fly ash samples varies from 1.94 to 5.25 N-min/g-m (11.6 to 31.4 in. W.C.-min-ft/lb). Filtration theory predicts that K_2 increases with decreasing particle size. A specific surface parameter, S_o^2, calculated from the mass median diameter and geometric standard deviation of a dust sample, may be used to characterize this relationship between K_2 and particle size.[1] The computed values of S_o^2 in Table 2 appear to be correlated with measured K_2 (correlation coefficient $r = 0.73$). The actual point scatter may be attributed to differences in particle shape, surface characteristics, or charge effects, although additional investigation is needed to resolve this issue.

The GCA fabric filter model was used to examine the effects of variations in K_2 on filter penetration and pressure drop. An average fabric filter system was defined, and K_2 was chosen to be 5.0 N-min/g-m (30 in. W.C.-min-ft./lb) in contrast to 2.0 N-min/g-m (12 in. W.C.-min-ft/lb), a value which is reported for conventional coal-fired boiler fly ash.[1]

Figures 1 and 2 show the effect of K_2 on penetration and pressure drop, respectively, as a function of filter face velocity. At an air-to-cloth ratio of 0.61 m/min (2 ft/min), the difference in K_2 results in roughly a 30 percent increase in fractional penetration and a 100 percent increase in pressure drop. To

***Table 1**. Summary of FBC Fly Ash Measurements*

Parameter/analysis	*Instrument/technique*
Particle size distribution	*Andersen Mark III (eight-stage) cascade impactor*
Specific resistance coefficient	*GCA/Technology Division bench-scale fabric filter test panel system*
Resistivity	*Denver Research Institute single- and multiple-cell resistivity apparatus*
Chemical/spectral analysis	*Amray Model 1200 SEM[a] with EDXRA[b]*
Carbon analysis	*Low-temperature ashing (LOI)[c]* *High-temperature ashing (CHN)[d]*
Morphology	*Amray Model 1200 SEM[a]*

[a] *Scanning Electron Microscope.*
[b] *Energy Dispersive X-ray Analysis unit.*
[c] *Loss on Ignition.*
[d] *Carbon-Hydrogen-Nitrogen test using a Perkin Elmer Model 240B Elemental Analyzer.*

Table 2. *Results of Fundamental Measurements Performed on FBC Fly Ash Samples*

Sample designation	Resistivity (ohm-cm) @ 10% moisture 149°C	 260°C	 370°C	Chemical/spectral analysis[a] constituents (% by weight) Al_2O_3	 SiO_2	 K_2O	 CaO	 TiO_2	 Fe_2O_3	 C[c]	Particle size distribution aMMD, x (μm)	 σ_g	Specific surface parameter S_o^2 (x 10^{-8})[b] (cm^{-2})	Specific resistance coefficient, K_2 (N-min/g-m)
A[d] - Alliance	3.3 x 10^7	1.2 x 10^7	[e]	11.1	33.2	1.8	10.1	1.0	4.1	33.7	6.0	2.8	5.77	4.89
B - SATR	3.2 x 10^{11}	5.0 x 10^{10}	5.0 x 10^9	21.4	48.5	1.7	10 7	1.6	3.6	7.5	5 3	2 6	6.39	5.25
C[d] - FluiDyne	8.0 x 10^{11}	1.4 x 10^{11}	5.0 x 10^9	12.0	39.5	3.0	20.7	1.8	7.8	10 2	7.3	2 6	3.37	1.94
D - FluiDyne	1 1 x 10^{12}	2.6 x 10^{11}	8.0 x 10^9	12.3	40.0	3.0	22.6	1.0	7.6	9.5	8.9	3 0	3.04	2.46
E - Georgetown	7.1 x 10^5	3.3 x 10^5	[e]	9 9	24.2	1.3	7.0	—	6.4	46.2	7.7	2.7	3.26	4.74

[a] The six oxides were derived from SEM/EDXR analysis, a method relatively insensitive to elements of low atomic number. Some elements (attributed to their common oxides; e.g., SO_3) could not be measured; hence the total does not equal 100%.

[b] The specific surface parameter, S_o^2, can be calculated from the particle size distribution parameters by the formula

$$S_o^2 = \left[6 \left(\frac{10^{1.151 \log^2 \sigma_g}}{MMD} \right) \right]^2$$

Particle density, used to convert aMMD to MMD, was assumed to be 2.0 g/cm^3.

[c] Percent carbon was determined using a CHN test. Results closely agree with those from a simple LOI determination For samples A, B, C, D, and E the percent combustibles (LOIs) were 25.9, 7.5, 12.4, 10.9, and 43 0, respectively.

[d] Without fly ash reinjection.

[e] Both samples A and E sparked over above 260°C (500°F), hence, testing could not be continued.

achieve a collection efficiency of 99.5 percent, for example, a 0.91 m/min (3 ft/min) filtering velocity would be acceptable with a fly ash having the lower K_2, but not with a fly ash at the higher K_2 level.

If it is found that FBC fly ash does not have dust-fabric release properties similar to conventional fly ash, then the leanability of the fabric would be expected to be different. For a K_2 of 5.0 N-min/g-m (30 in. W.C.-min-ft/lb) and an air-to-cloth ratio of 0.61 m/min (2 ft/min), the model calculates that approximately 25 percent of the fly ash is removed by cleaning. As the degree of cleaning increases from 10 to 40 percent, pressure drop is reduced by approximately 70 percent while penetration increases by roughly 12 percent. Clearly, the ease of dust removal from the bag surface as a result of cleaning is an important factor in predicting fabric filter operating pressure drop and performance.

Particle resistivity is an important consideration in the application of ESPs to FBC. Very low concentrations of SO_3 have been recorded in FBC flue gas, which implies a reduced conditioning effect on the particles, resulting in increased resistivity. In addition, all sorbent materials ($CaCO_3$, CaO, MgO, and $CaSO_4$) have high resistivities. However, carbon content exerts a strong influence in lowering fly ash resistivity.

Samples B, C, and D exhibited resistivities in the moderate to high range generally observed with conventional coal-fired boiler fly ash. The characteristic variation of resistivity with temperature was also observed. The unusually low resistivities for samples A and E may be attributed to the high carbon contents present. These resistivities were similar to results obtained from a test run conducted on a hot ESP at the Rivesville, WV, FBC, where the carbon content was 47 percent.[6] In view of the conditions that promote high carbon carryover in an AFBC unit, it may be a more significant operating problem than in conventional combustion. This emphasizes the importance of the primary cyclone in providing reliable, high efficiency particulate collection capability so that unburned carbon is returned to the boiler for efficient combustion and the downstream collector is protected from the effects of carbon carryover.

Figure 3 shows the effect of fly ash resistivity on cold ESP overall mass collection efficiency as a function of specific collection area. The slope of the reference line reflects the exponential design relationship between SCA and collection efficiency. The SoRI ESP model was used to predict the collection efficiencies at an SCA of approximately 49.3 $m^2/(m^3/sec)$, (250 ft^2/1000 acfm), for samples B, C, and D using their measured resistivities at 149°C (300°F) and particle size distributions. These results were extrapolated over a range of SCAs using the slope of the reference line shown by the cross-hatched band. It is noted that the predicted SCA requirements for samples B, C, and D, with resistivities between 10^{11} and 10^{12} ohm-cm, fall within the range of design experience for cold ESPs applied to the collection of conventional fly ash.

The SoRI model was also used to investigate particle size effects on ESP performance. The use of cyclones for fly ash recycle in FBC systems may result in finer particle sizes, relative to conventional fly ash, reaching the ESP. Model results show that the collection of smaller particles requires a larger ESP for a given efficiency, if all other factors are held constant. Because the cyclones also reduce the ESP inlet loading, the smaller particle size distribution of FBC fly ash does not necessarily imply a higher SCA requirement. However, depending on the collection efficiencies of the cyclones, as well as other important factors such as rapping reentrainment losses, a more conservative estimate of SCA may be required.

Field Operating Considerations

Some of the more common problem areas encountered with fabric filter operation include fabric/dust deposit interaction, bag failures, design or maintenance failures relating to bag support and the cleaning mechanism, and structural design problems including isolation dampers and the ash removal system. For example, a dust which is hygroscopic may, in the presence of moisture, cause blinding, impede proper cleaning, cause excessive pressure buildup across the fabric, reduce bag service life, and promote ash removal problems.

Potential problem area considerations for ESPs applied to FBC units include:

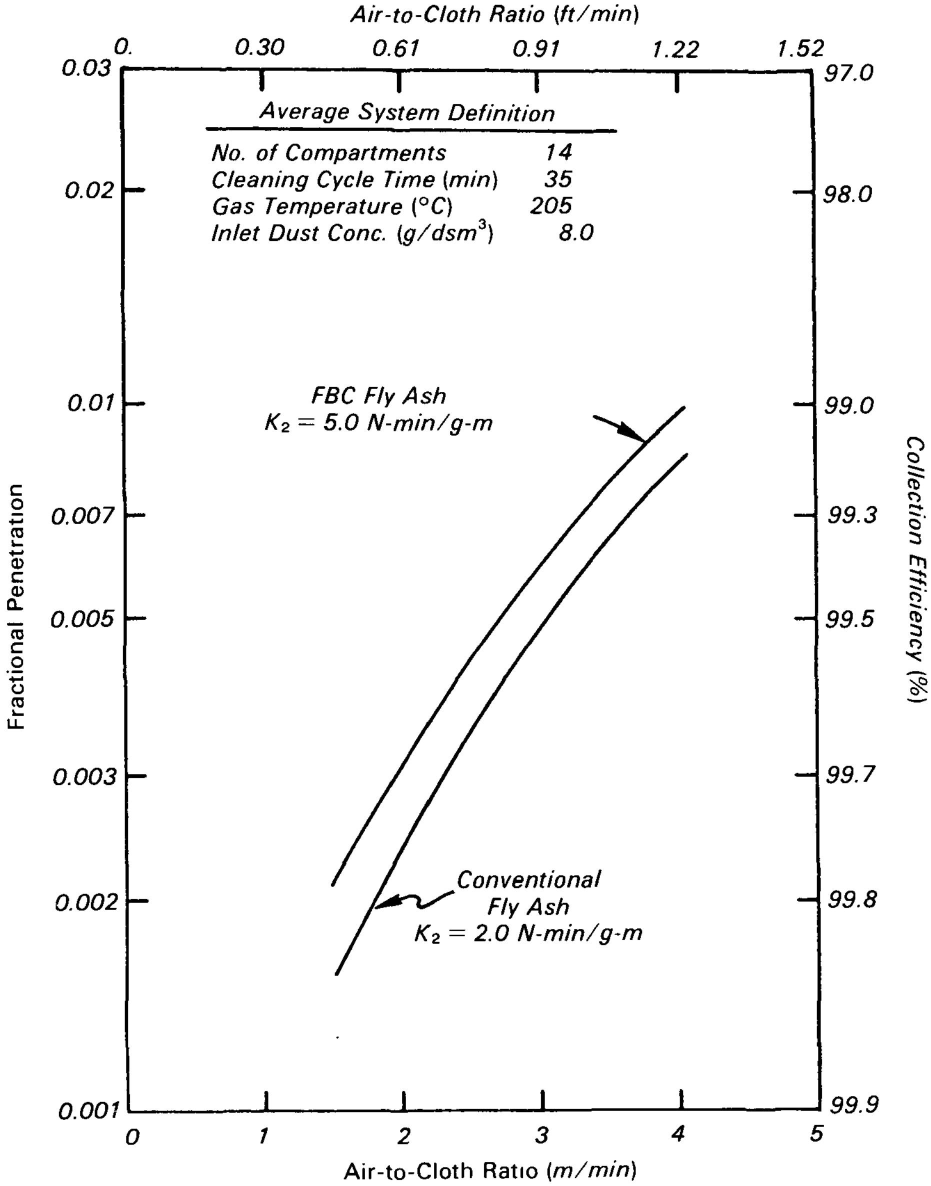

Figure 1. *The effect of air-to-cloth ratio on particle penetration for different K_2 levels.*

electrode fouling due to buildup of fly ash on the wires; local burning on the wires due to high carbon carryover (and manifested by heavy sparking); rapping reentrainment losses; and transient conditions associated with boiler startup.

The performance of the final particulate collector depends on the FBC operating parameters; in particular on cyclone efficiency, carbon burnup cell combustion efficiency, optimized freeboard height, bed depth, and fluidizing velocity. The carryover of unburned carbon during startup or during a transient boiler operating condition may severely deteriorate electrical conditions in an ESP, with the possibility of ignition and fire. In fabric filters, this same condition may cause fabric blinding and permanent damage. Low load conditions can reduce cyclone efficiency and add to the carbon carryover problem. One important conclusion of this report is that the precollector or cyclone must be considered as an integral part of the total particulate control system. Furthermore, the entire collector system must be flexible enough in both design and operation to handle most of the potential transient conditions in AFBC operation.

References

1. Dennis, R., et al. Filtration Model for Coal Fly Ash with Glass Fabrics. GCA/Technology Division. EPA-600/7-77-084 (NTIS PB 276489). August 1977.
2. Dennis, R., and H.A. Klemm. Fabric Filter Model Format Change: Volume I. Detailed Technical Report. GCA/Technology Division. EPA-600/7-79-043a (NTIS PB 293551). February 1979.
3. Dennis, R., and H.A. Klemm. Fabric Filter Model Format Change: Volume II. User's Guide. GCA/Technology Division. EPA-600/7-79-043b (NTIS PB 294042). February 1979.
4. McDonald, J.R. A Mathematical Model of Electrostatic Precipitation (Revision 1): Volume I. Modeling and Programming. Southern Research Institute. EPA 600/7-78-111a (NTIS PB 284614). June 1978.
5. McDonald, J.R. A Mathematical Model of Electrostatic Precipitation (Revision 1): Volume II. User Manual. Southern Research Institute. EPA-600/7-78-111b (NTIS PB 284615). June 1978.
6. Pope, Evans, and Robbins, Inc. Multicell Fluidized-Bed Boiler Design, Construction and Test Program. Research and Development Report No. 90, Interim Report No. 1 for Period October 1972-June 1974. Prepared for the U.S. Department of the Interior. PB 236 254. August 1974.

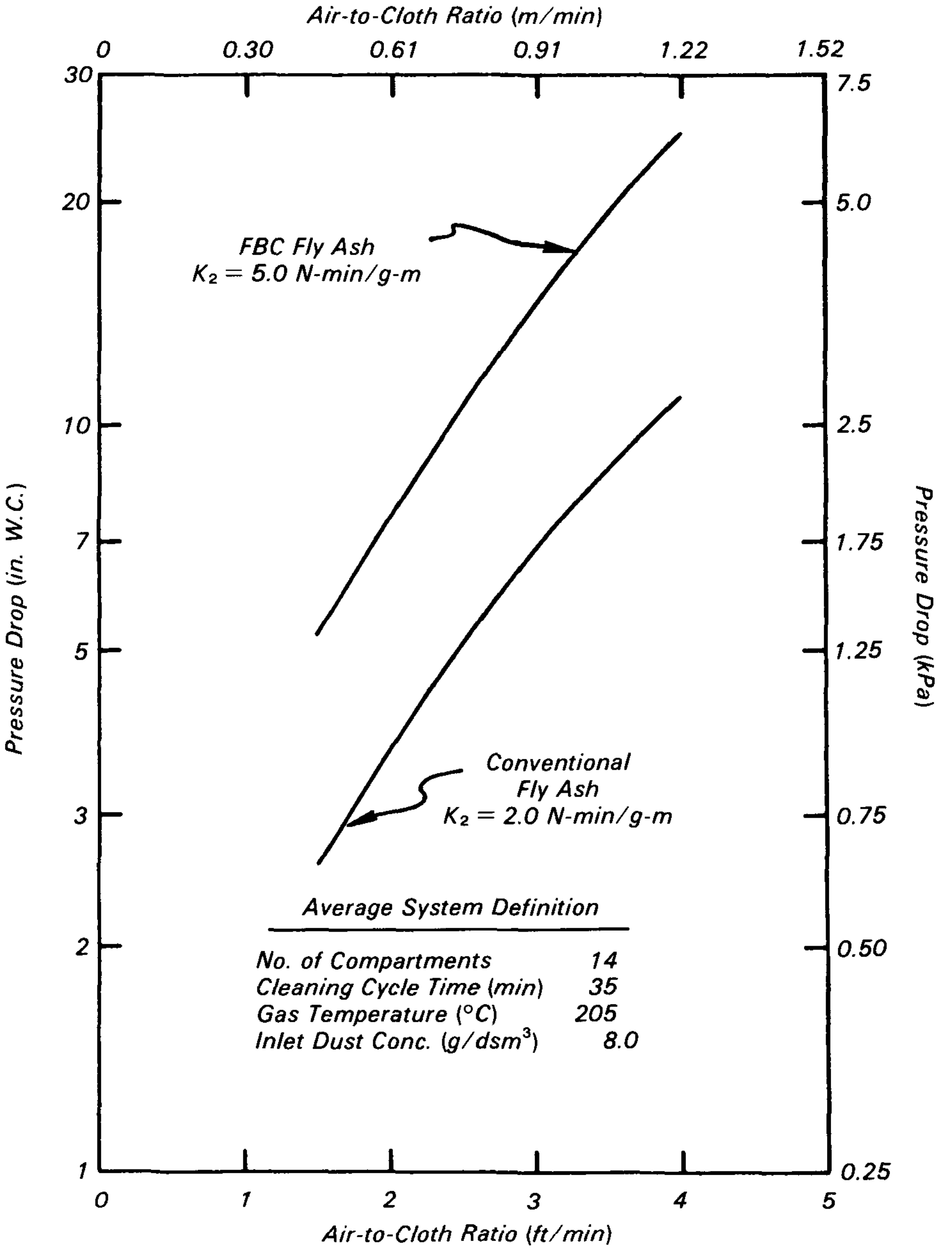

Figure 2. The effect of air-to-cloth ratio on filter pressure drop for different K_2 levels.

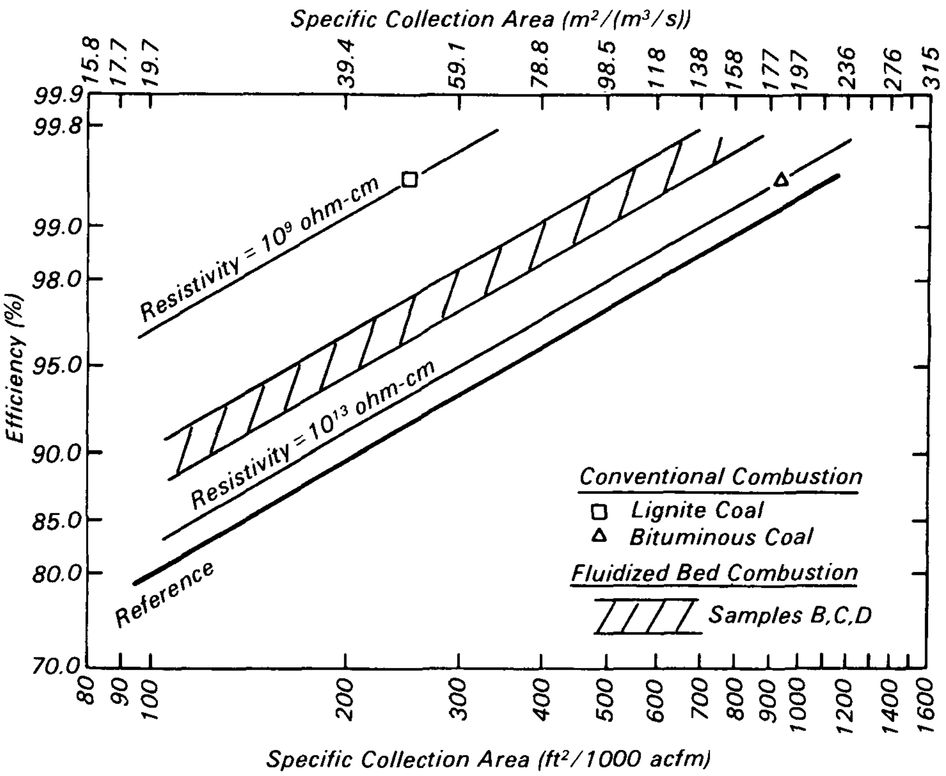

Figure 3. Effect of fly ash resistivity on cold ESP overall mass collection efficiency as a function of specific collection area.

D. V. Bubenick, R. R. Hall, and J. A. Dirgo are with GCA/Technology Division, Burlington Road, Bedford, MA 01730.
John O. Milliken is the EPA Project Officer (see below).

The complete report, entitled "Control of Particulate Emissions from Atmospheric Fluidized-Bed Combustion with Fabric Filters and Electrostatic Precipitators," (Order No. PB 82-115 528; Cost: $10.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

☆ U.S. GOVERNMENT PRINTING OFFICE:1981--559-092/3361

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

PS 0000329
U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604