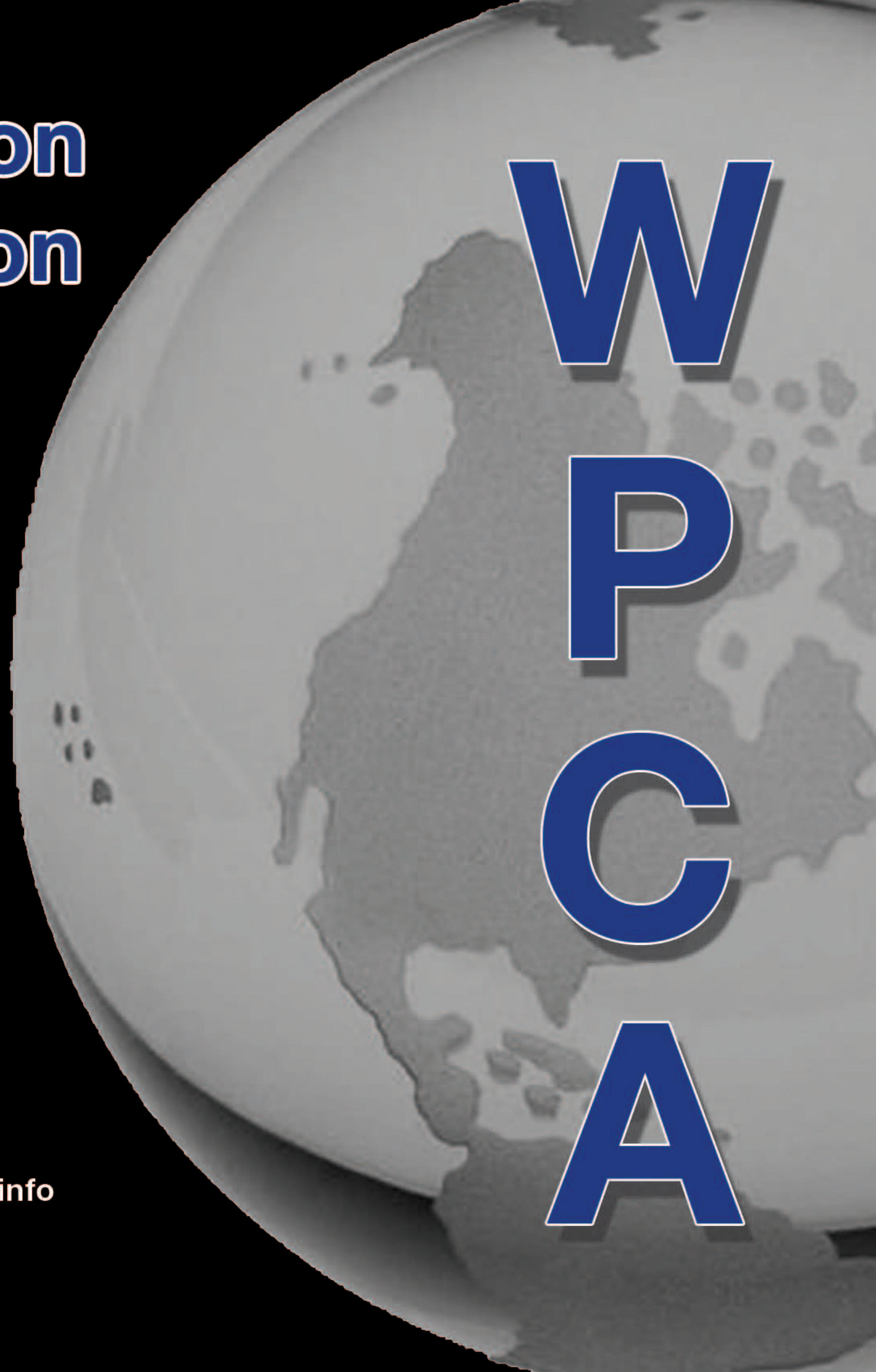
Worldwide Pollution Control Association

Duke Energy Seminar

September 3 – 5, 2008

Concord, NC



Vist our website at www.wpca.info

ESP Basics

By

Tom Lugar

Buell APC

Fisher-Klosterman, Inc.

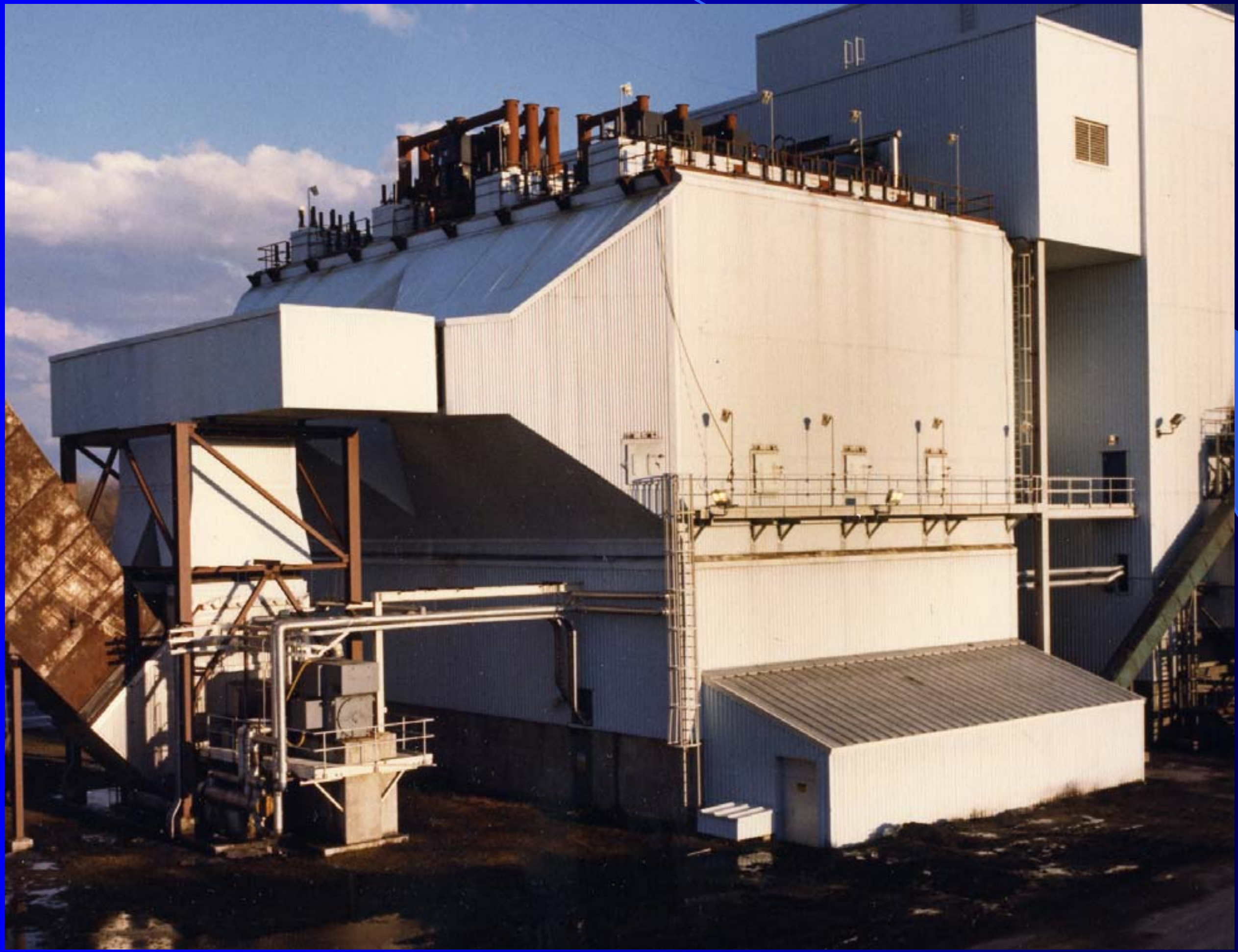
A CECO Environmental Company

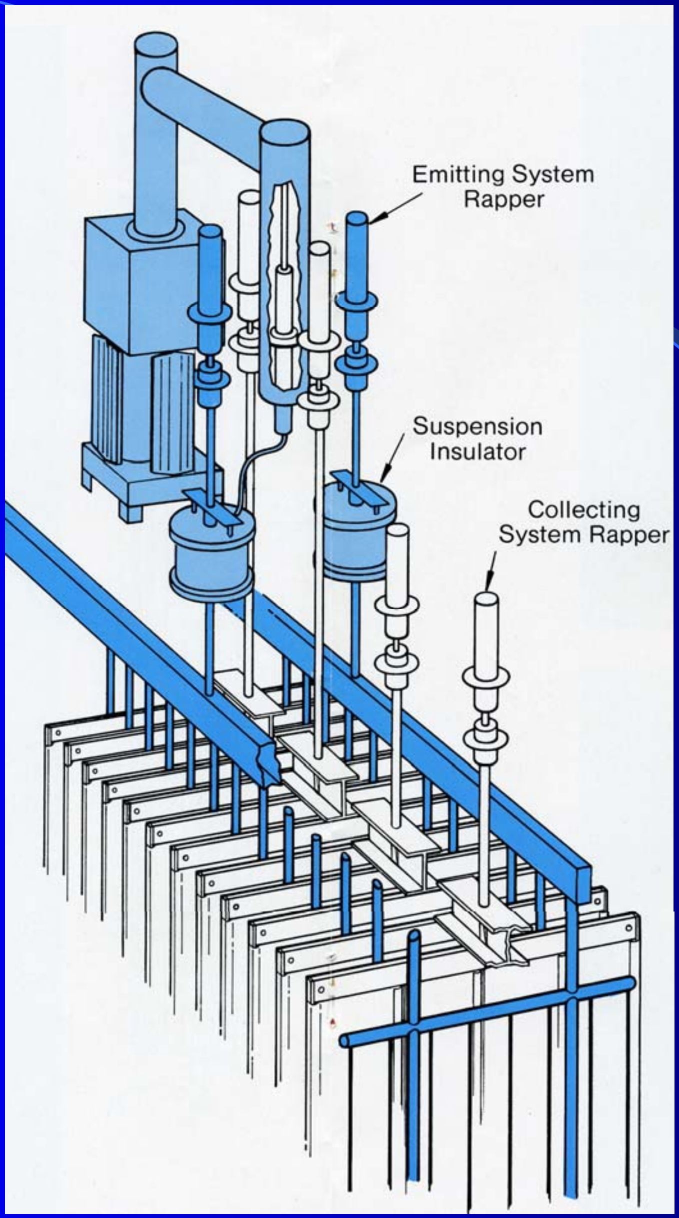
Fundamentals of Electrostatic Precipitator (ESP) Operation

The Process in Electrostatic Precipitation

- Particle Charging
- Particle Collection
- Removal of Collected Particulate

Electrostatic Precipitator
'A Box with Wires and Plates'

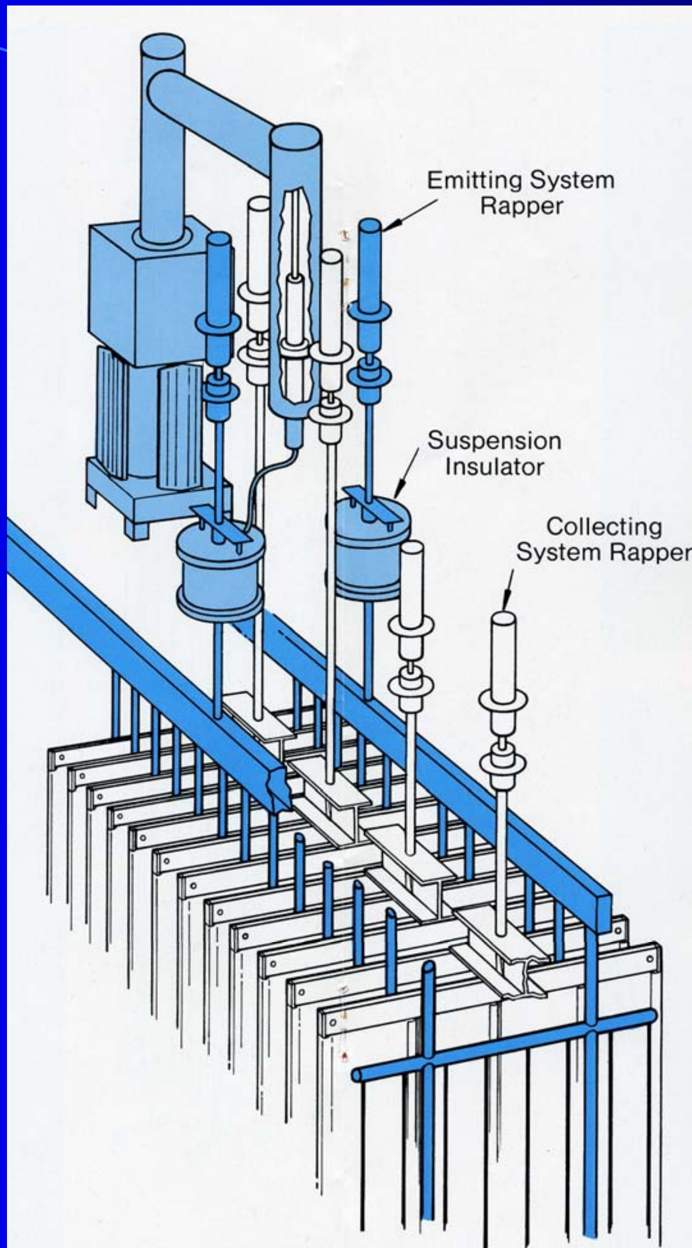



Emitting System
Rapper
Suspension
Insulator
Collecting
System Rapper

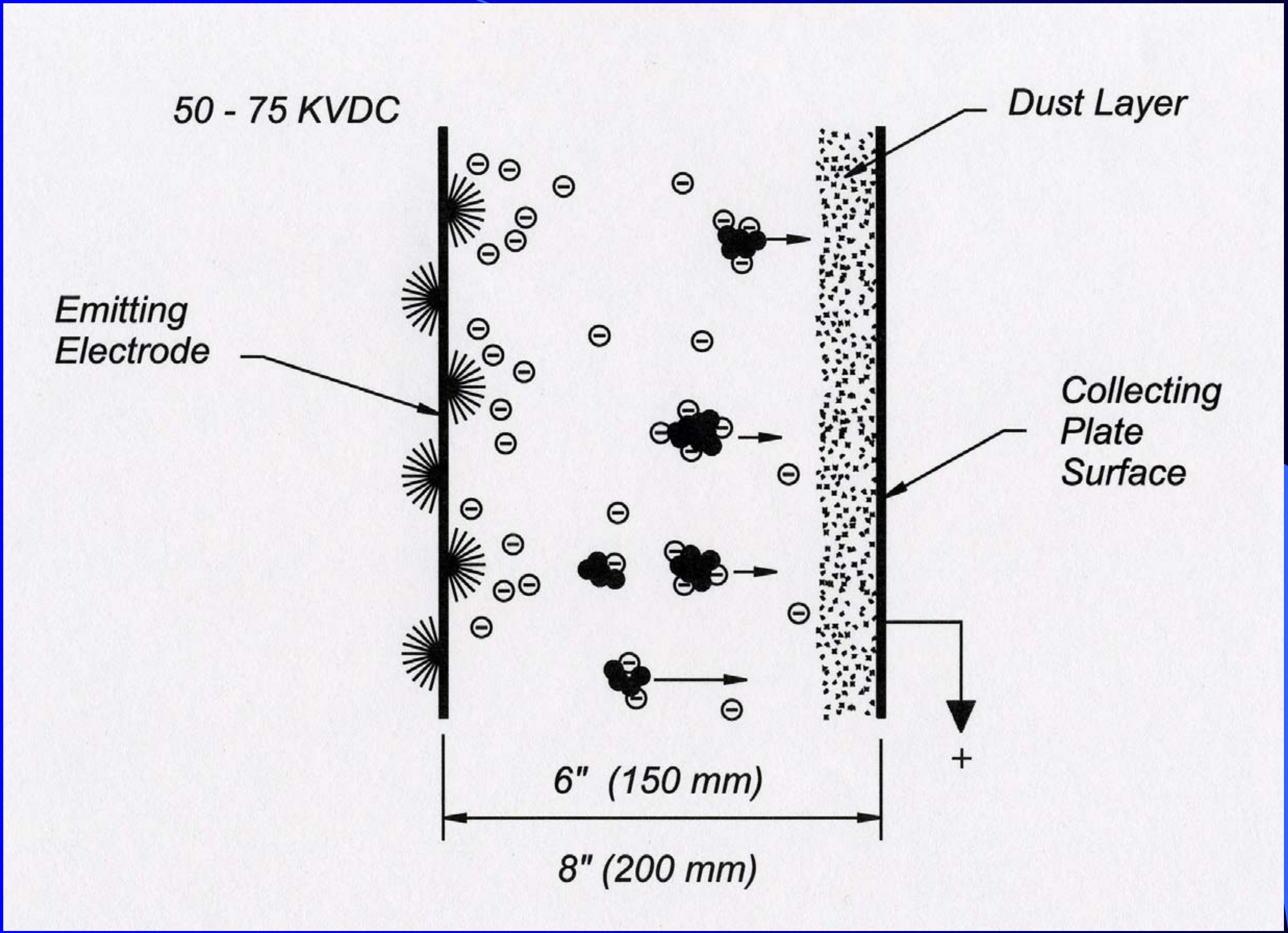
ESP Roof Area: H.V. Transformers, Rappers, Insulator Houses

H.V. Insulator 'House'

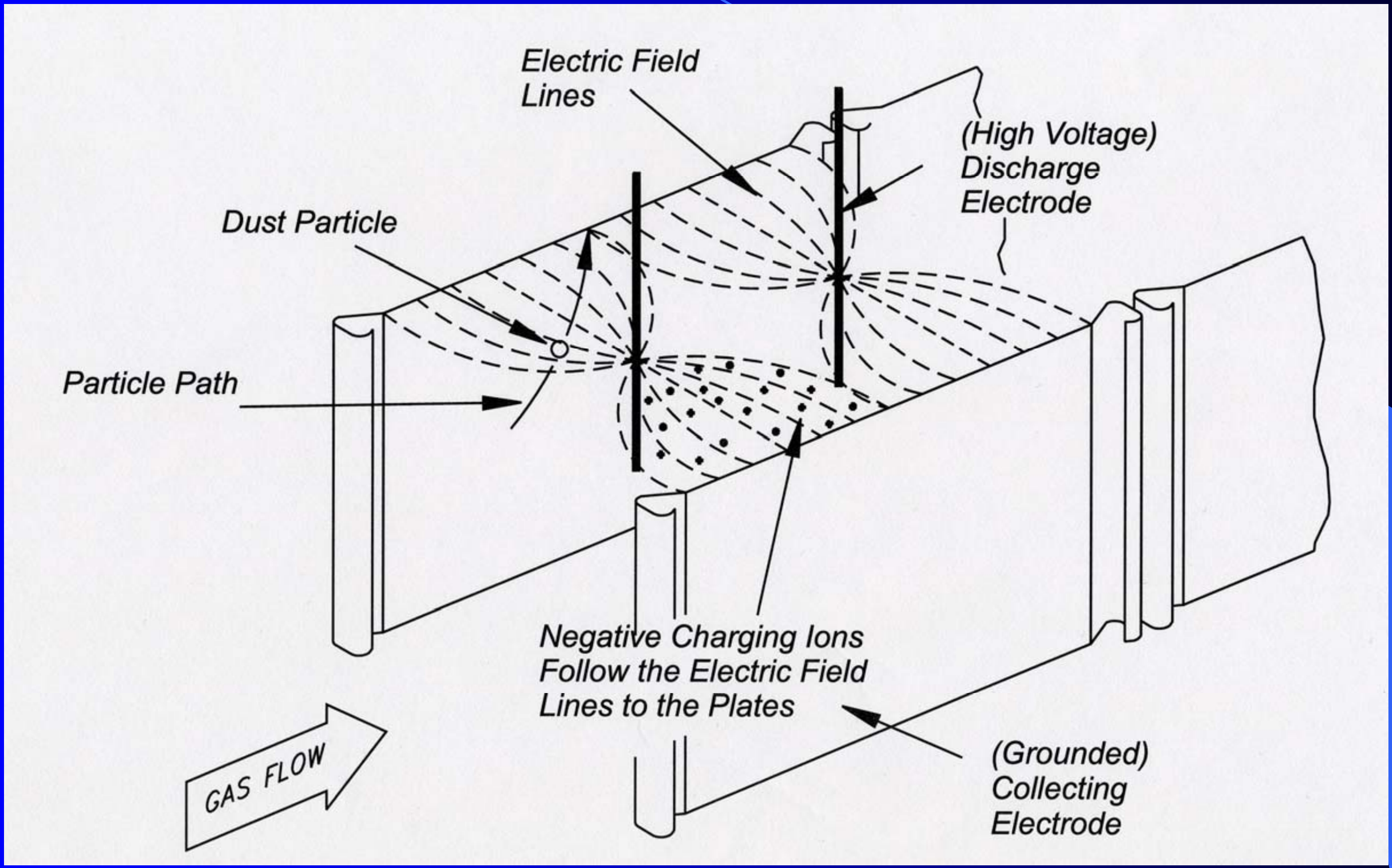
Gas Passages – 9” Centers


Emitting System
Rapper
Suspension
Insulator
Collecting
System Rapper

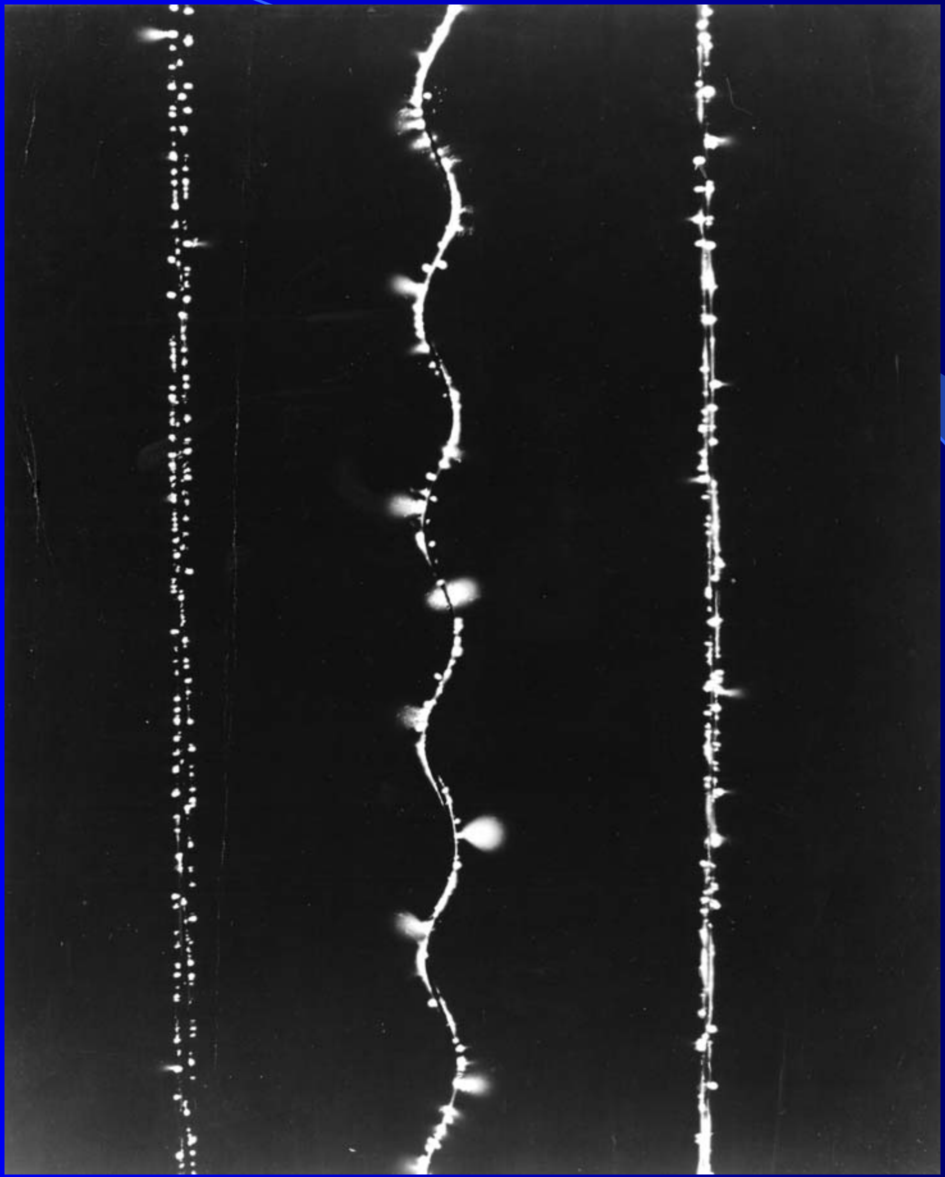
Particle Charging and Collection



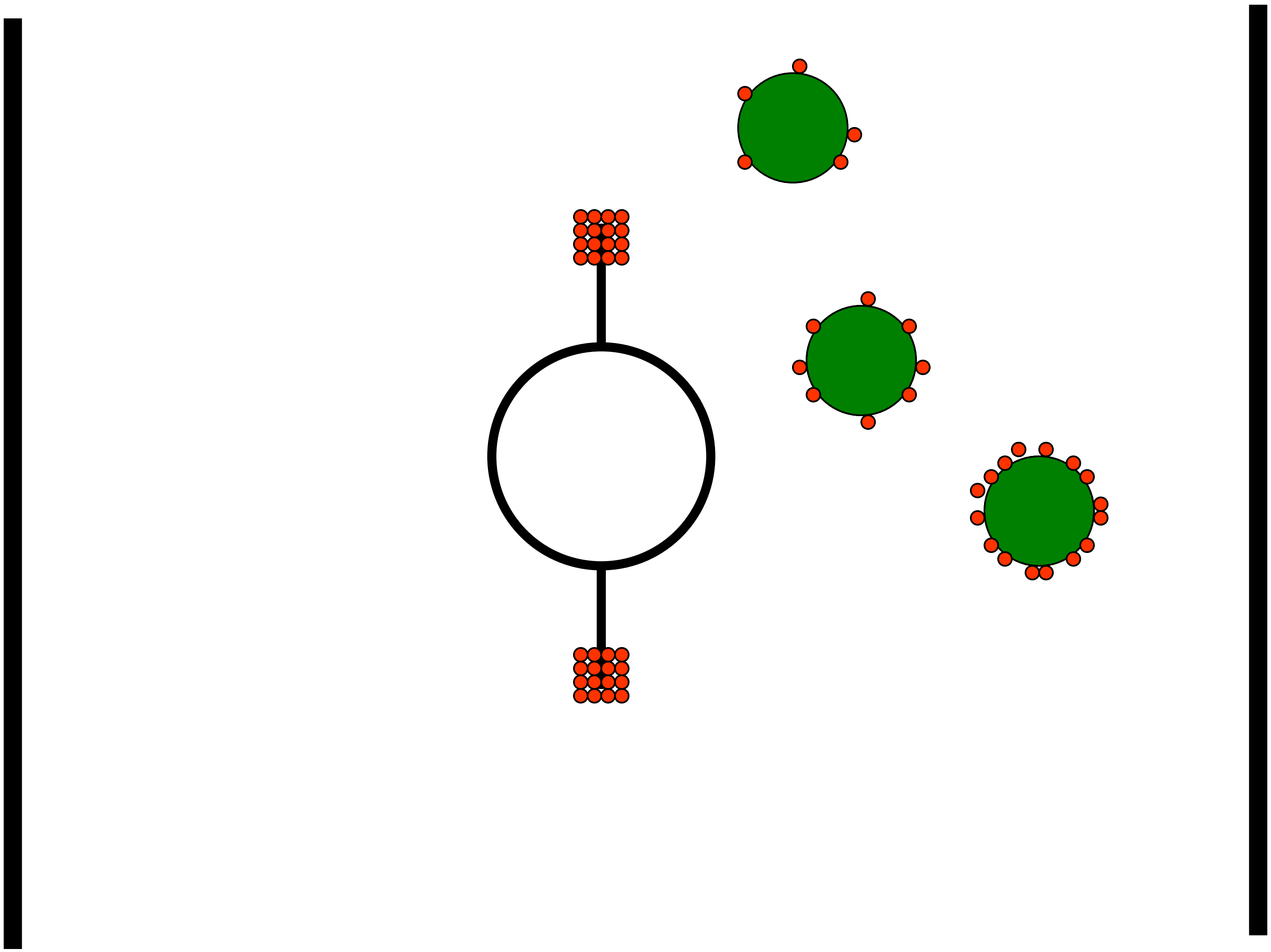
ESP Gas Passage – Particle Charging & Collection

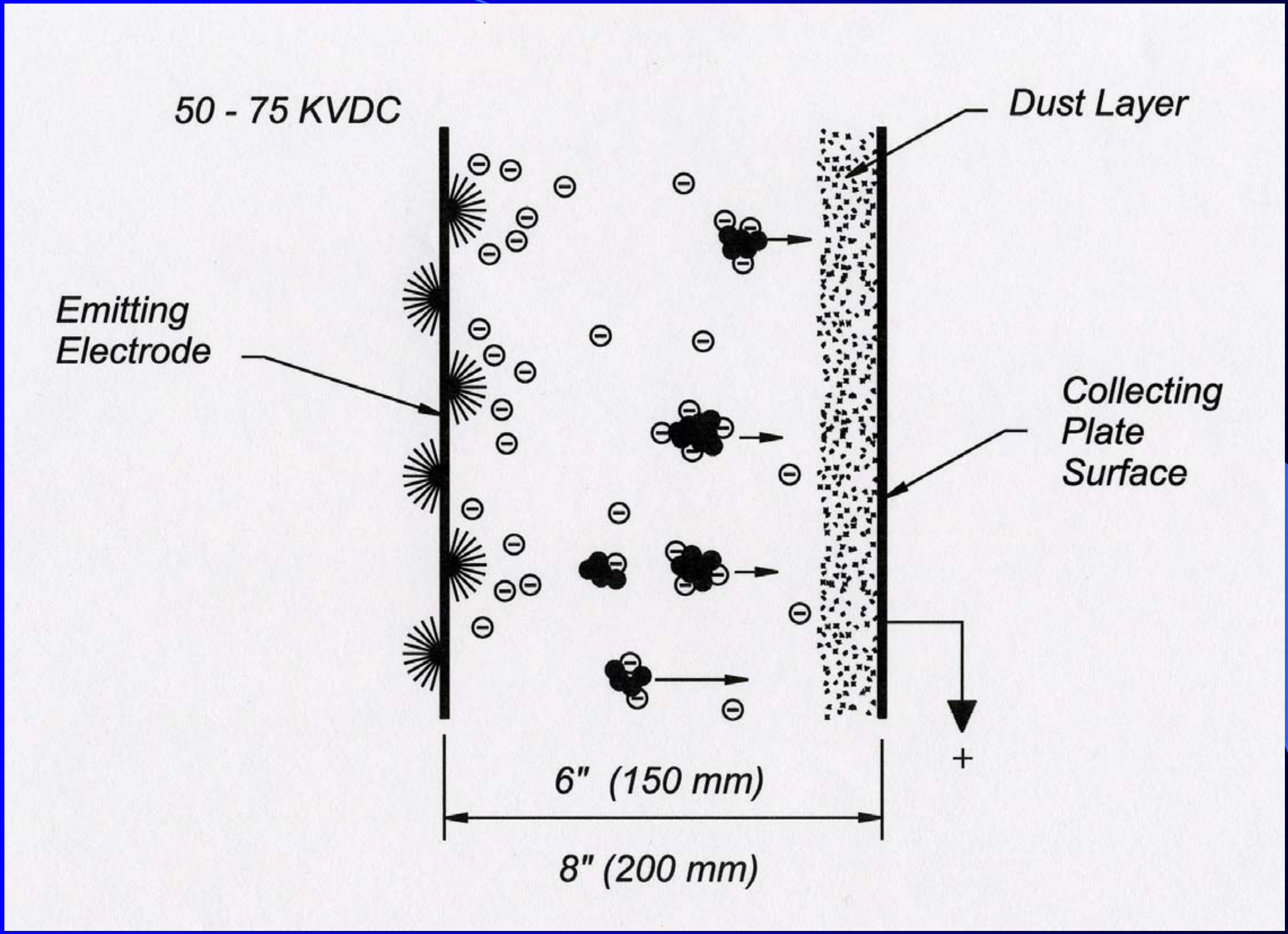


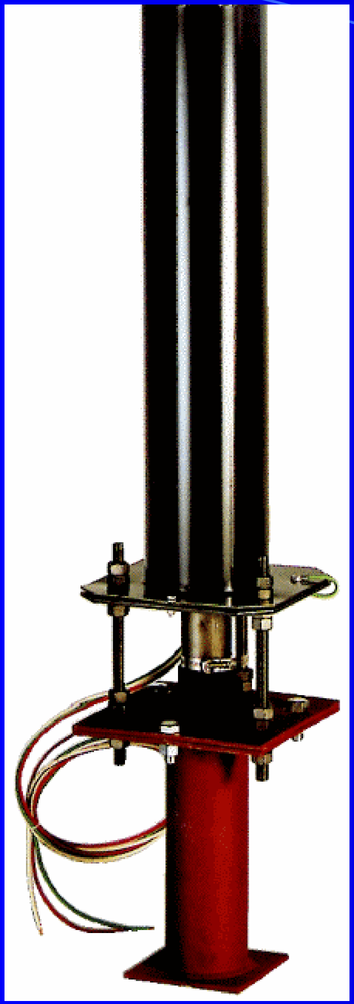
Emitting Electrodes Corona Emission



Emitting Electrodes Corona Emission




50 - 75 KVDC
Dust Layer
Emitting
Electrode
Collecting
Plate
Surface
+
6" (150 mm)
8" (200 mm)

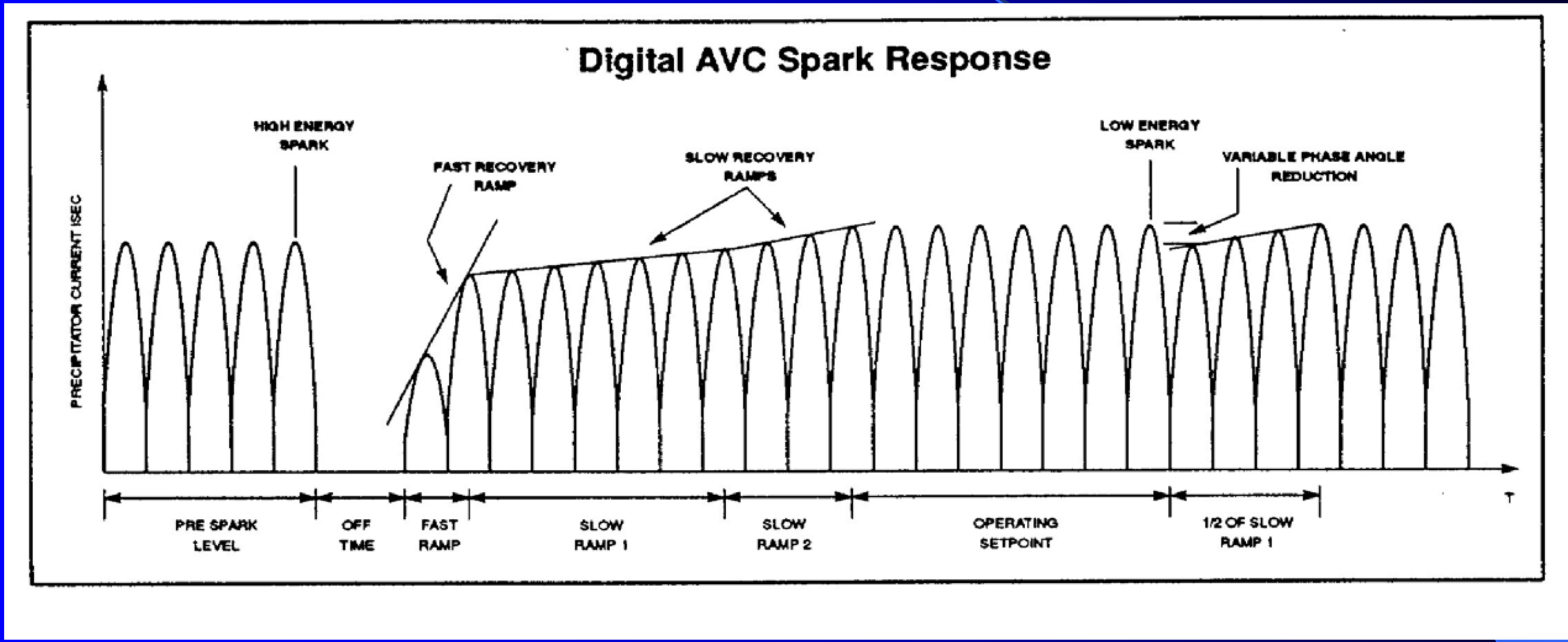


Typical Electromagnetic Impact Rapper

Typical Rotating Hammer Rapper Rapping System

Rotating Hammer Rapping System

Automatic Voltage Control (Typical)



Factors Affecting ESP Sizing and Performance

Precipitator Sizing

Deutsch Equation for ESP Collection Efficiency

$$\eta = 1 - e^{-(Aw/Q)}$$

Where: **η = Collection Efficiency, fraction**

A = Collecting Plate Area, ft^2

Q = Flue Gas Volume, ft^3/sec (actual)

W = Charged Particle Migration Velocity, ft/sec

The migration velocity of the charged particulate is roughly proportional the precipitator voltage.

$$W \propto V^2$$

It is therefore critical that a high voltage level be maintained in the precipitator for optimal charging and collection.

Specific Collecting Area - SCA

$$\text{SCA} = \frac{\text{Collecting Plate Area ft}^2}{\text{1000 ft3/min. flue gas treated}}$$

Example: 400,000 ft^2 plate area
1,000,000 ACFM Gas Flow

SCA = 400

ESP Sizing and Performance

For a given gas volume, precipitator sizing and performance are dependent on the following specified or assumed parameters:

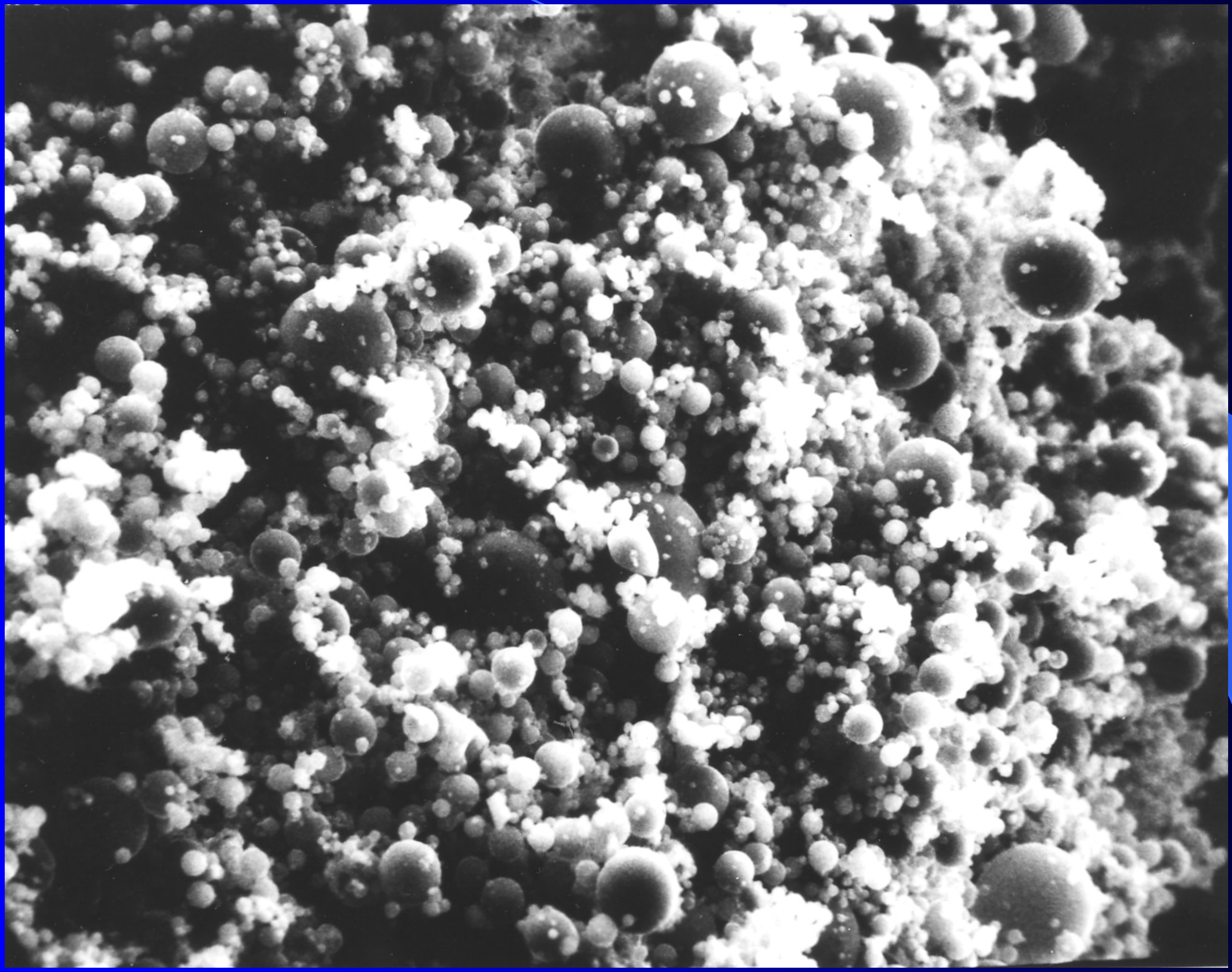
- Ash Particle Size
- Ash Loading
- Ash Resistivity

The above parameters vary depending on the type of boiler, fuel, flue gas temperature and flue gas constituents.

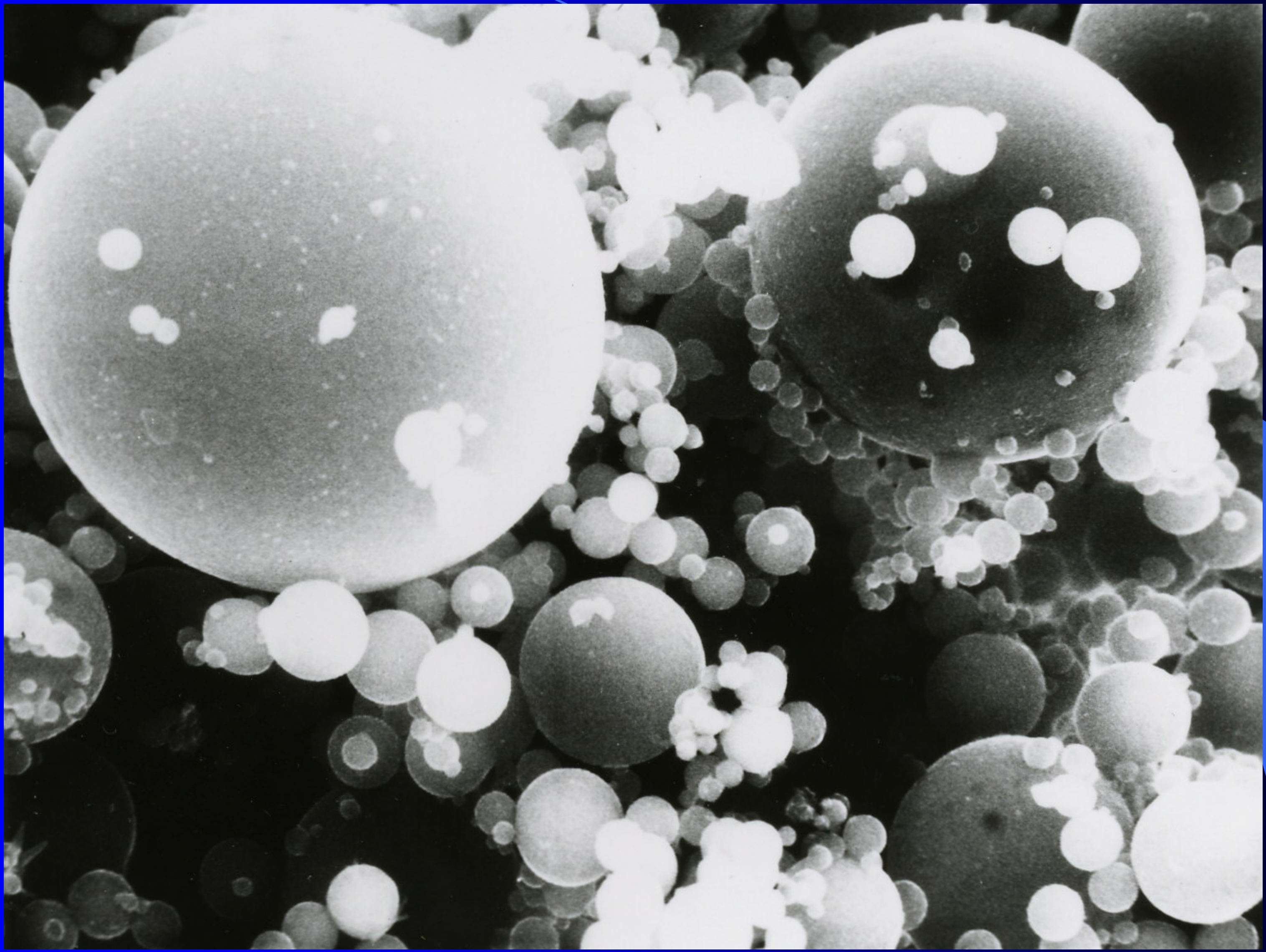
Particle Size Considerations

- Very fine particles, less than one micron diameter, provide small cross sections or targets for capture of negative ions.
- Fine particles require more treatment time to capture a sufficient number of ions to attain an adequate charge.
- Charged particles less than 1 micron travel to the grounded plates in a random motion instead of a more direct path as taken by larger ash particles.
- The particulate removal efficiency of the outlet electrical fields of an ESP will be less than that of the inlet fields.

ESP Collecting Plate Flyash Layer
Scanning Electron Microscope Image – 500X



ESP Collecting Plate Flyash Layer
Scanning Electron Microscope Image -2000X



Ash Loading Considerations

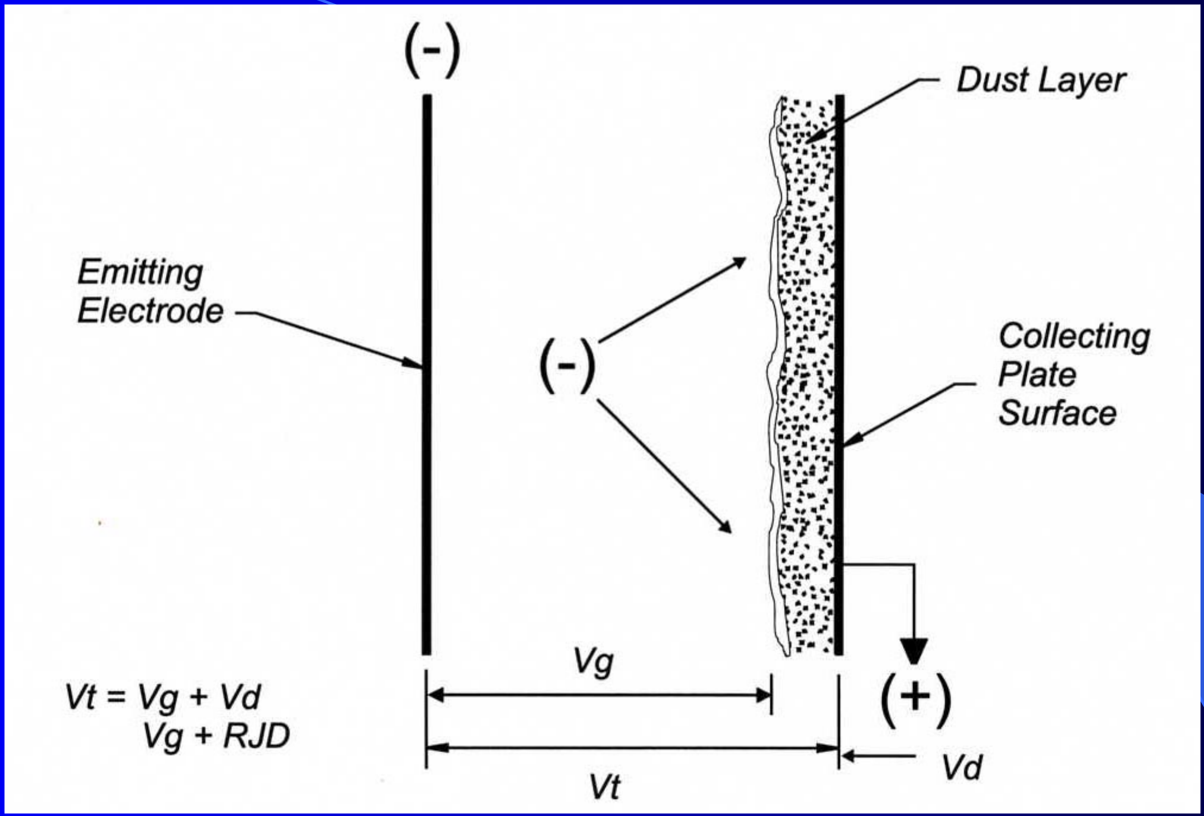
- **High ash loadings interfere with particle charging by suppressing the corona from the emitters and thus the negative ions generated for charging.**
- **The effect of suppression becomes significant if the higher ash loading has a large population of fines.**

Ash Resistivity

Definition: The degree of electrical conductivity of the ash expressed in ohms-cm.

Typical Range: 1×10^{9} - 1×10^{13}

The value of resistivity depends on the flue gas temperature, gas constituents, and chemical composition of the flyash.



- Due to the resistive ash layer on the collecting plate, ionic charge is stored on the ash layer surface and only a small amount of current flows through the ash layer to the grounded plate.
- Most of the voltage drop is in the ash layer and not in the gap where particle charging occurs.

Car Battery Analogy

Current flow is reduced due to the resistivity of the corrosive layer between the battery clamp and terminal.

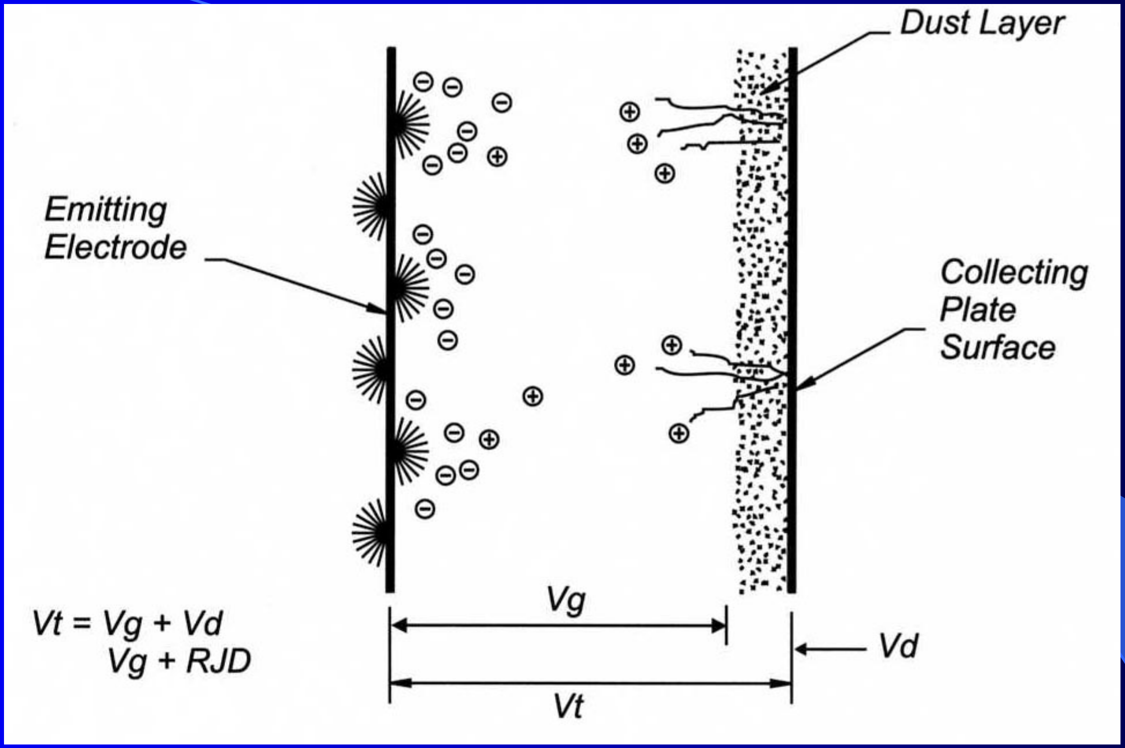
Effect of Low Ash Resistivity, <1 x 10^8

- Collected ash particles lose their charge quickly and become re-entrained into the gas steam.

Effect of High Ash Resistivity, 10^{12} -10^{13}

- Low power levels, low voltage sparking, back corona formation.

Back Corona

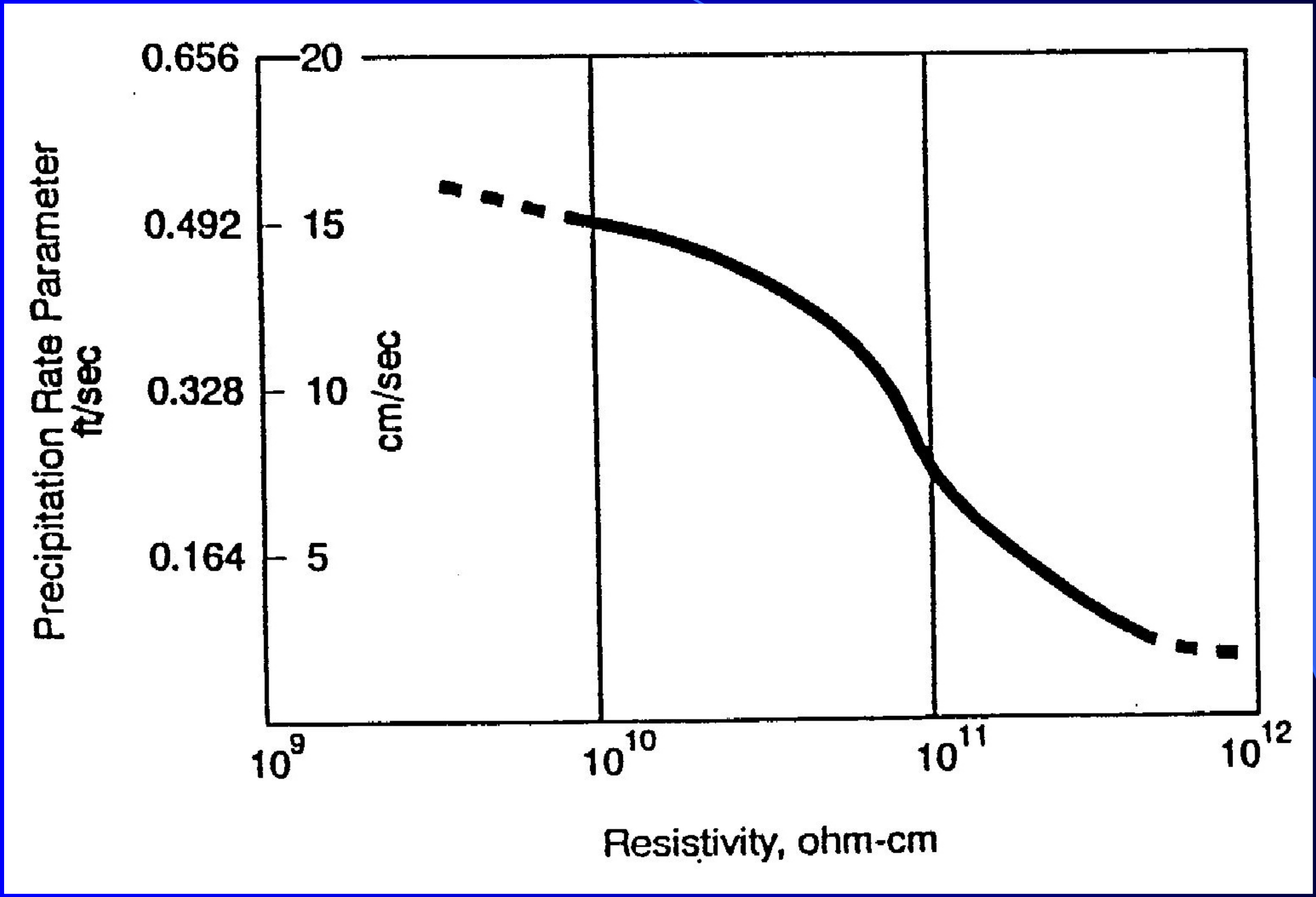


- If the ash layer voltage drop is very large due to very high resistivity, Back Corona will form when the ash layer breaks down and the total voltage, Vt, is not sufficient for sparkover.

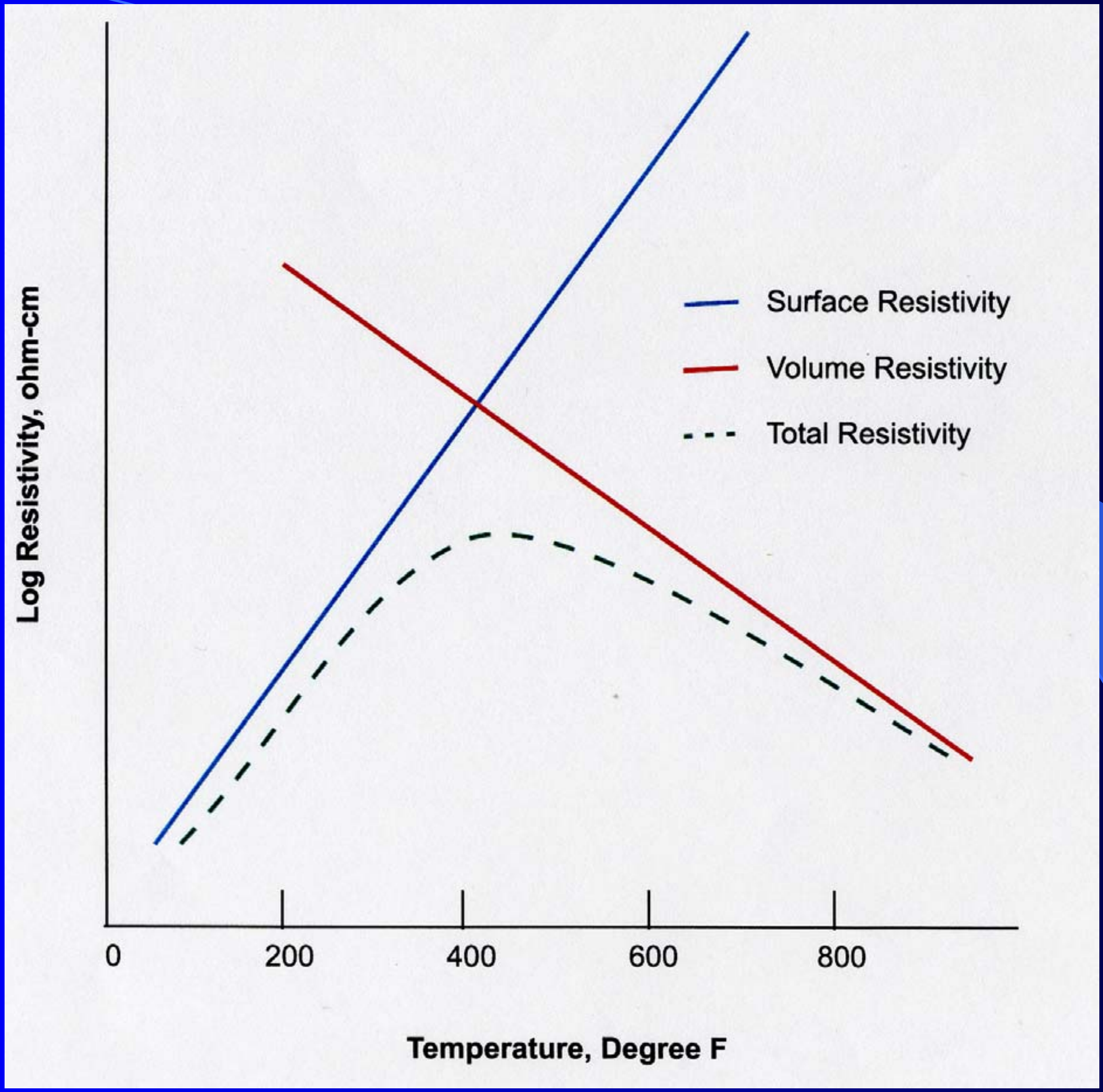
- With Back Corona, positive corona occurs on the ash layer surface forming positive ions that are attracted to the negative polarity emitters. Positive ions encounter negative ions effectively canceling their contribution to the particle charging process.

Back Corona Glow Regions on Collecting Plate Ash Surfaces
Plan View – Looking Down Into a Gas Passage

Effect of High Ash Resistivity on Charged Particle Migration Velocity

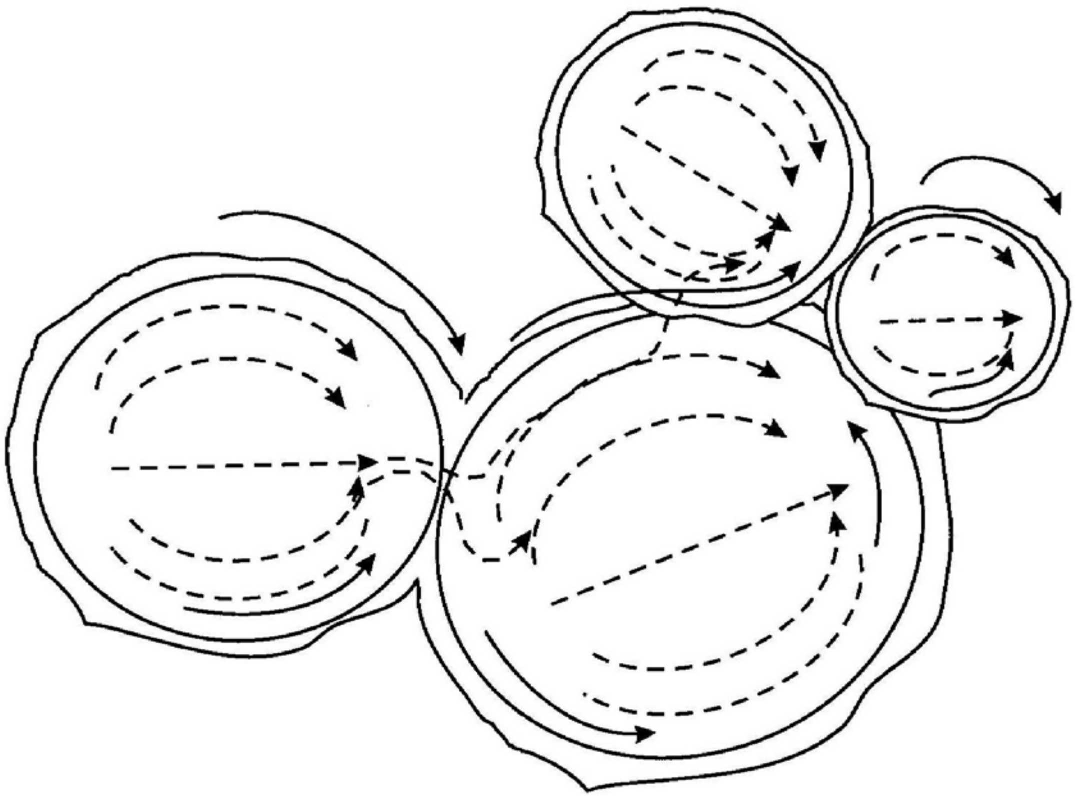


Factors Affecting Flyash Resistivity



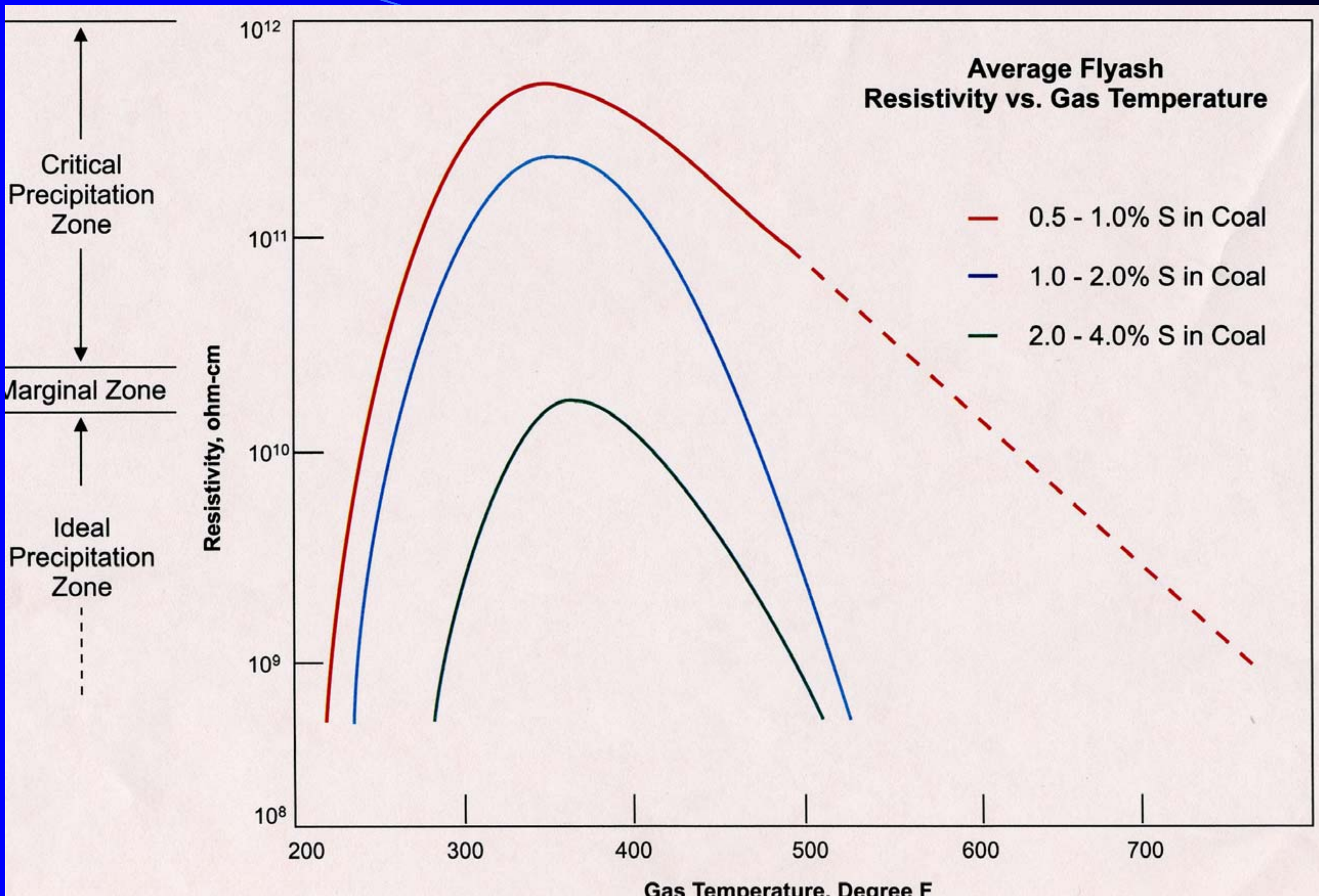
Log Resistivity, ohm-cm
Surface Resistivity
Volume Resistivity
Total Resistivity
0
200
400
600
800
Temperature, Degree F

Surface and Volume Conduction

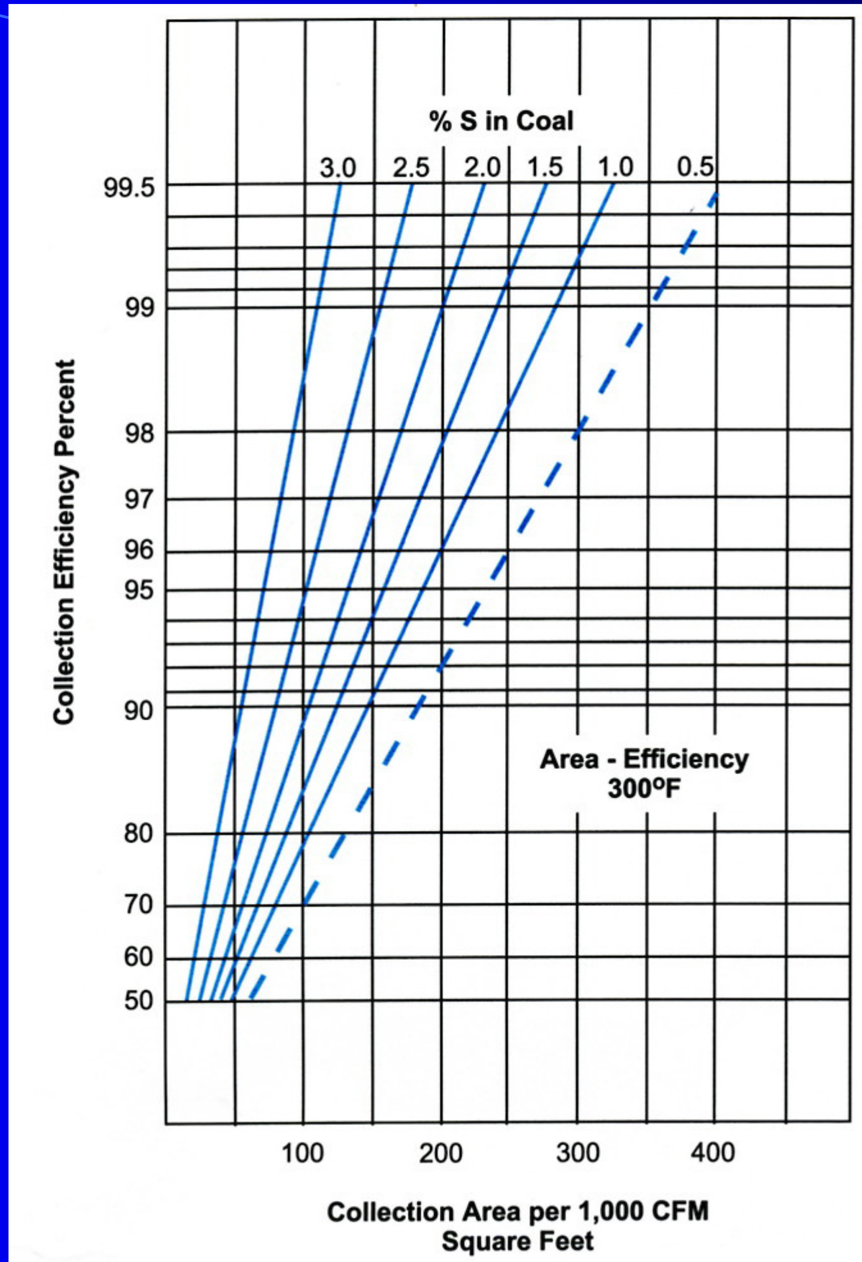


Surface Conduction ⟶ *Volume Conduction* - - - - - - - →

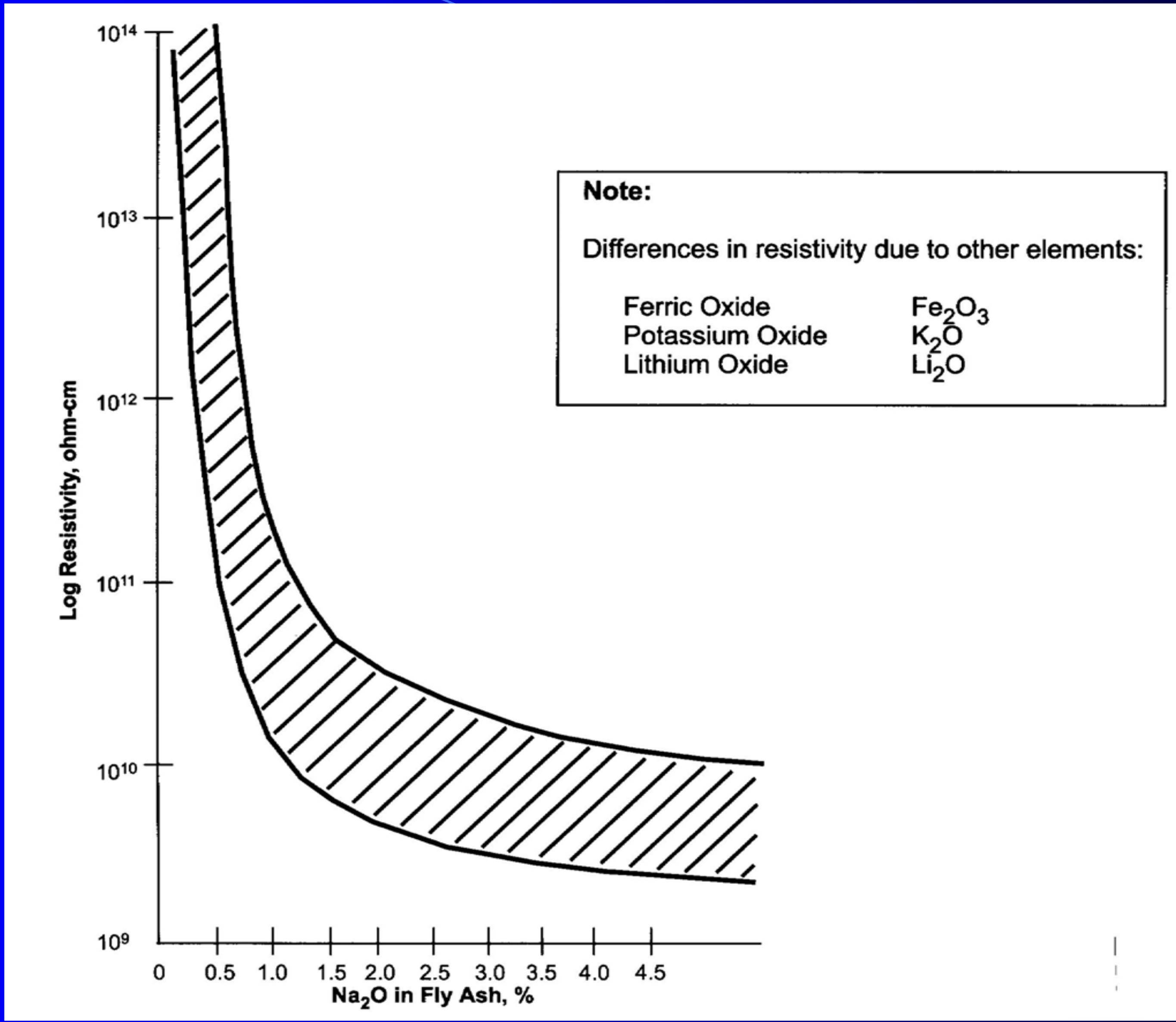
Surface Conduction Charge Carriers: H^+, OH^-, Na^+, K^+, Li., HSO^-_4, SO^-_4 Ions
Volume Conduction Charge Carriers: Na^+, K^+, Li^+ Ions

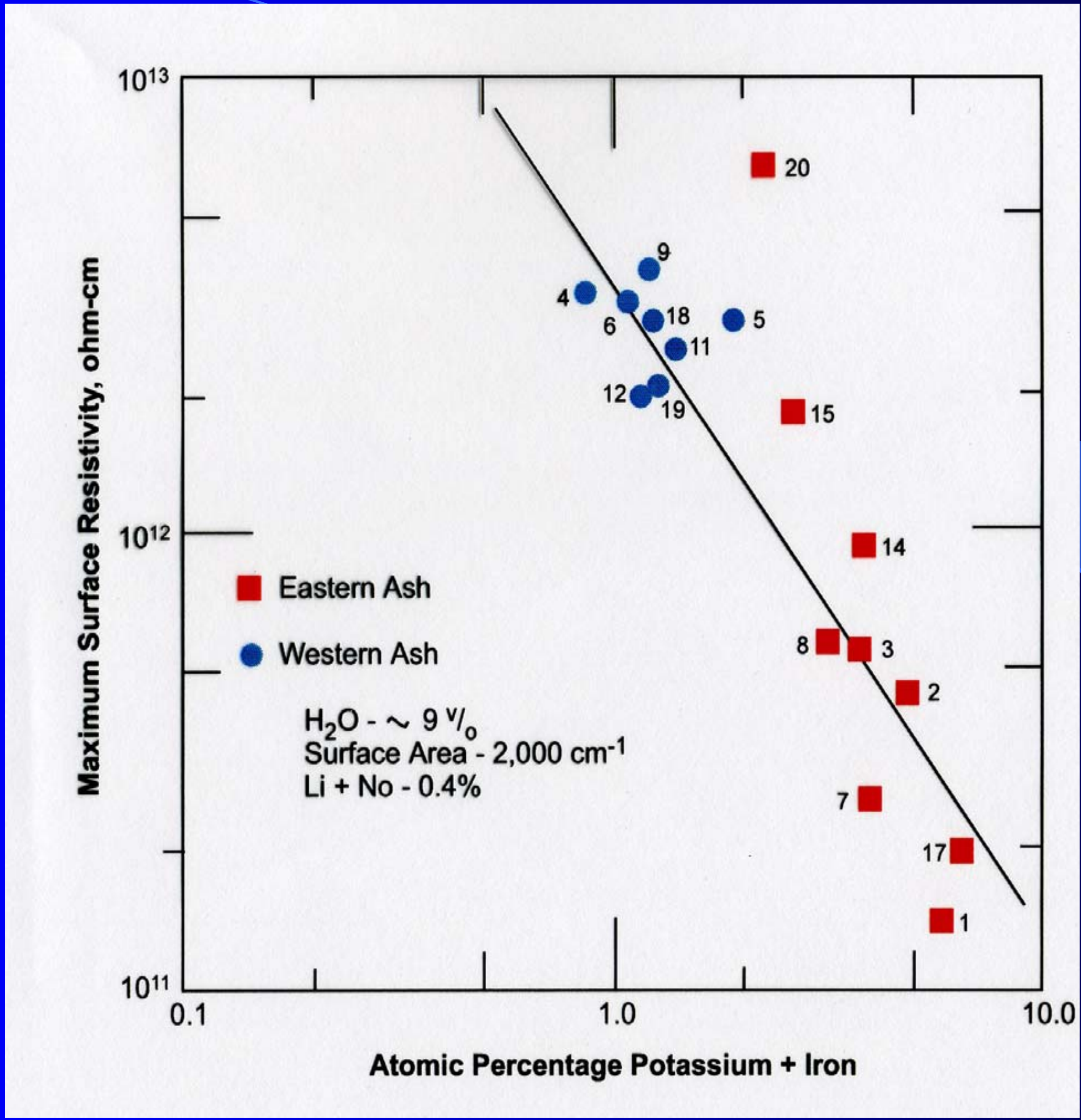


Critical Precipitation Zone
larginal Zone
Ideal Precipitation Zone
10^12
10^11
10^10
10^9
10^8
Resistivity, ohm-cm
Average Flyash Resistivity vs. Gas Temperature
0.5 - 1.0% S in Coal
1.0 - 2.0% S in Coal
2.0 - 4.0% S in Coal
200
300
400
500
600
700
Gas Temperature, Degree F


% S in Coal
3.0
2.5
2.0
1.5
1.0
0.5
99.5
99
98
97
96
95
90
80
70
60
50
Collection Efficiency Percent
Area - Efficiency
300°F
100
200
300
400
Collection Area per 1,000 CFM
Square Feet

Resistivity of Flyash from Low Sulfur Coal @ 300°F





10¹³
10¹²
10¹¹
0.1
1.0
10.0
Maximum Surface Resistivity, ohm-cm
Atomic Percentage Potassium + Iron
Eastern Ash
Western Ash
H₂O - ~ 9 v/o
Surface Area - 2,000 cm⁻¹
Li + No - 0.4%
20
9
4
6
18
5
11
12
19
15
14
8
3
2
7
17
1

Elemental Analysis of Flyash

Typical Range of Constituents

Component	Maximum %	Minimum %
SiO_2	61.00	41.20
Al_2O_3	31.00	17.90
Fe_2O_3	23.70	3.90
CaO	23.50	0.30
MgO	5.50	0.90
Na_2O	2.66	0.13
K_2O	3.90	0.28
Li_2O	0.07	0.01
TiO_2	2.30	0.80
P_2O_5	1.00	0.16
SO_3	1.83	0.07

The Major Ash Resistivity Effects Due to Mineral Compounds in the Ash are:

SiO_2, Al_2O_3, CaO, MgO - Increases Ash Resistivity

Na_2O, Li_2O - Reduces Ash Resistivity

A Most Difficult Combination of Ash and Coal Constituents For ESP Operation:

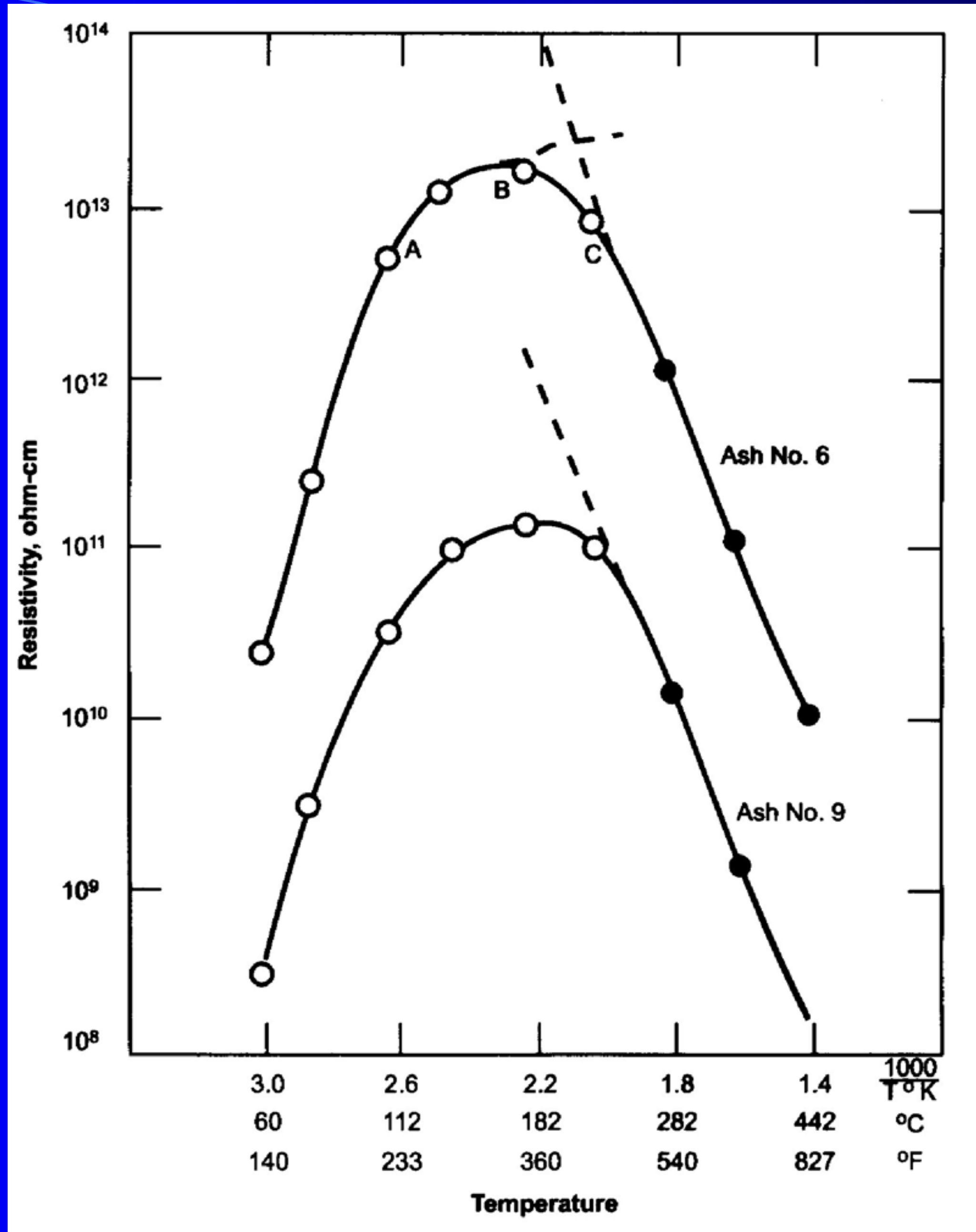
$SiO_2 + Al_2O_3 > 80\%$
$Fe_2O_3 < 5\%$
$Na_2O < 0.5\%$

Coal Sulfur Content < 1%
ESP Flue Gas Temperature 330 to 350^oF

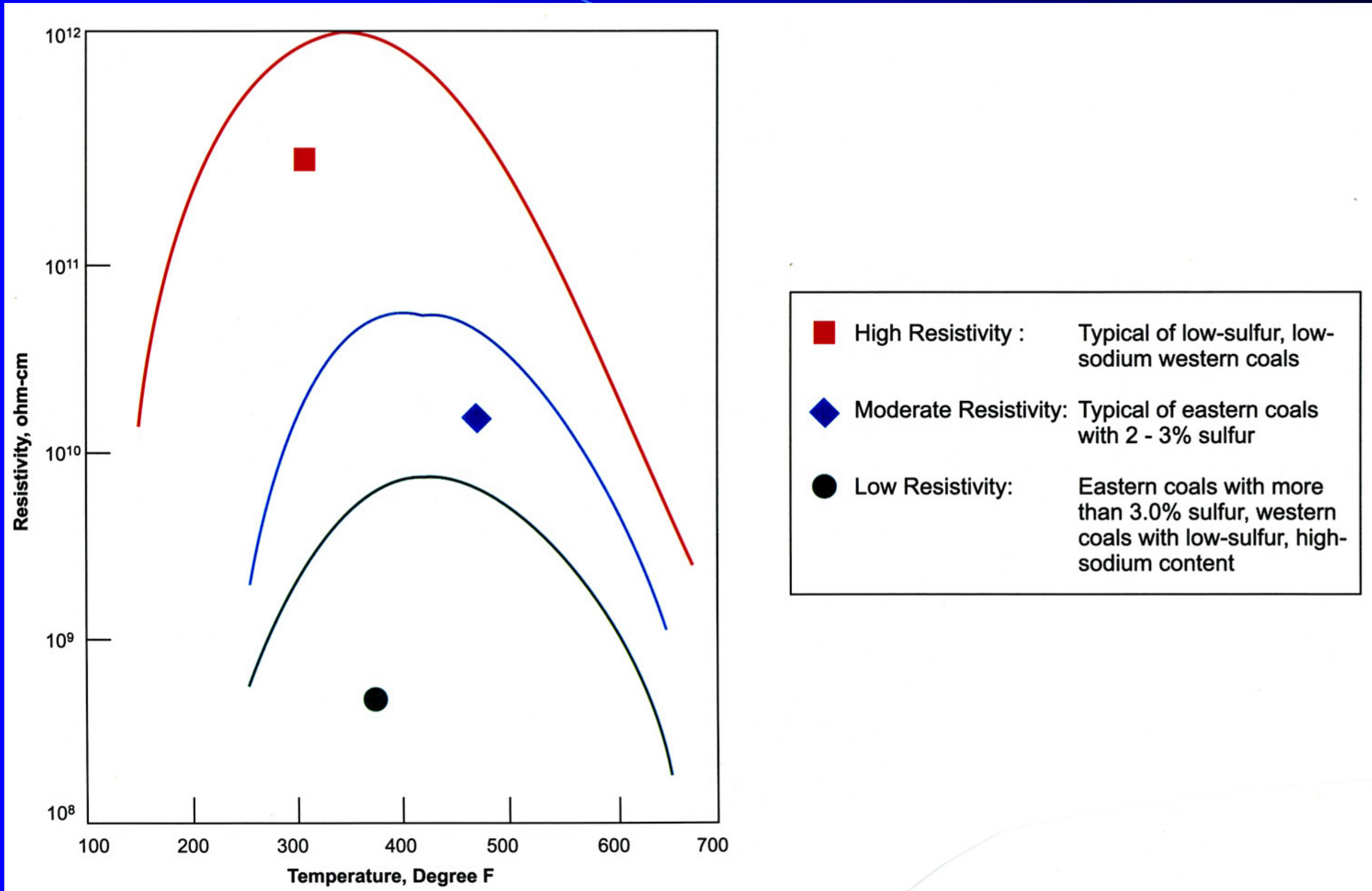
Chemical Analyses of Ashes in Weight Percent

Ash No.	Li_2O	Na_2O	K_2O	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2	TiO_2	P_2O_5	SO_4[a]	Loss on Ignition
1	0.02	0.32	3.10	1.04	2.62	20.50	19.60	46.40	1.69	0.60	1.56	2.10
2	0.01	0.35	2.36	1.66	3.72	16.10	17.80	43.30	1.27	0.36	0.93	10.30
3	0.03	0.38	3.34	1.29	1.04	9.70	25.90	49.90	1.98	0.32	0.29	4.40
4	0.03	0.20	0.26	5.76	22.60	4.25	21.00	38.80	1.19	0.32	0.97	0.33
5	0.01	1.84	0.20	12.75	31.00	11.20	14.80	22.00	0.60	0.39	2.19	0.41
6	0.01	0.25	0.89	1.88	11.10	3.71	23.60	55.60	1.56	0.14	0.22	0.74
7	0.04	0.33	3.88	1.57	0.77	10.01	27.50	51.40	1.79	0.32	0.25	1.50
8	0.04	0.29	2.69	0.98	0.64	9.12	29.10	52.00	2.55	0.42	0.15	1.40
9	0.01	2.31	0.91	1.04	12.10	4.23	25.10	49.60	1.39	0.19	0.21	0.45
11	0.02	1.77	1.13	1.93	6.36	4.61	24.60	53.70	1.49	1.06	0.75	1.49
12	0.01	0.25	0.81	2.57	13.30	4.66	23.60	53.60	0.88	0.19	0.19	0.00
14	0.05	0.38	2.99	1.42	1.00	10.91	26.70	49.10	1.87	0.41	0.29	3.20
15	0.03	0.43	2.58	1.00	0.62	5.63	28.10	49.60	2.29	0.39	0.44	0.58
17	0.04	0.28	2.25	1.04	4.55	24.70	21.20	39.80	1.24	0.31	0.43	5.49
18	0.02	1.28	0.78	3.22	9.14	4.85	19.50	55.10	1.79	0.35	0.72	0.93
19	0.02	1.83	1.19	0.94	5.18	3.81	27.16	57.27	1.05	0.17	0.40	0.60
20	0.07	0.27	2.72	0.76	0.38	3.88	29.78	52.74	1.88	0.18	0.28	7.08

a) soluble sulfate



10¹⁴
10¹³
10¹²
10¹¹
10¹⁰
10⁹
10⁸
Resistivity, ohm-cm
A
B
C
Ash No. 6
Ash No. 9
3.0
2.6
2.2
1.8
1.4
1000/T°K
60
112
182
282
442
°C
140
233
360
540
827
°F
Temperature



10¹²
10¹¹
10¹⁰
10⁹
10⁸
Resistivity, ohm-cm
100
200
300
400
500
600
700
Temperature, Degree F
High Resistivity :
Typical of low-sulfur, low-sodium western coals
Moderate Resistivity:
Typical of eastern coals with 2 - 3% sulfur
Low Resistivity:
Eastern coals with more than 3.0% sulfur, western coals with low-sulfur, high-sodium content

Deterioration of ESP Performance Over Time

Ageing of the Box

Excessive Emitter & Plate Ash Buildup

Cracked Support insulator

ESP Rebuild

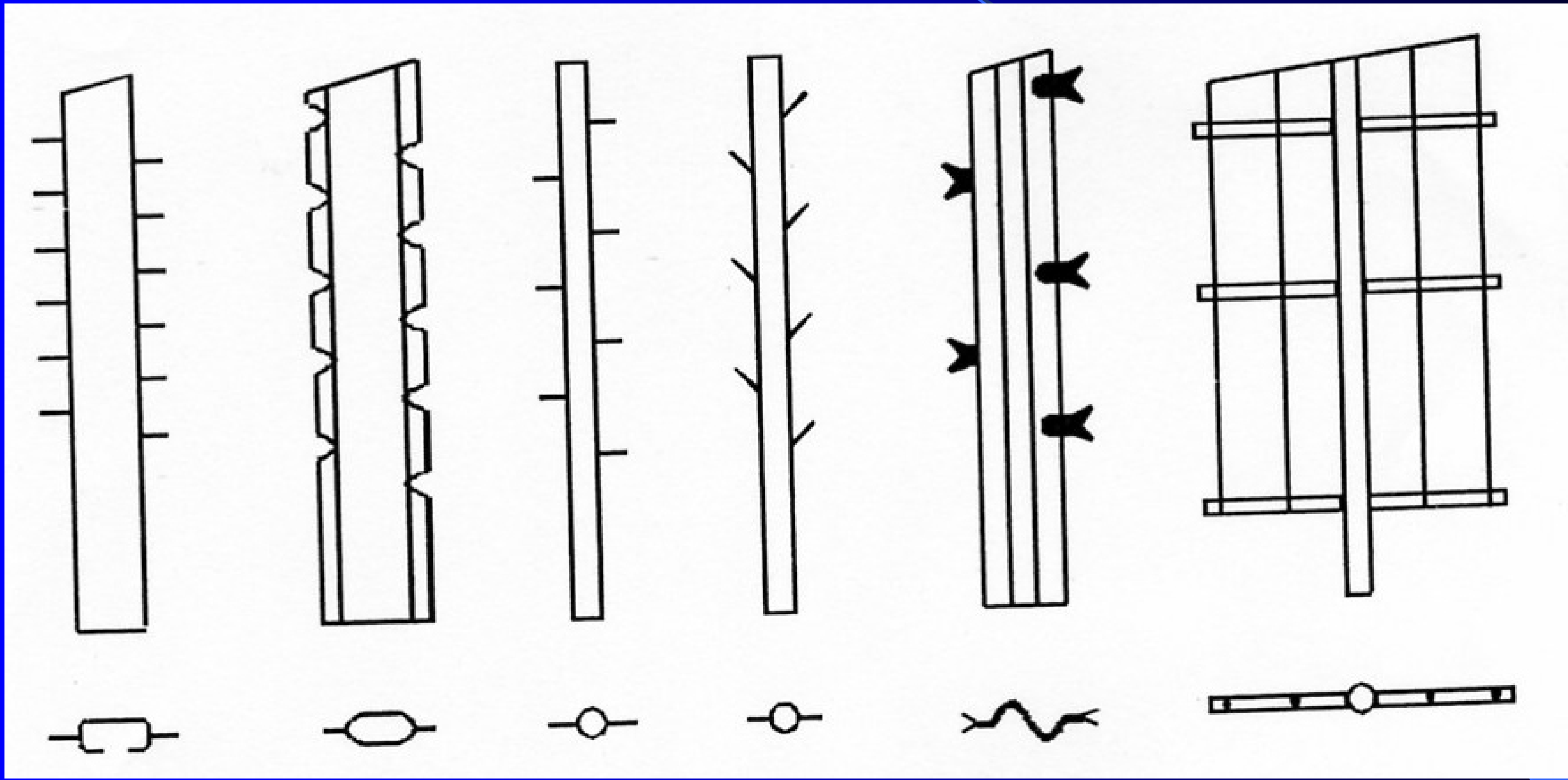
- Restore Performance
- Reduce Maintenance Requirements
- Life Extension of the ESP

Precipitator Design Practice - U.S. OEMS

Design Characteristics	Prior	Current
Plate-to-Plate Spacing	8”- 9”	12” - 16”
Precipitator Voltage	45KV	55-75KV
Emitting Electrode	Wire-Weight	Rigid
Rapping System	Vibrators/Electro-magnetic Impact, Rotating Hammer	AllElectro-Mag. Impact, Rotating Hammer
Control System	Analog	Microprocessor based with Host Computer

Note: Rebuild with Rigid Emitters requires increased plate spacing, 10”-12”

Rigid Emitting Electrode Sampling

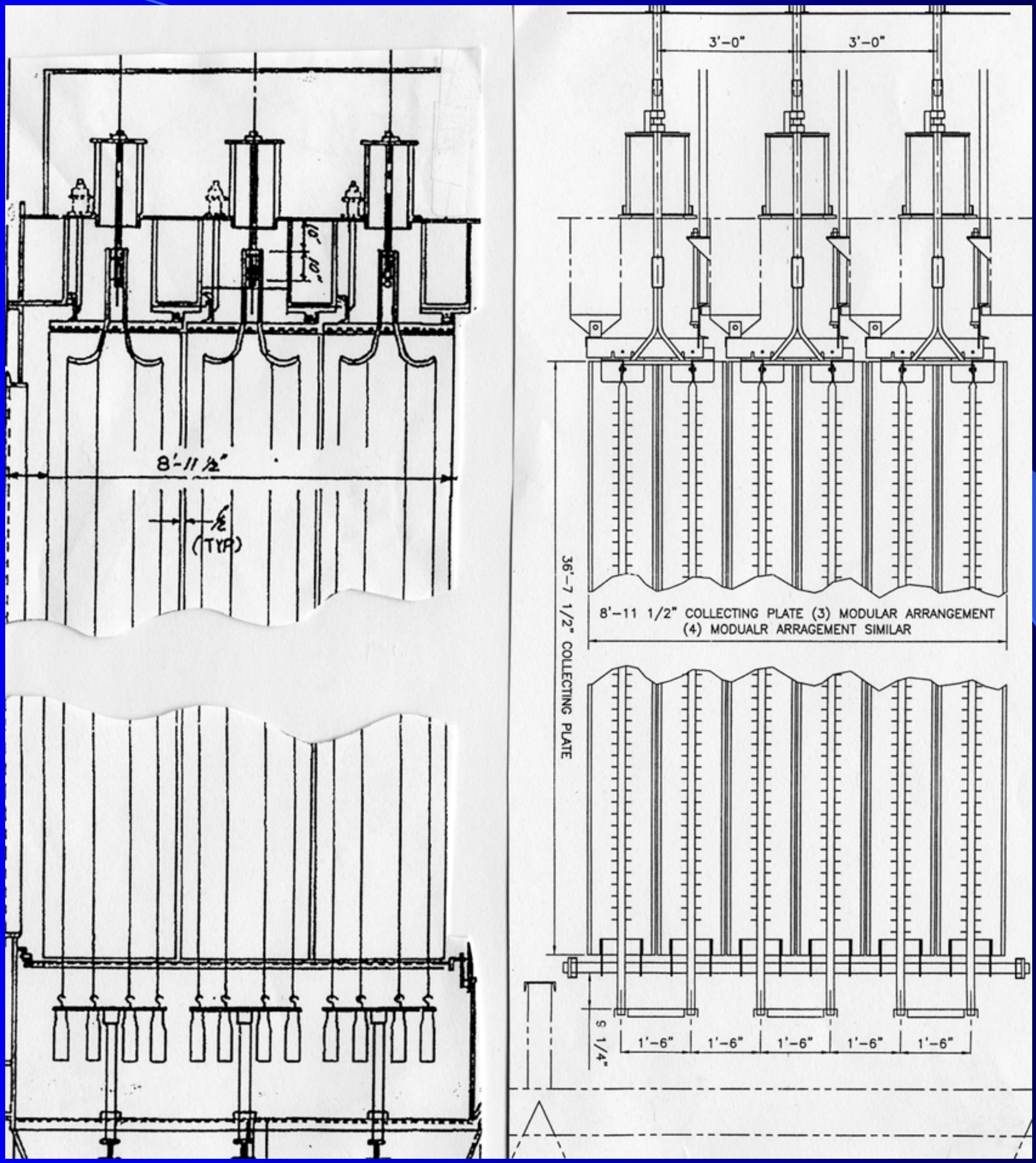


Rigid Emitting Electrode Example
Pipe & Pin

Rigid Emitting Electrode Example
Mast Type

Rigid Emitting Electrode Example
Pipe and Flared Strip Emitters

Typical Rebuild with Pipe & Pin Emitters



Rebuild With Rigid Emitters will Require Wider Collecting Plate Spacing in the ESP

Doesn’t Less Collecting Plate Area (SCA) In the Same ESP Box Mean Less Particulate Collection Efficiency?

Answer: No

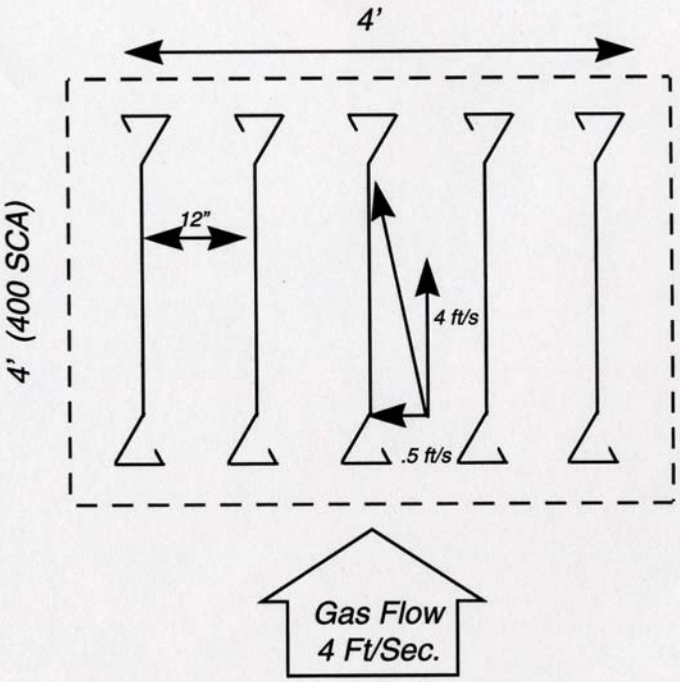
Wide Plate Spacing

For a Given Precipitator Casing, Collecting Plate Area Can be Reduced by Increasing the Plate-To-Plate Spacing While Maintaining the Collection Efficiency

- The Charged Particle Migration Velocity Increases in Proportion to the Increase in ESP Voltage With Spacing.
- The Increased Voltage Creates an Increased Electric Field That Further Accelerates the Charged Particles Attracted to the Grounded Plates.

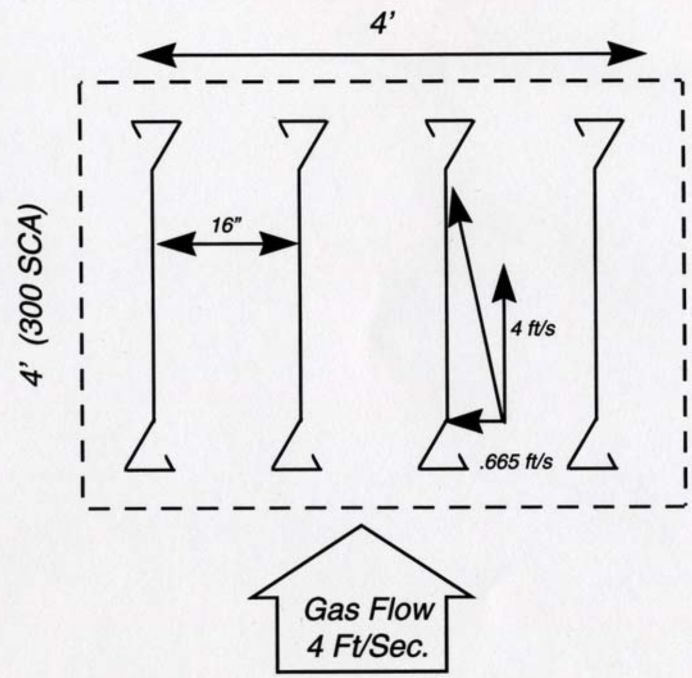
Wide Plate Spacing

12" Spacing Design
(Plan View)



The majority of particles have resultant migration velocity of 4.03 ft/sec. and will be collected within 4 feet of collector.

16" Spacing Design
(Plan View)



The majority of particles have resultant migration velocity of 4.05 ft/sec. and will be collected within 4 feet of collector.

RESULT: A 16" spacing unit has the same collection efficiency as the 12" unit but at 75% of the SCA.