FIRST ESP WITH WIDE PLATE SPACING APPLIED TO A CYCLONE FIRED BOILER

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Abstract

The electrostatic precipitator (ESP) which serves Boiler #1 at KCBPU's Quindaro Station is the first with wide plate spacing applied to a cyclone fired boiler. Performance and operating characteristics of the ESP along with corresponding coal and fly ash data are presented and discussed. Given the fine fly ash typical of cyclone fired boilers, particular attention is paid to indications of space charge current suppression. The effects on performance and operation of varying coal, SCA and power input are examined. Selected operating characteristics from several combinations of boiler type and ESP plate spacing are presented and compared. Measured changes in ESP performance resulting from varying specific parameters are compared with predictions of these changes determined using the SoRI ESP math model.

Introduction

Early in 1990, Kansas City Board of Public Utilities (KCBPU) initiated a life extension program for #1 cyclone boiler at Quindaro Station. Service into the next century is planned. Burns & McDonnell was selected as the architect-engineer for the project, which included, among other things, conversion of the boiler from a pressurized to a balanced draft system and replacement of the two field, weighted wire precipitator. The new rigid electrode design precipitator with wide plate spacing is required to provide

- low stack opacity and fly ash emissions
- greater reliability
- increased fuel flexibility
- capacity to accommodate added emissions from a future SO_2 control process

Environmental Elements Corporation (EEC) was awarded the contract for the new precipitator which started up in June 1992. The scope of equipment designed supplied and installed by EEC is listed below:

- Precipitator complete
- Access
- Inlet plenum with transition
- Outlet transition
- Full roof weather enclosure
- Prefabricated and prewired control room
- Thermal insulation and lagging
- Low voltage wiring

The precipitator discussed in this paper is of interest because it is the first with wide plate spacing to collect the fine fly ash from a cyclone fired furnace. Table 1 below provides general information about EEC's experience with cyclone fly ash precipitators.

Table I

EEC Cyclone Fly Ash Precipitators

Number of Units	15
Boiler Ratings (MW)	55 to 540 (2650 Total)
Plate Spacing (inches)	9, 10, 11, 12, 15.5
Period	1960 thru 1993

Background

The number of precipitators with wide plate spacing, (typically about 400 mm or 16 inches), collecting pulverized coal (PC) fly ash in North America has increased significantly over the past eight (8) years. Included among the reasons for greater acceptance of this technology for PC fly ash are:

- Results of EPRI's precipitator wide plate spacing study [1].
- Increased full size equipment and data base throughout the world [2, 3, 4, 5].

Precipitators with wide plate spacing have also been proposed to collect fly ash from cyclone furnaces. However, acceptance of the technology for this application has been very limited. Some engineers with EPRI and some of the A&E firms have avoided endorsing the technology for cyclone fly ash because of concerns related to the fineness of the ash. For comparison, typical particle size distributions for PC and cyclone fly ashes are shown in Figure 1.

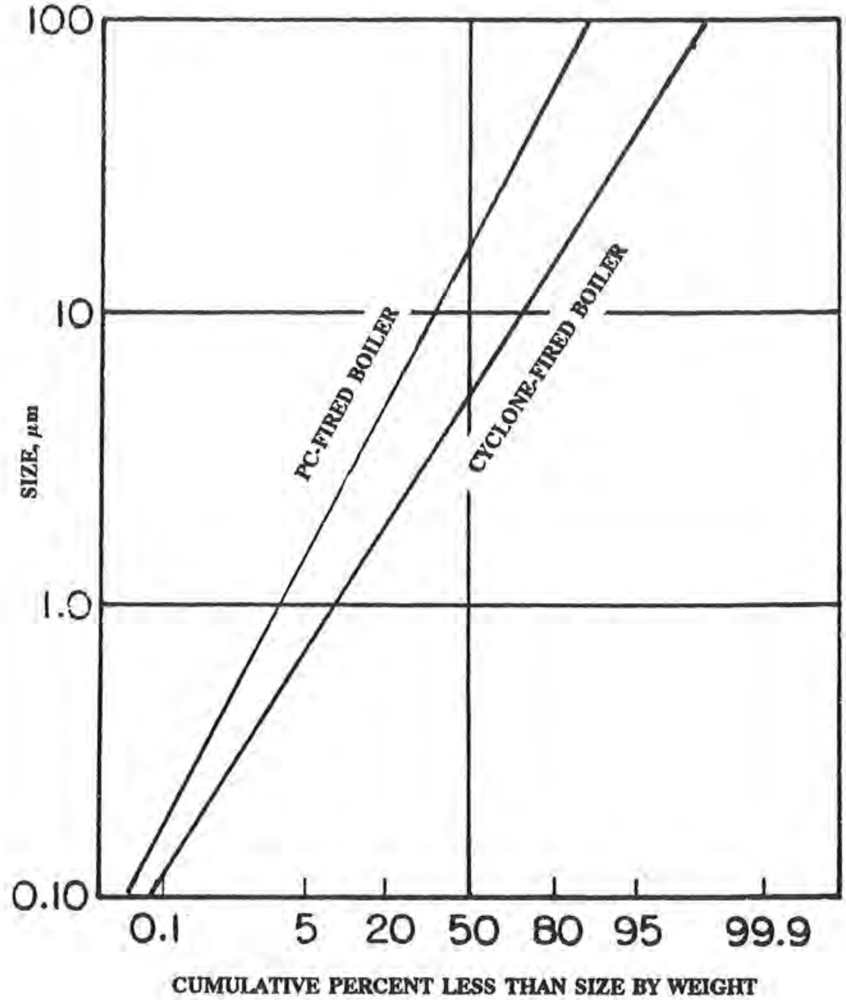

Figure 1. Fly ash particle size distribution

On average the mass median diameter of cyclone fly ash may be only a third of that for PC fly ash.

The principal concern about fine cyclone fly ash in a precipitator with wide plate spacing is the increased potential for space charge current suppression. Space charge is actually one of the two fundamental requirements for sustained corona to exist [6]. Without it in a clean non-electronegative gas, sparkover between the emitting electrode and passive electrode would occur when the voltage between the electrodes is raised to a level that would correspond to corona onset [6]. Although space charge is needed for the process, too much can be a problem.

For a given fly ash mass concentration, as particles become finer, the specific surface available for charging increases. Fine particles have considerably lower mobilities than gas ions, and when these particles are charged, they form a relatively slow moving cloud of charge within the interelectrode space. This cloud increases the electric field near the plate (collecting field), but it also tends to decrease the electric field near the discharge electrode (charging field). Increasing the collecting field actually helps the precipitation process. Conversely, decreasing the charging field can reduce charging current and precipitator performance. Space charge is also increased by increasing plate spacing. All else being equal, increasing plate spacing for any particle size distribution will increase the number and mass of charged particles per discharge and collecting electrode.

The above discussion indicates that space charge is increased by both fine particles and wide plate spacing. This may imply that collecting cyclone fly ash in a precipitator with wide plate spacing will lead to a space charge current suppression problem. Evaluation of some of the governing parameters will help to quantify important characteristics. In Table II below pertinent parameters of 'typical' PC and cyclone fly ashes are compared.

Table II

Comparison of Pertinent PC & Cyclone Fly Ash Parameters

	'Typical' **PC Fly Ash**	*'Typical'* **Cyclone Fly Ash**		
Particulate Mass Median Dia. (microns)	17.7	5.7	5.7	5.7
Particulate Specific Surface (cm^2/gm)	2,050	5,400	5,400	5,400
Fly Ash ÷ Coal Ash (gm/gm)	0.8	0.30	0.35	0.40
Coal Heat Value (Btu/lb)	11,000	11,000	11,000	11,000
Coal Ash (%) as Rec'd	10	10	10	10
Particulate Mass Concentration (gm/m^3)	4.66	1.75	2.04	2.33
Particulate Surface Concentration (cm^2/m^3)	9,553	9,450	11,016	12,582

This is a simplified representation of some fly ash characteristics in well known terms. Consideration of other important characteristics, such as the bimodal nature of fly ash, is beyond the scope of the analysis. The examples in Table II indicate that, depending on which ash carryover fraction is used, 'typical' cyclone fly ash has about 0 to 35% more particulate 'surface concentration' than PC fly ash. Variations approaching this magnitude can exist among PC fly ashes. 'Surface concentration' may be an approximate indicator of space charge level because it represents the concentration of available chargeable particulate area. This indicator, which considers both particulate mass concentration and specific surface, is used for the PC and cyclone fly ash examples because even though cyclone fly ash is finer than PC fly ash, its mass concentration is typically also lower. The results in Table II do not necessarily indicate a significant space charge current suppression problem as related to plate spacing. Over the years, the plate spacing of precipitators applied to cyclone furnaces has varied from 9" to 12". This increase of 33% has produced no significant problems with cyclone fly ash precipitators.

It is important to note that for the same resistivity and any given plate spacing, the design and operating migration velocities (w) for cyclone fly ash will be lower than those for PC fly ash. This is due to basic physics of the motion of a charged particle in a gas under the influence of an electric field. Simply stated, migration velocity is approximately proportional to particle diameter.

Design

General design data for boiler #1 at Quindaro Station are presented in Table III.

Table III

Boiler #1 Design Data

Supplier	Babcock-Wilcox Corp.
Furnace Type	Cyclone
Boiler Rating	625,000 Lbs. Steam/Hr.
Gross Heat Input	907 x 10^6 Btu/Hr.
Outlet Gas Flow Rate	881,000 Lb/Hr @ 340°F
Fuel	Varying mixes of Brushy Creek and Hanna River Basin coal

General design data for the new Unit #1 precipitator are presented in Table IV.

Table IV

New Unit #1 Precipitator Design Data

Volumetric Flow Rate	76,000 to 380,000 (ACFM)
Flue Gas Temp	230 to 350 (°F)
Operating Pressure	-3 to -26 (In. H_2O)
Inlet Fly Ash Concentration	1.0 to 8.85 (GR/ACF)
Particulate Emissions	0.03 Lb/10^6 Btu *
Stack Opacity	≤ 10%
Coal Sulfur	≥ 0.4%
Type of Discharge Electrode	Rigid Electrode
Number & Size of Fields	8 @ 7.625′ x 50′
Gas Passage Width	15.5″
Type of Rappers	Electric Impulse
Number & Rating of T/R's	8 @ 1000 MA; 70 KV DC Avg.

* With up to 38% of the precipitator deenergized depending on the fuel mix burned.

Two features of the new unit #1 precipitator help to deal with space charge effects as they relate to current suppression. The first feature (shown in Figure 2) is the corona generation mechanism of the rigid discharge electrode.

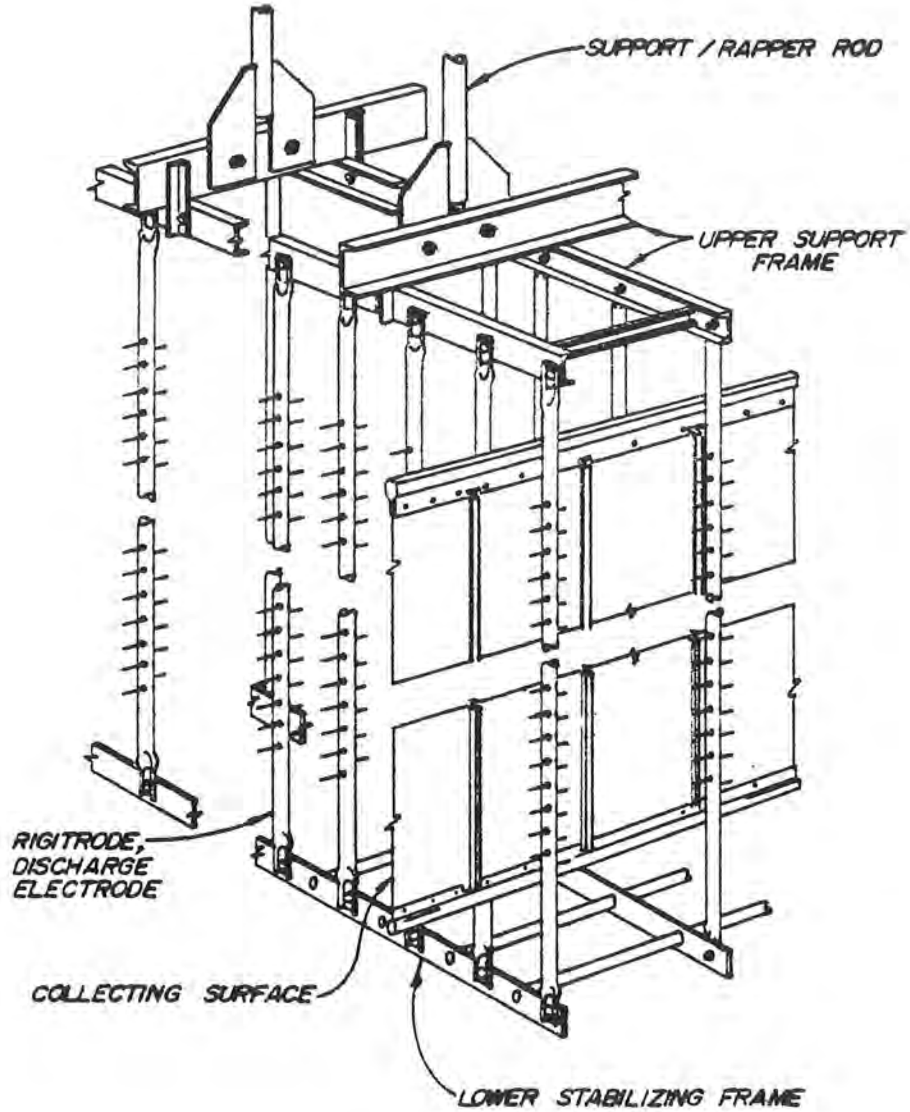

Figure 2. Discharge electrode system

Corona is initiated at the points of the studs which are welded to the electrode tube. Past experience indicates that a barbed type electrode with relatively low corona onset voltage is generally more effective (especially for precipitator inlet fields) than standard round wire in applications with high space charge. A notable example of switching from standard round wire electrodes to barbed type for controlling space charge current suppression occurred in the pulp and paper industry many years ago. Specifically, salt cake from a recovery boiler has fume like characteristics which cause considerable space charge current suppression in precipitator inlet fields. Electrode switching in this case was normally limited to the first or first and second fields. The switching generally provided a measurable improvement in current density. As shown in Figure 3, the rigid electrode provides the same corona onset point as a barbed wire, whereas corona onset for the round wire is significantly higher.

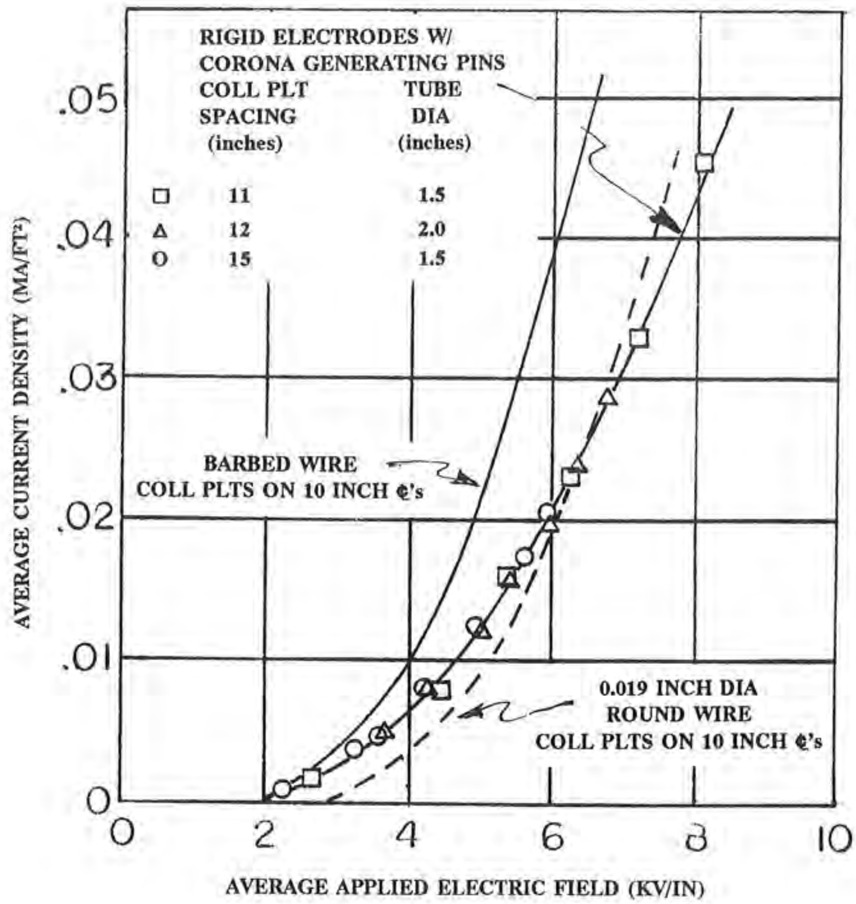

Figure 3. Air load V-I Curves for full scale precipitators with clean electrodes

When space charge is high, the corona onset point is important, because (depending on the severity of the space charge effect) it is possible to approach, very closely, sparkover before current starts to flow. Because of its lower corona onset point, a barbed type electrode provides some extra charging current before sparkover when space charge is high. It should be noted that for the three (3) rigid electrode cases shown in Figure 3, the average applied field vs. average current density curves are essentially identical. This indicates that in clean air space charge effects are the same as plate spacing varies from 11" to 15".

The second feature (shown in Figure 4) is the provision of eight (8) independently energized fields in the direction of gas flow.

Gas ↓ Flow

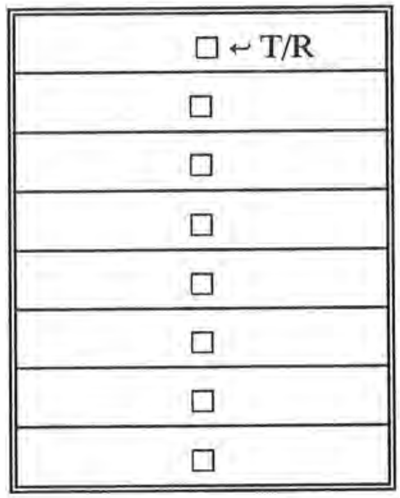

Figure 4. Precipitator electrical sectionalization.

The extremes of electrical sectionalization are, on the one hand, isolating and independently energizing each individual electrode (which of course is impractical for industrial equipment) and on the other energizing the entire precipitator with a single T/R (a very rare occurrence). Debate over the degree and configuration of sectionalization within these extremes has raged for years. Some of the factors considered in determining how to optimize sectionalization include, a) precipitator component design and reliability, b) process conditions and upsets, c) auxiliary equipment performance, etc.. When process conditions lead to a high level of space charge, use of numerous small independent sections in the direction of gas flow tends to isolate those most severe effects, which occur at the inlet, to a small percentage of the precipitator. Even if the particulate concentration reduction and particle agglomeration are only modest in the short field, behavior of the next field will benefit. The net effect is an overall net improvement in performance.

Operation and Performance

Data

Summarized in Table V are pertinent operation and performance data for Q#1 precipitator which have been accumulated since start up.

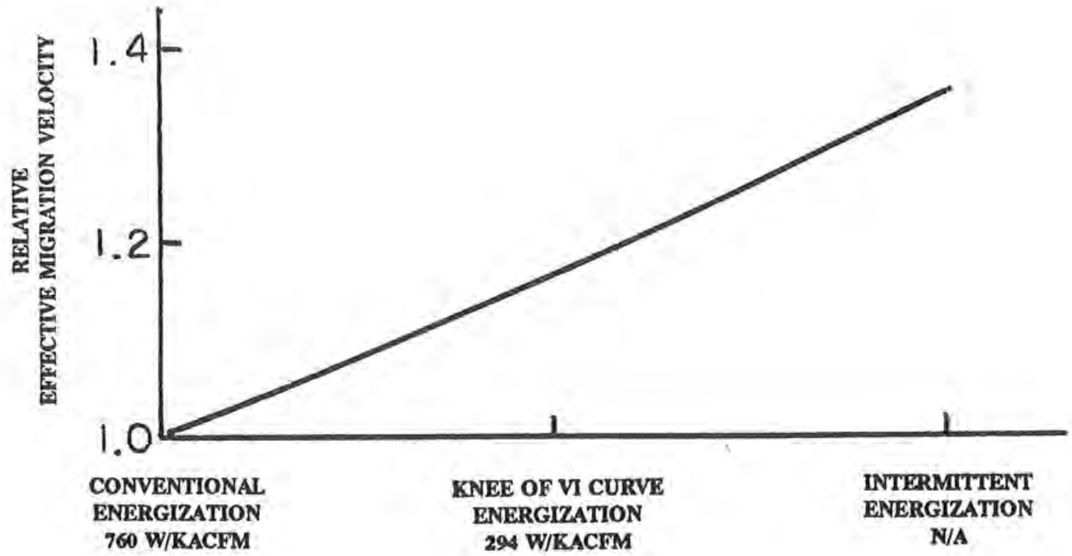

Figure 7. Relative effective migration velocity vs. mode of energization

Reduction of back corona in the KoVIC and IE modes of energization produced considerable improvement in performance as compared with conventional energization. Lab resistivity measurements for fly ash samples taken from the hoppers during testing vary from about 1.2 x 10^{11} Ωcm to 1.2 x 10^{12} Ωcm at 325°F and 8% H_2O. Calculated resistivity values using analyses of coal and ash samples range from 2.5 x 10^{10} to 1.4 x 10^{11} Ωcm. The reasons for the order of magnitude difference between the calculated and lab measured resistivity values are not known. Regardless of what lab measurements and/or calculations of resistivity indicate for fly ash samples removed from the precipitator, it's the resistivity of the fly ash resident layer on the collecting plates during operation that counts. When collecting plate deposit is relatively thin, as is the case with Q#1 precipitator, the best indicator of its operating resistivity is the precipitator's electrical characteristics. Initiation of back corona has been observed in Q#1 precipitator at a current density as low as 0.007 MA/ft^2. This tends to imply an operating resident layer resistivity in the 10^{12} Ωcm range.

Particle Size Distribution

The inlet particle size distribution measurements in Table V indicate an unexpectedly fine fly ash even for a cyclone furnace. Typically, cyclone fly ash has a mass median diameter of between 5 and 6 microns. The reason for the unusual fineness of Q#1 fly ash is not known. To estimate the change in particulate emissions which would result if the size distribution was more typical, the SoRI computerized math model of the precipitation process was used. The prediction was done for knee of the V-I curve energization mode because the model is not yet designed to accommodate either back corona or IE. Results of the computer runs, listed below, predict that a more typical size distribution would reduce particulate emissions by a factor of two (2) (all other conditions the same).

	Q#1 Fly Ash	**Q#1 Fly Ash**	**"Typical" Cyclone Fly Ash**
Mass Median Dia. (microns)	2.25	2.65	5.7
Standard Deviation	4.89	3.58	3.5
Particulate Emissions Calculated	0.0184	0.0166	0.0083
(lb/10^6 Btu) Measured	0.0162	0.0162	

Space Charge Effect

One way to approximate the effect of space charge on current density is to deenergize the inlet section of the precipitator and monitor current density in the next energized field. Given the fine particle size distribution of Q#1 fly ash, reduction in particulate concentration through the deenergized region is considered insignificant and ignored. For this case therefore, the first energized field will become the new "inlet" field. If space charge is the dominant factor which influences current density, the new "inlet" field current density should reach, essentially immediately, the value of the real inlet when it was energized. Some tests for Q#1 precipitator required that the first two (2) of the eight (8) fields be deenergized. Data from these tests are presented in Figure 8 in the form of plots of current density for field 3 as a function of time following deenergization of fields 1 & 2. In both trials shown, current density decreased gradually with time to approximately original inlet field level. This result indicates that space charge is not the dominant factor which influences current density since the current density change was not immediate. Rather, the fact that hours were required to reach original inlet field current density implies that other mechanisms more strongly affect current density. One possibility is gradual change of discharge and collecting electrode deposits until they simulate those of the original inlet.

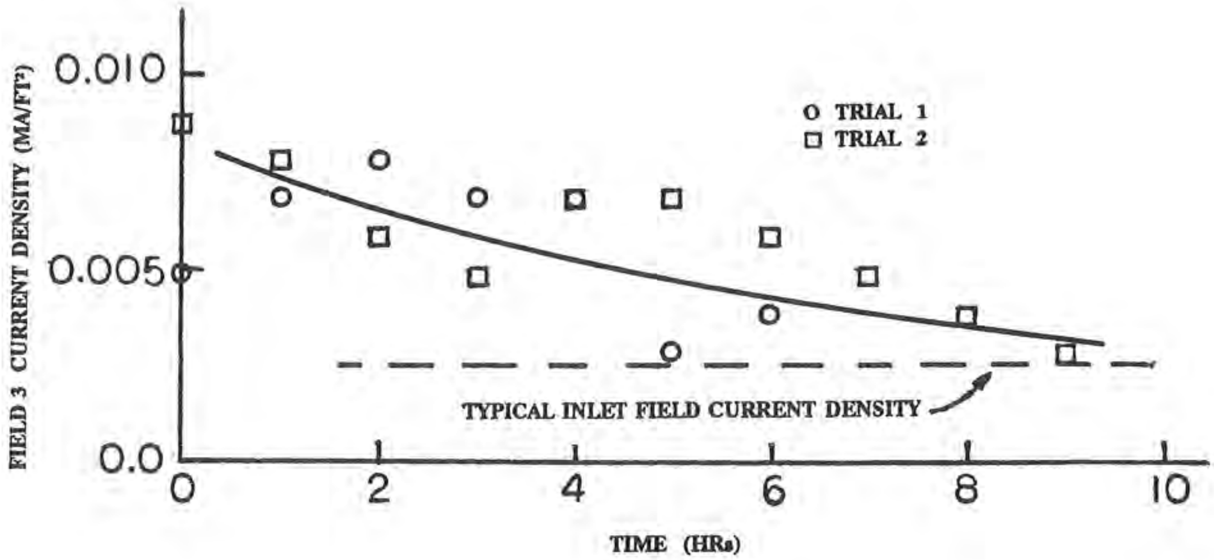

Figure 8. Field 3 current density vs. time following deenergization of fields 1 & 2

Finally, the following comparison is presented between inlet field current density and other parameters of Q#1 precipitator and a PC fly ash precipitator which collects abnormally fine PC fly ash.

	Q#1 ESP	Plant A ESP
Furnace Type	Cyclone	PC
Fly Ash Mass Media (microns)	2.45 avg.	7.0
Fly Ash Surface Concentration (cm^2/m^3)	27,260	10,070
Approximately Ash Layer Resistivity (Ωcm)	10^{12}	10^{12}
Collecting Plate Spacing (inches)	15.5	12
Inlet Field Current Density (MA/ft^2)	0.0025	0.0025
Avg. Applied Electric Field (KV/in) (at sparkover)	8.5	8.0

In the case of this simplified example, significant variation of fly ash surface concentration and plate spacing appears to have essentially no influence on current density. This implies less than expected space charge effect.

Observations and Conclusions

-- Controlling back corona via IE improves Q#1 precipitator operation considerably.

-- Inlet fly ash is considerably finer than expected even for a cyclone furnace. Stack particulate emissions are calculated to be about half of those measured if Q#1 fly ash had a 'typical' particle size distribution.

-- Given the fineness and resistivity of Q#1 fly ash, inlet field current density is not out of line, implying no abnormal space charge current suppression.

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