

Worldwide Pollution Control Association

FirstEnergy ESP Seminar
November 27th – 28th, 2007

W
P
C
A



Visit our website at www.wpca.info

ESP Basics



By

Tom Lugar

Buell Division

Fisher-Klosterman, Inc.

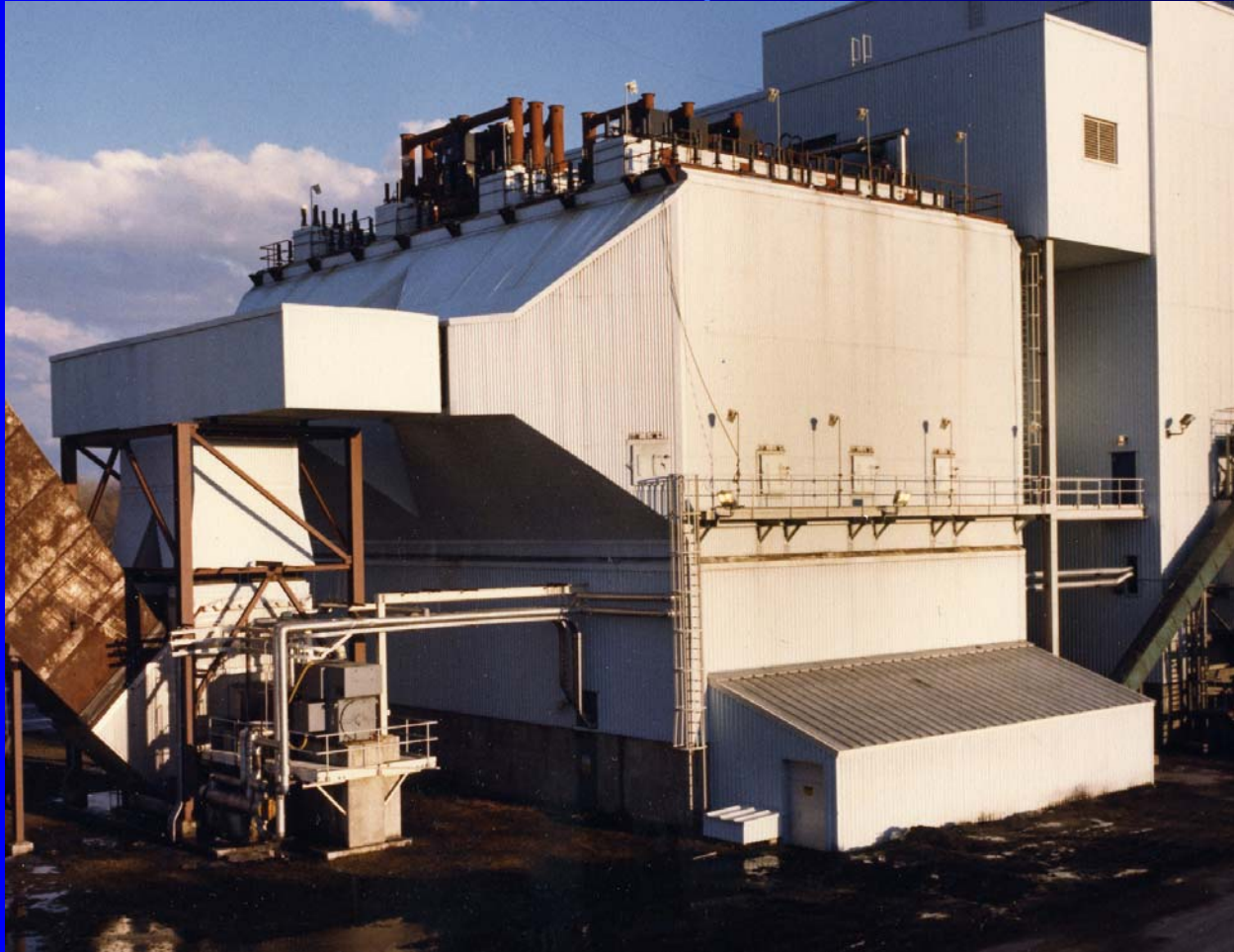


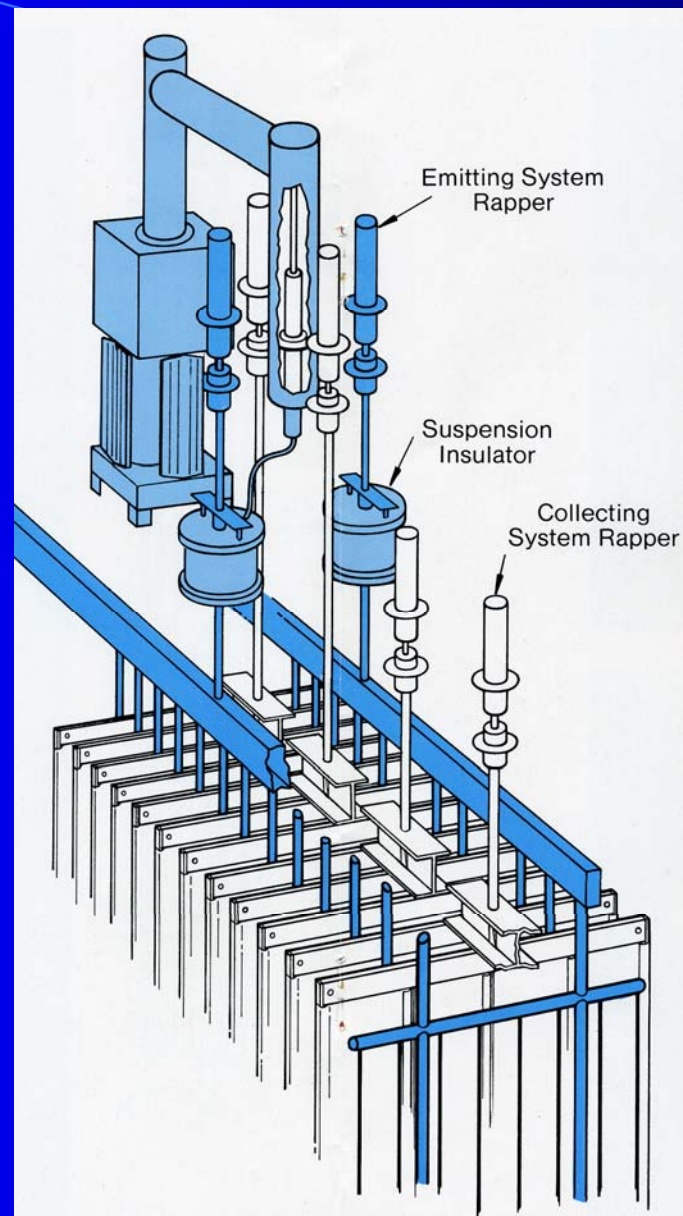
**Fundamentals
of
Electrostatic Precipitator
(ESP) Operation**

The Process in Electrostatic Precipitation

- **Particle Charging**
- **Particle Collection**
- **Removal of Collected Particulate**

Electrostatic Precipitator 'A Box with Wires and Plates'





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

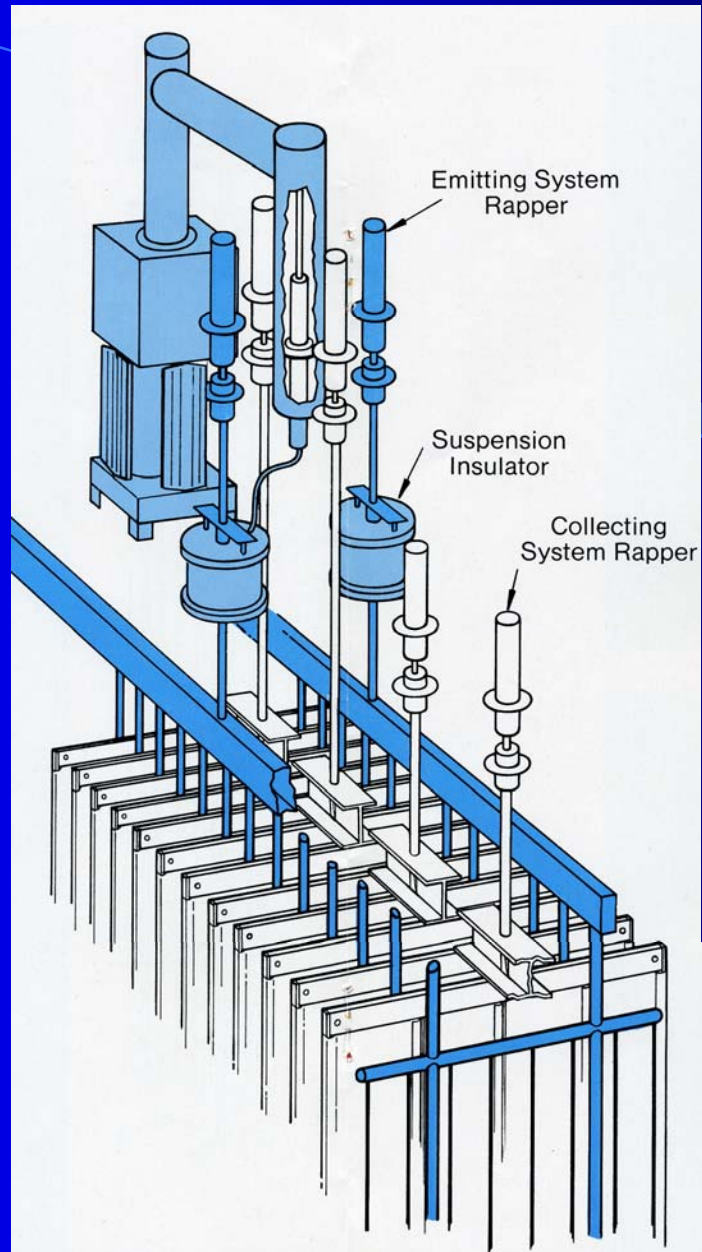


H.V. Insulator 'House'

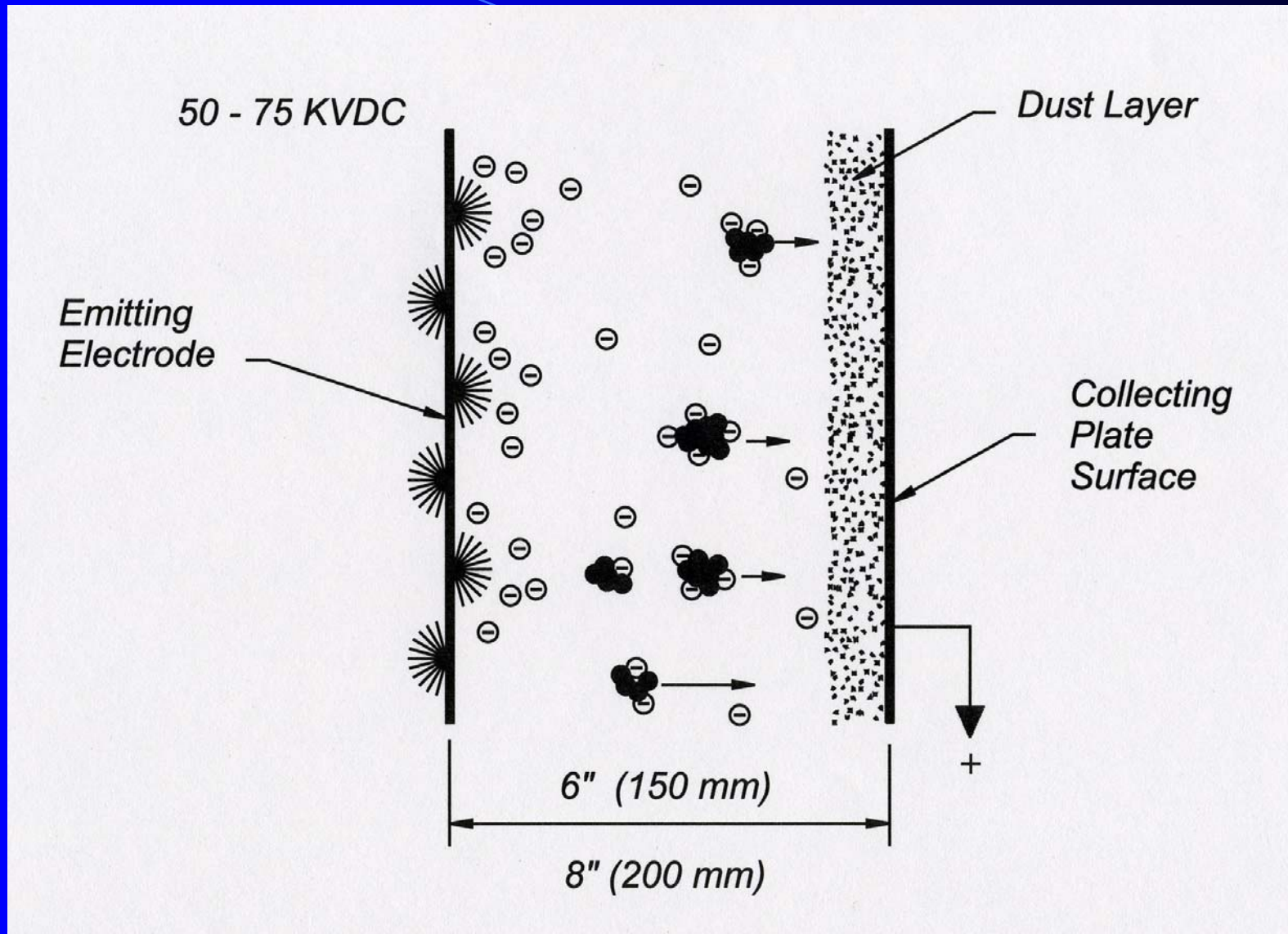


Gas Passages – 9” Centers

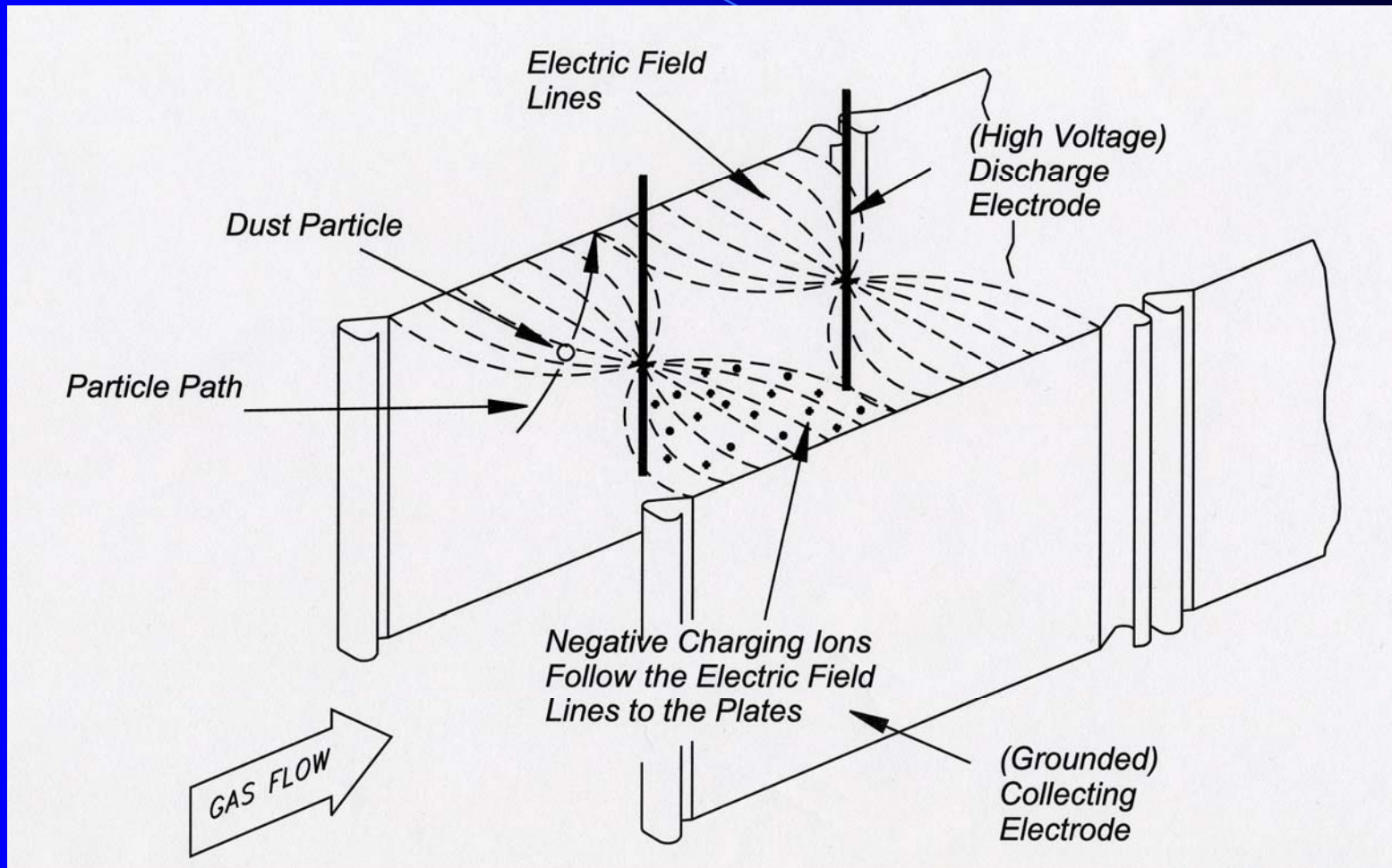




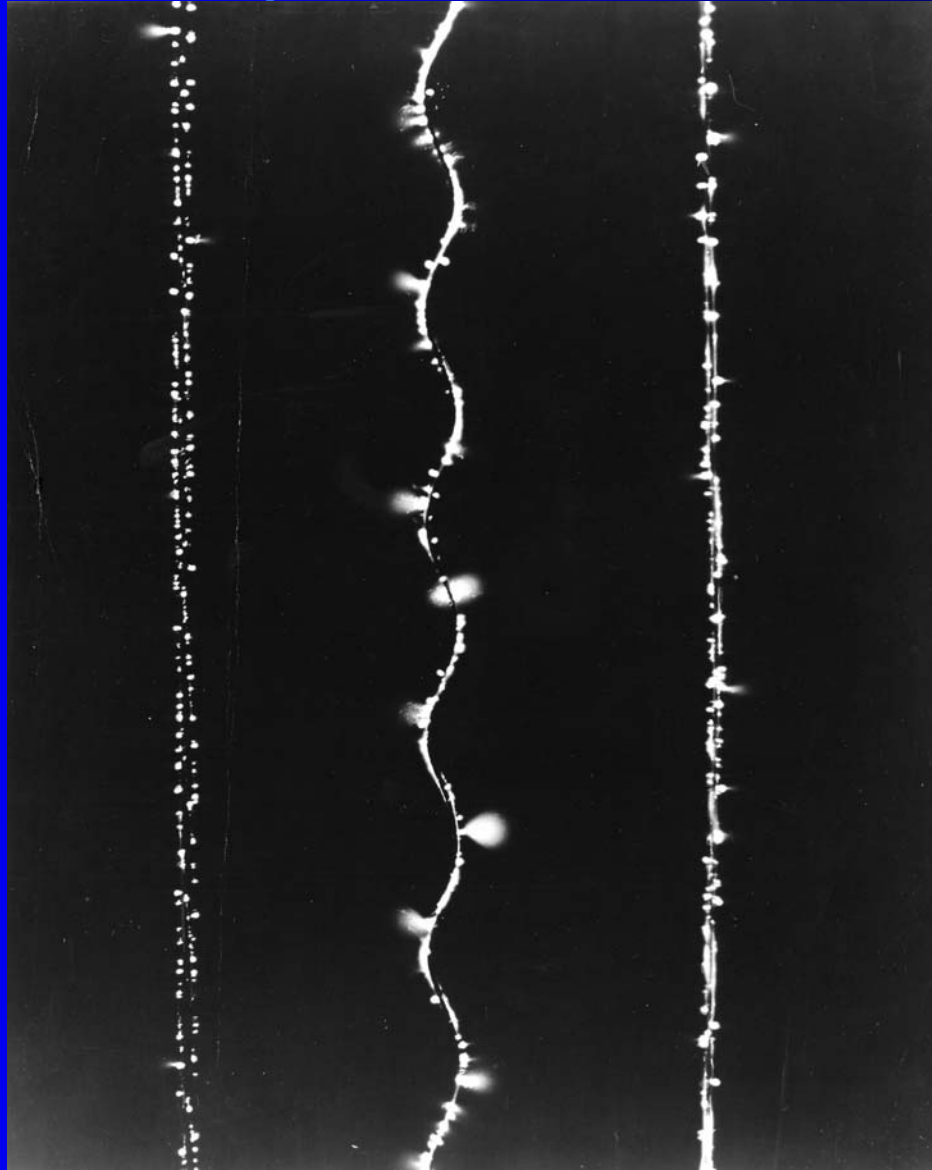
Particle Charging and Collection



ESP Gas Passage – Particle Charging & Collection

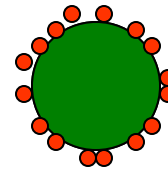
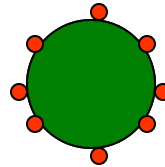
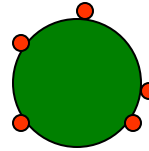
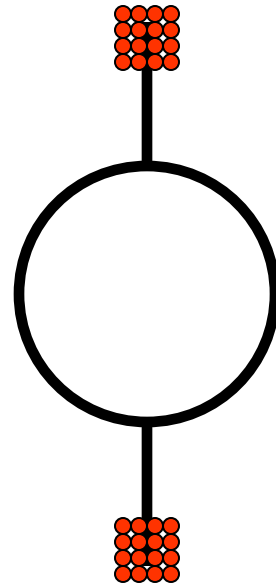


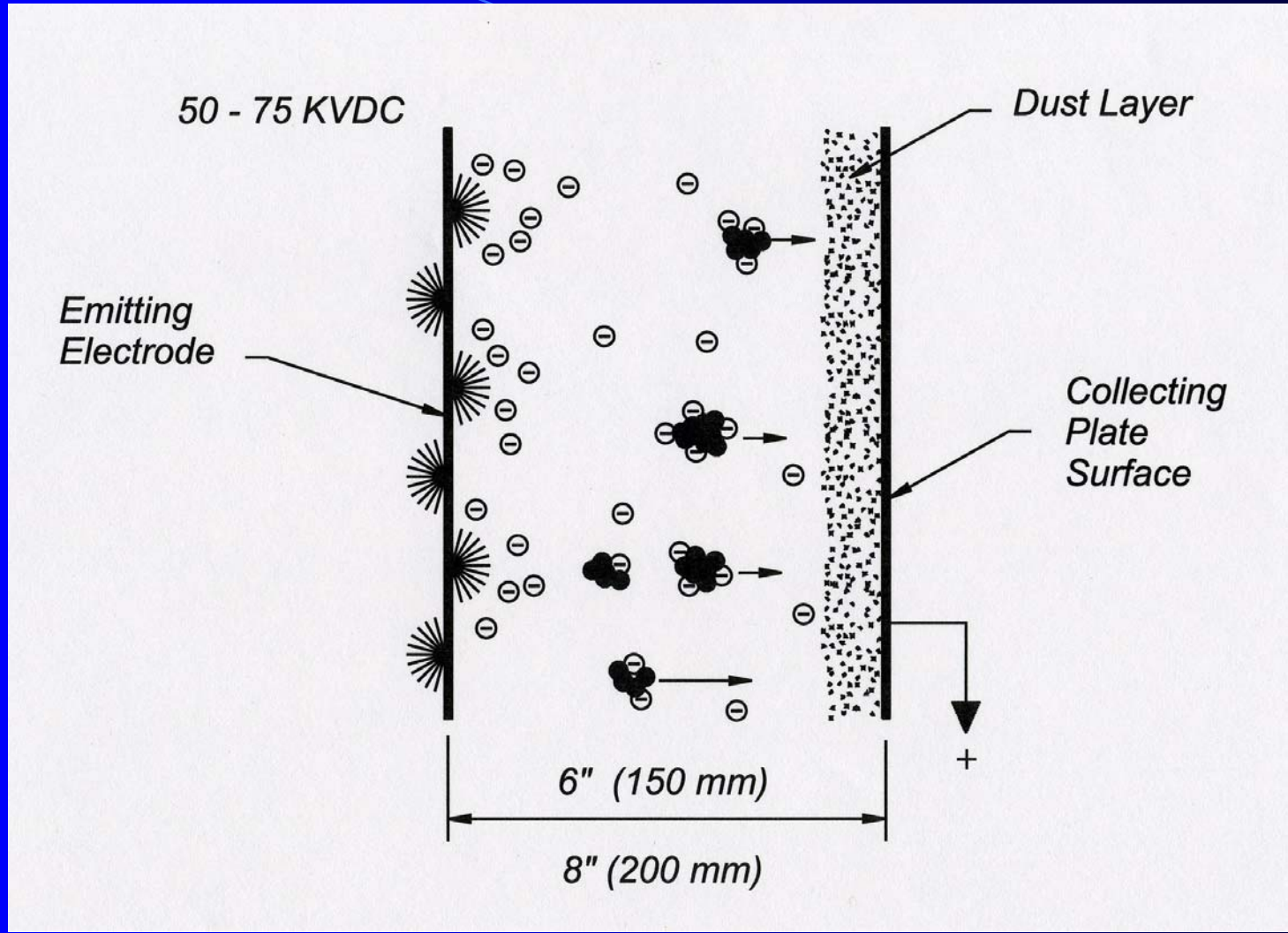
Emitting Electrodes Corona Emission

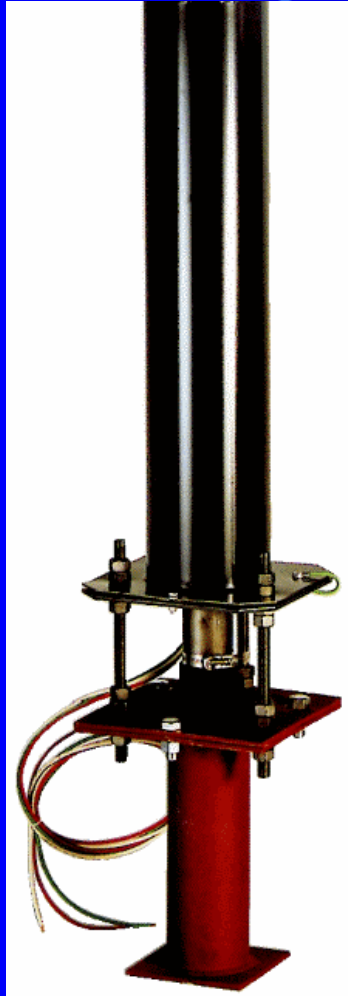


Emitting Electrodes Corona Emission









**Typical Electromagnetic
Impact Rapper**

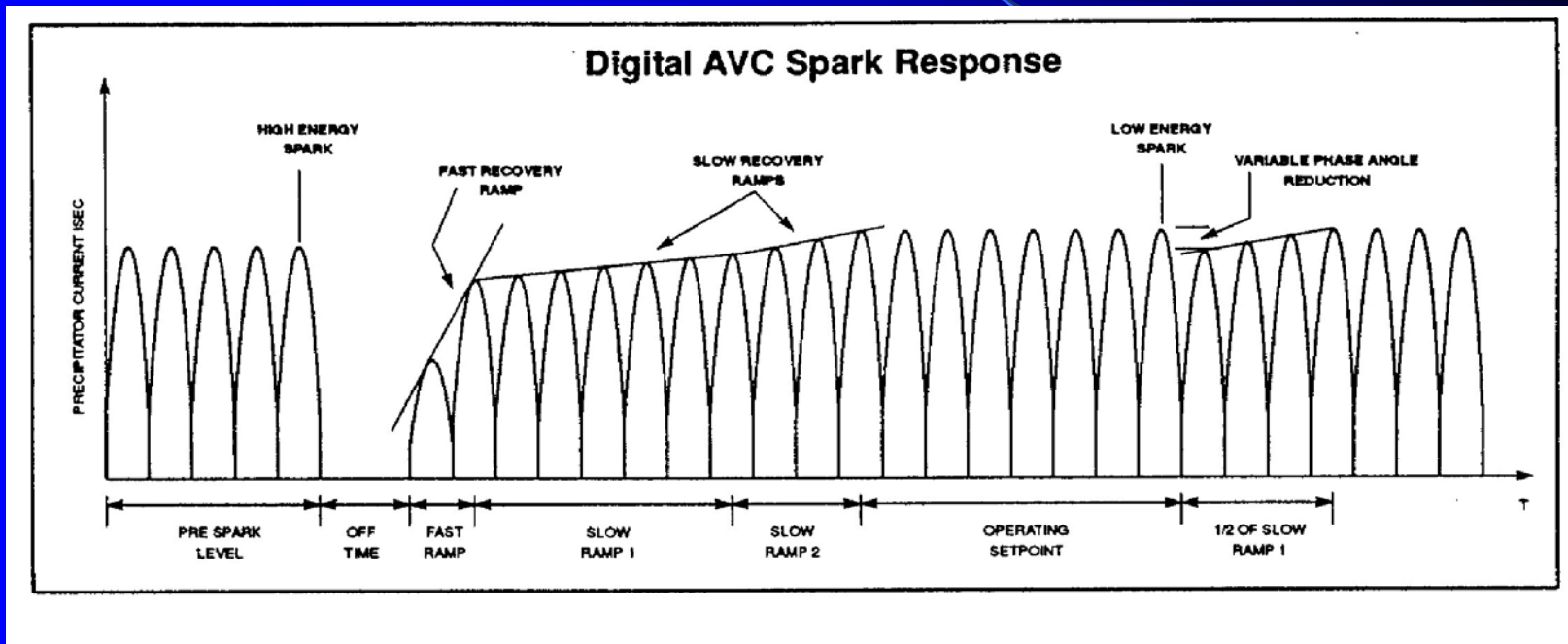


**Typical Rotating Hammer
Rapper Rapping System**



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, ft²

Q = Flue Gas Volume, ft³/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

$$\text{SCA} = \frac{\text{Collecting Plate Area ft}^2}{1000 \text{ ft}^3/\text{min. flue gas treated}}$$

Example: 400,000 ft² plate area
1,000,000 ACFM Gas Flow

$$\text{SCA} = 400$$

ESP Sizing and Performance

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

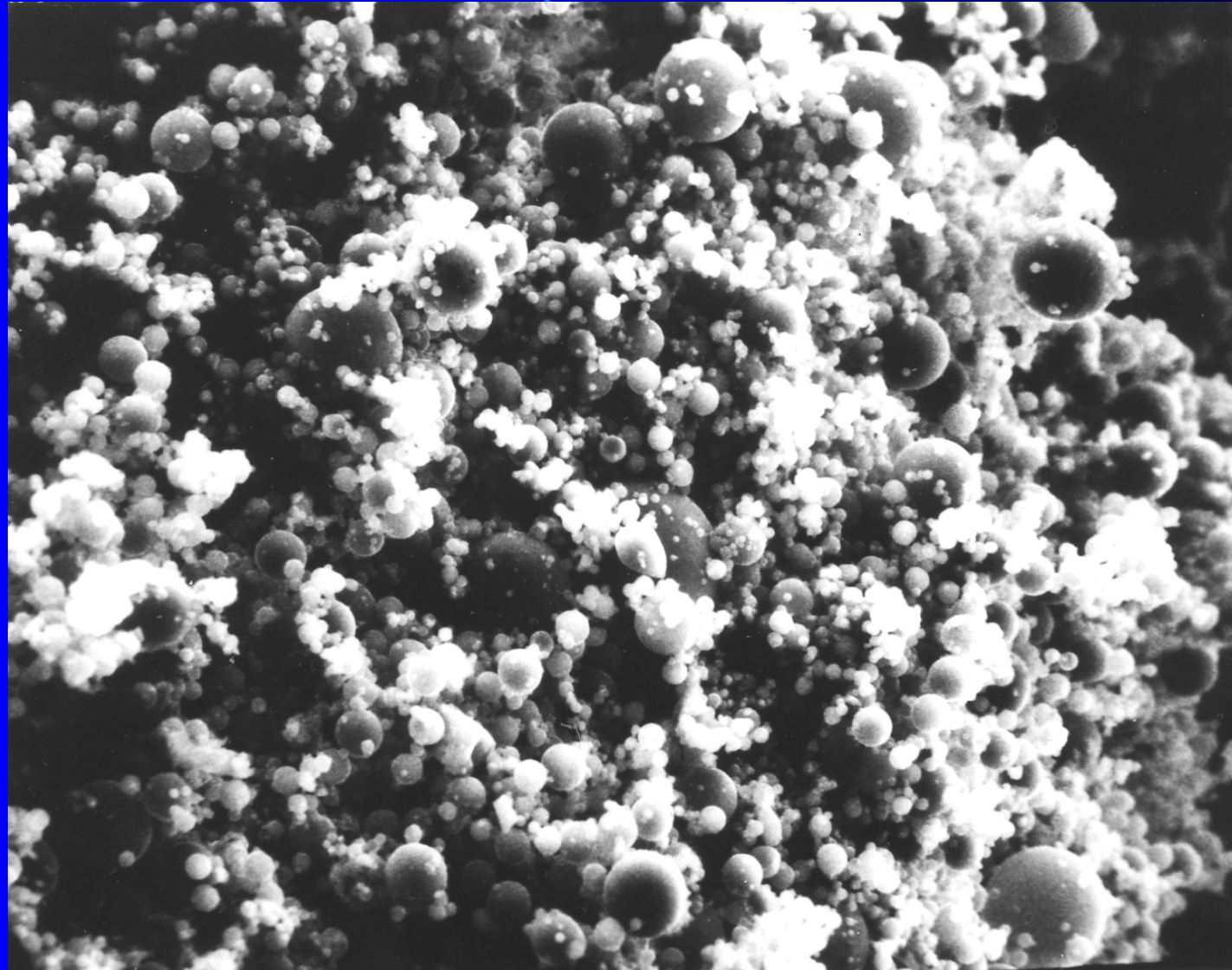
- Ash Particle Size
- Ash Loading
- Ash Resistivity

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

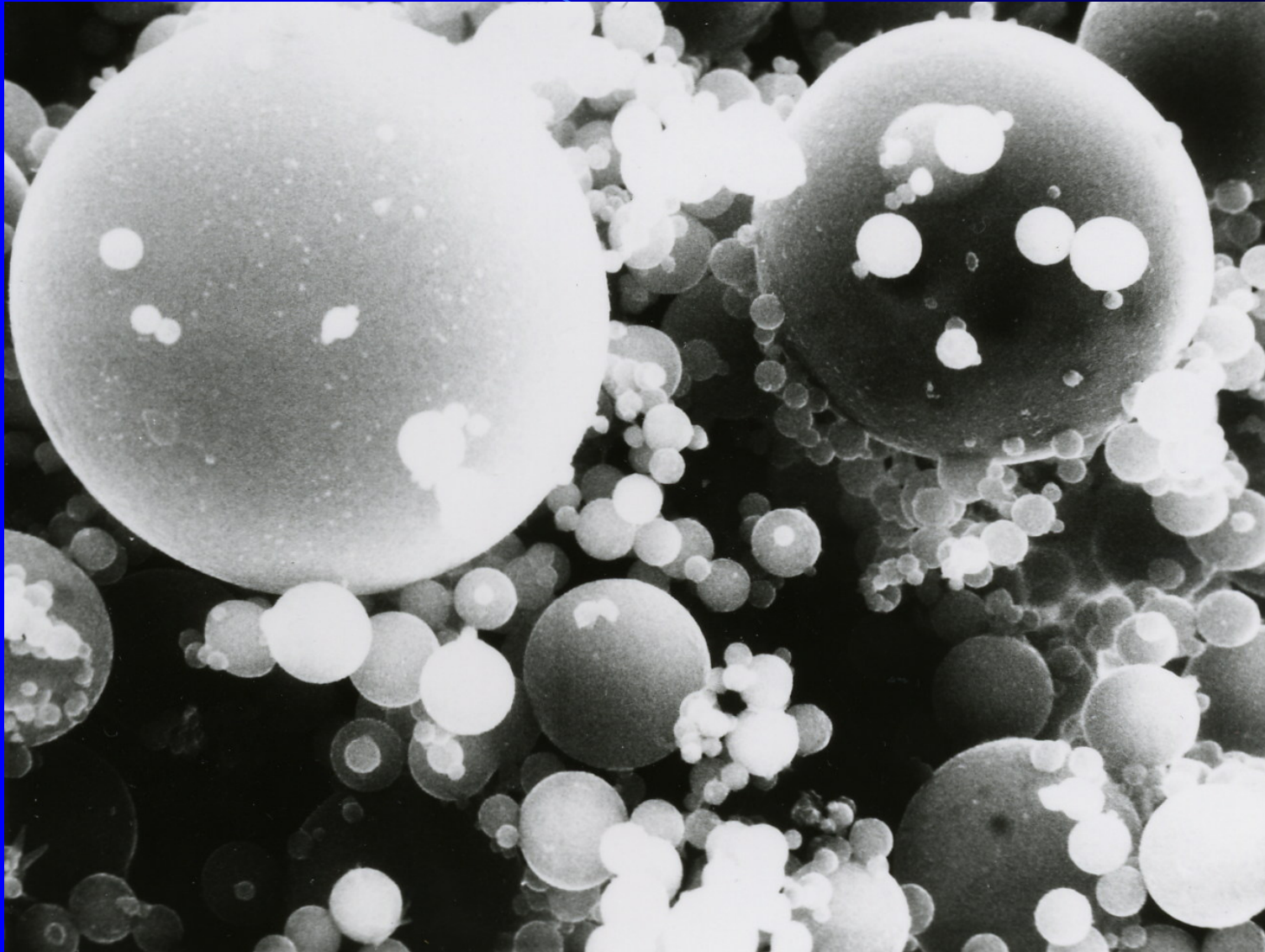
Particle Size Considerations

- **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

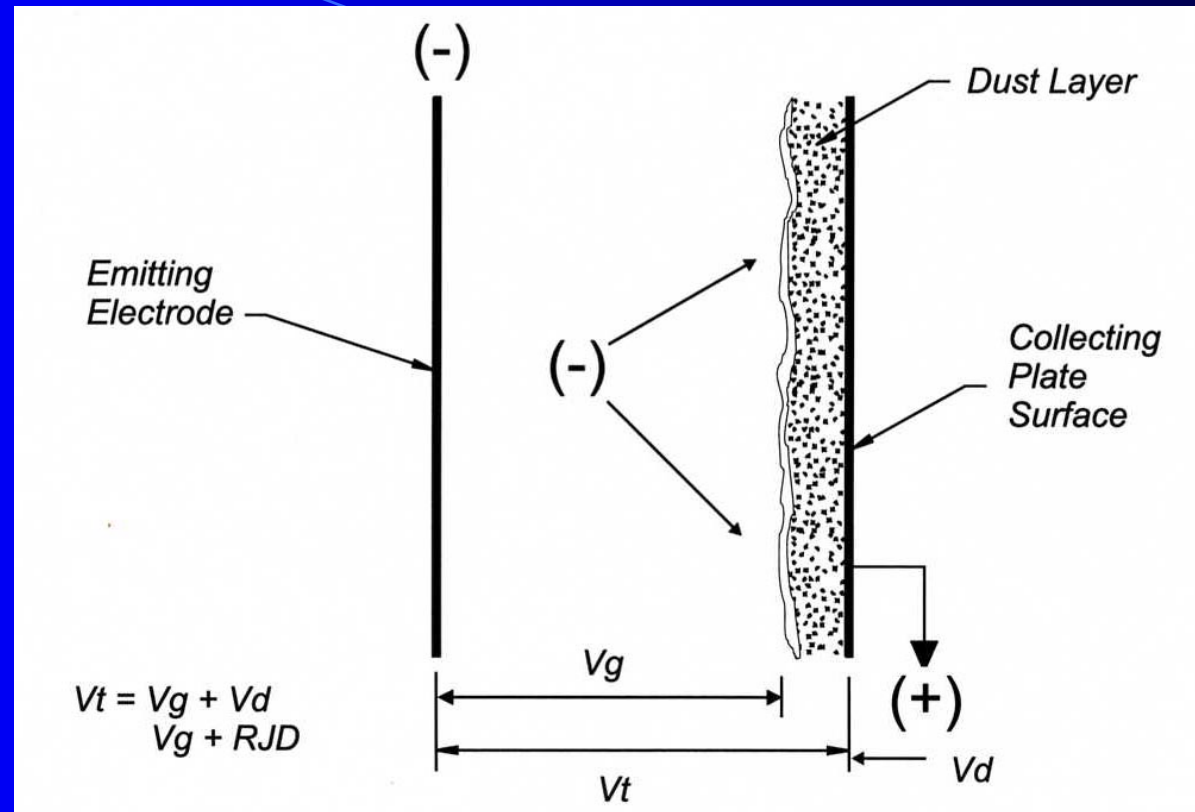
- **High ash loadings interfere with particle charging by suppressing the corona from the emitters and thus the negative ions generated for charging.**
- **The effect of suppression becomes significant if the higher ash loading has a large population of fines.**

Ash Resistivity

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

Typical Range: $1 \times 10^9 - 1 \times 10^{13}$

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.

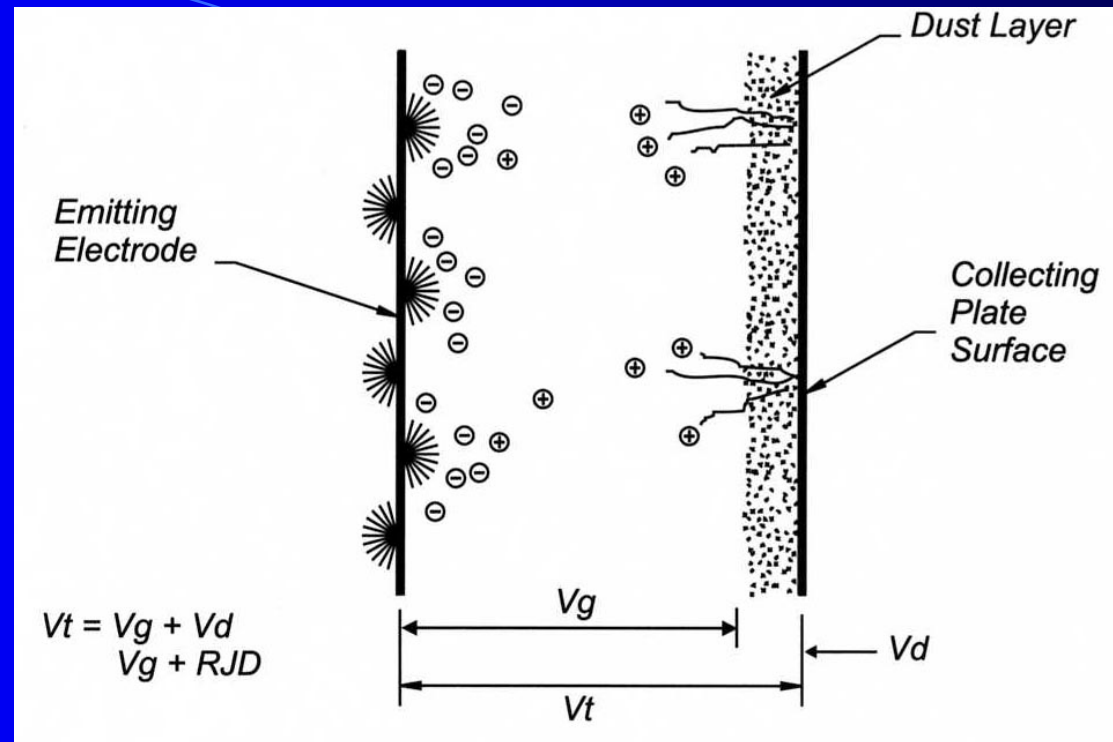
Effect of Low Ash Resistivity, $<1 \times 10^8$

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

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

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

Back Corona

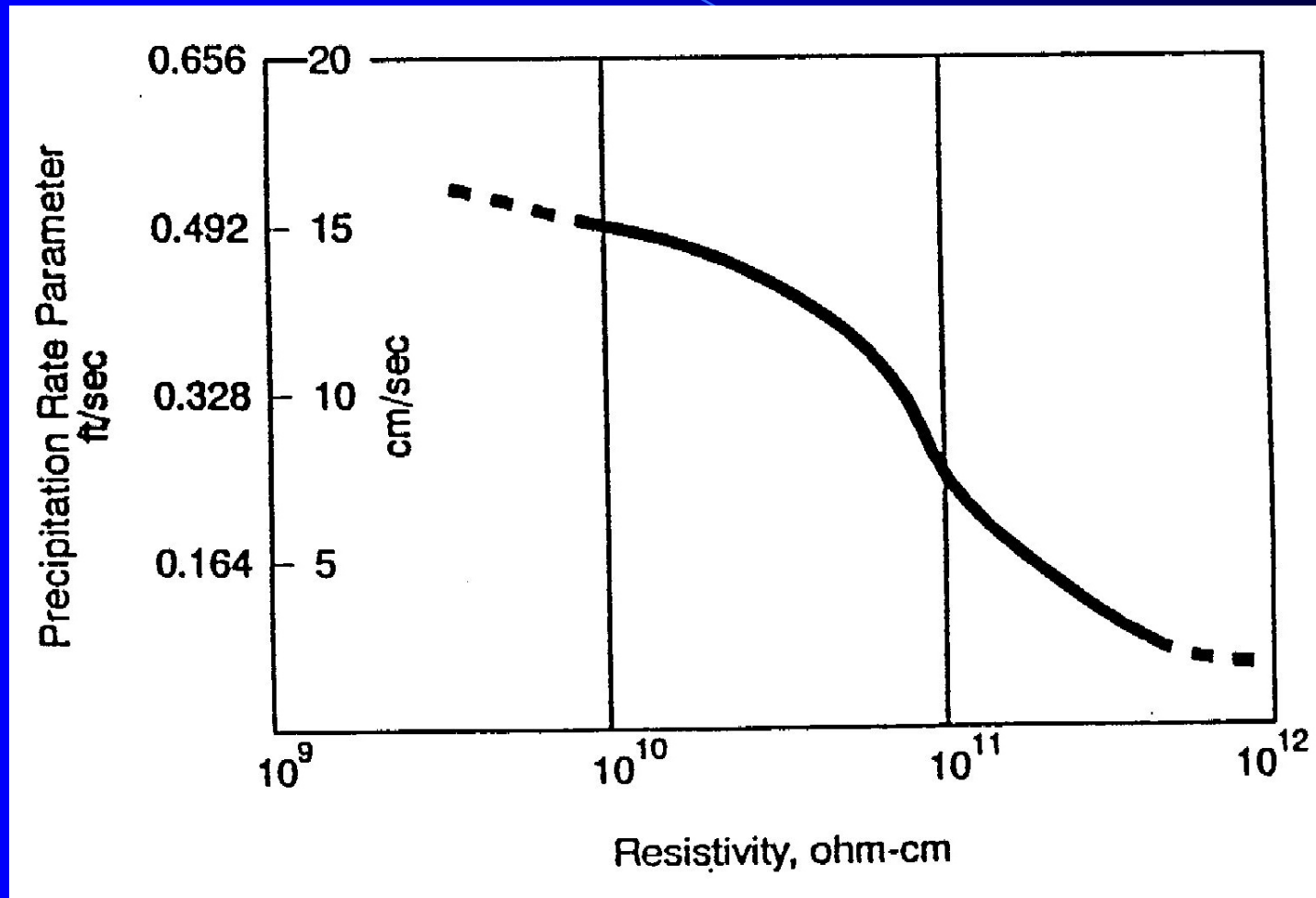


- If the ash layer voltage drop is very large due to very high resistivity, **Back Corona** will form when the ash layer breaks down and the total voltage, V_t , is not sufficient for sparkover.
- With **Back Corona**, positive corona occurs on the ash layer surface forming positive ions that are attracted to the negative polarity emitters. Positive ions encounter negative ions effectively canceling their contribution to the particle charging process.

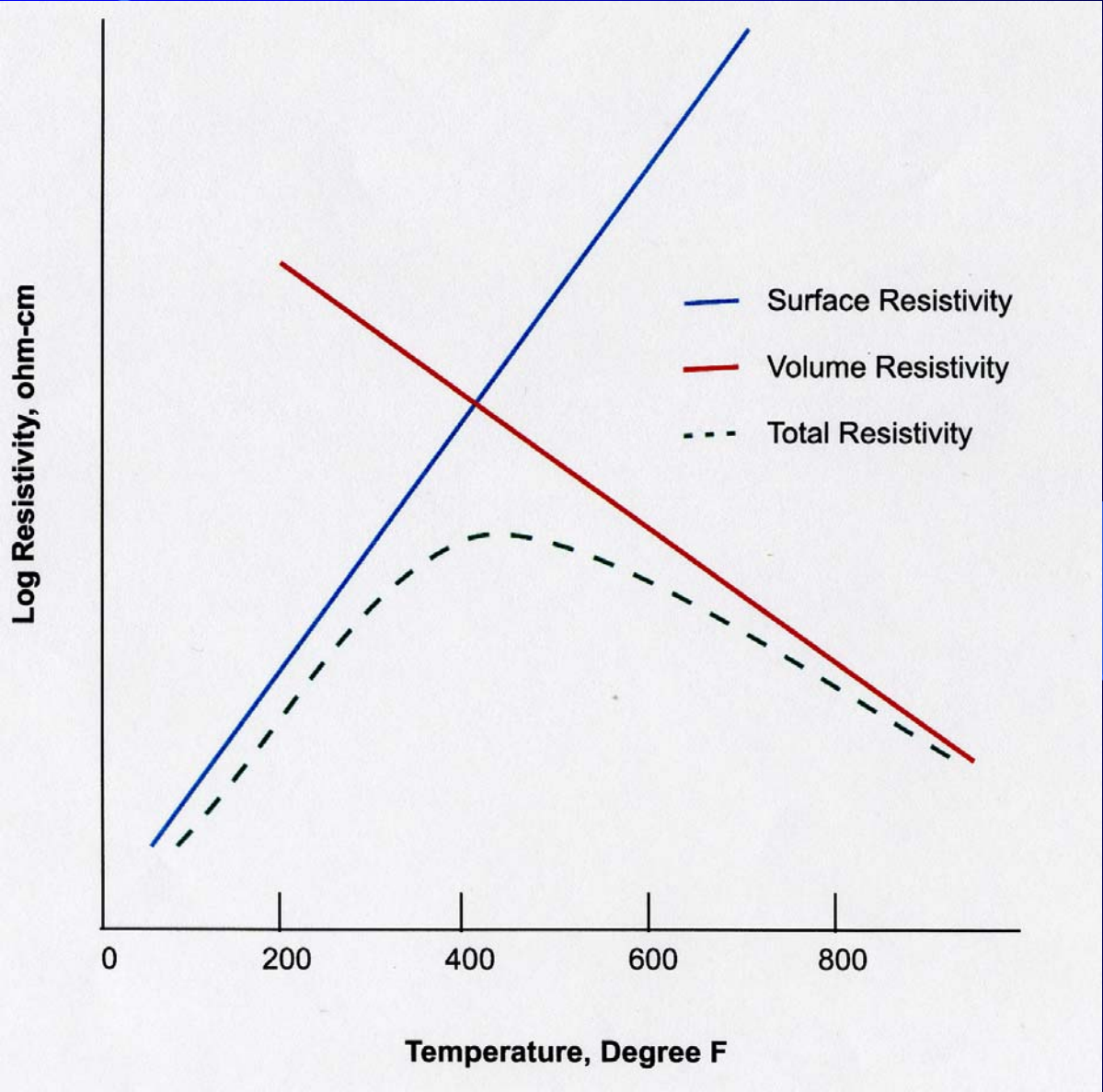


Back Corona Glow Regions on Collecting Plate Ash Surfaces
Plan View – Looking Down Into a Gas Passage

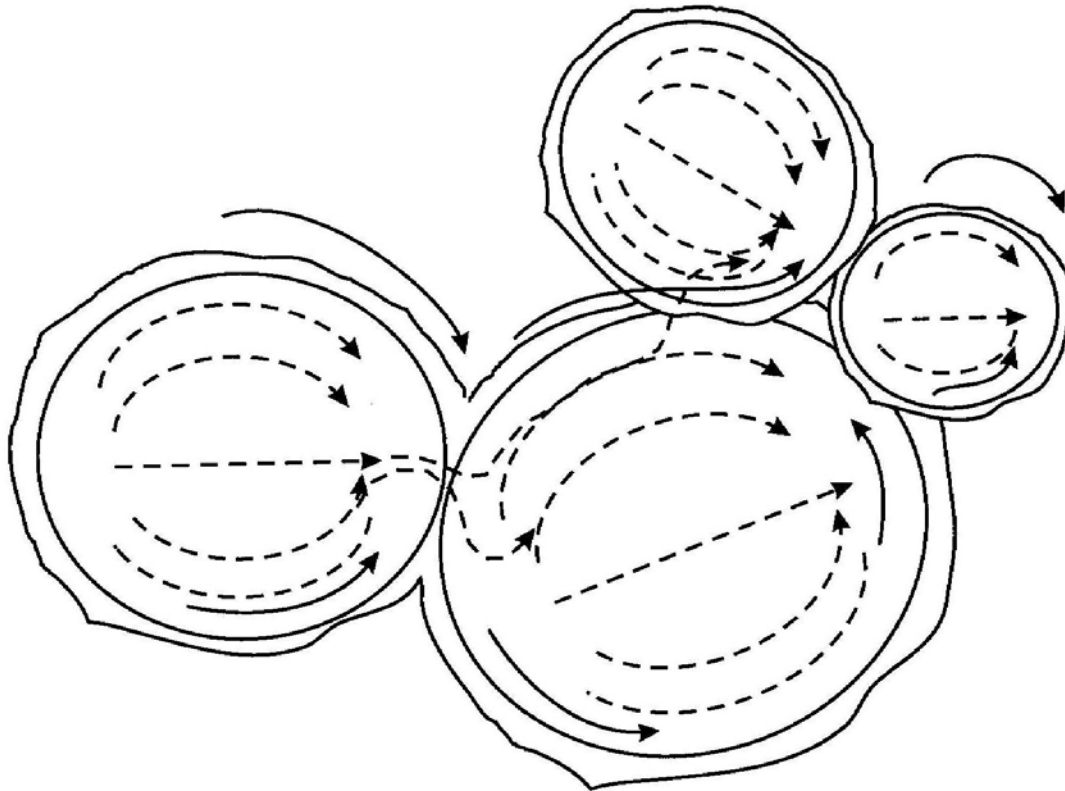
Effect of High Ash Resistivity on Charged Particle Migration Velocity



Factors Affecting Flyash Resistivity



Surface and Volume Conduction

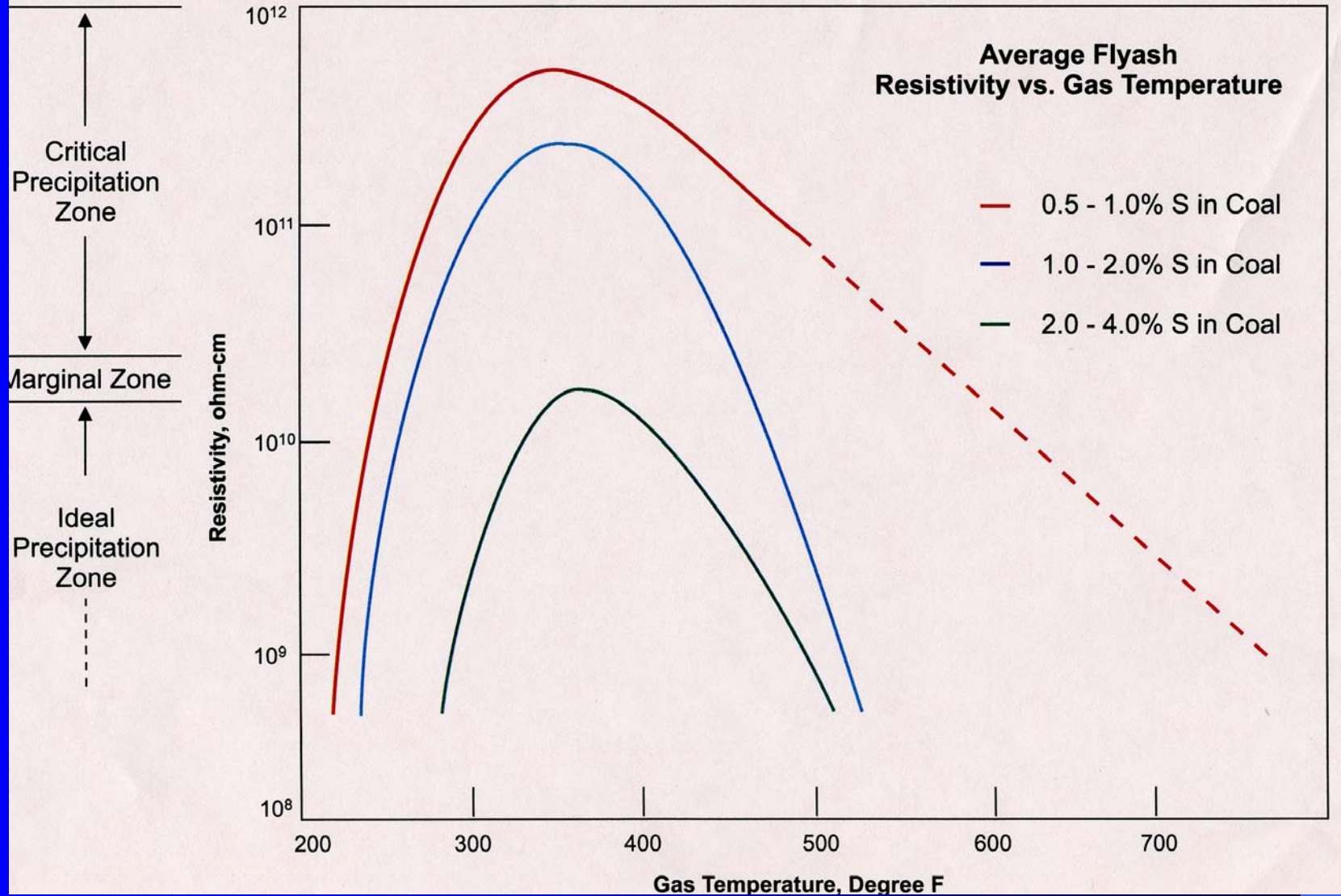


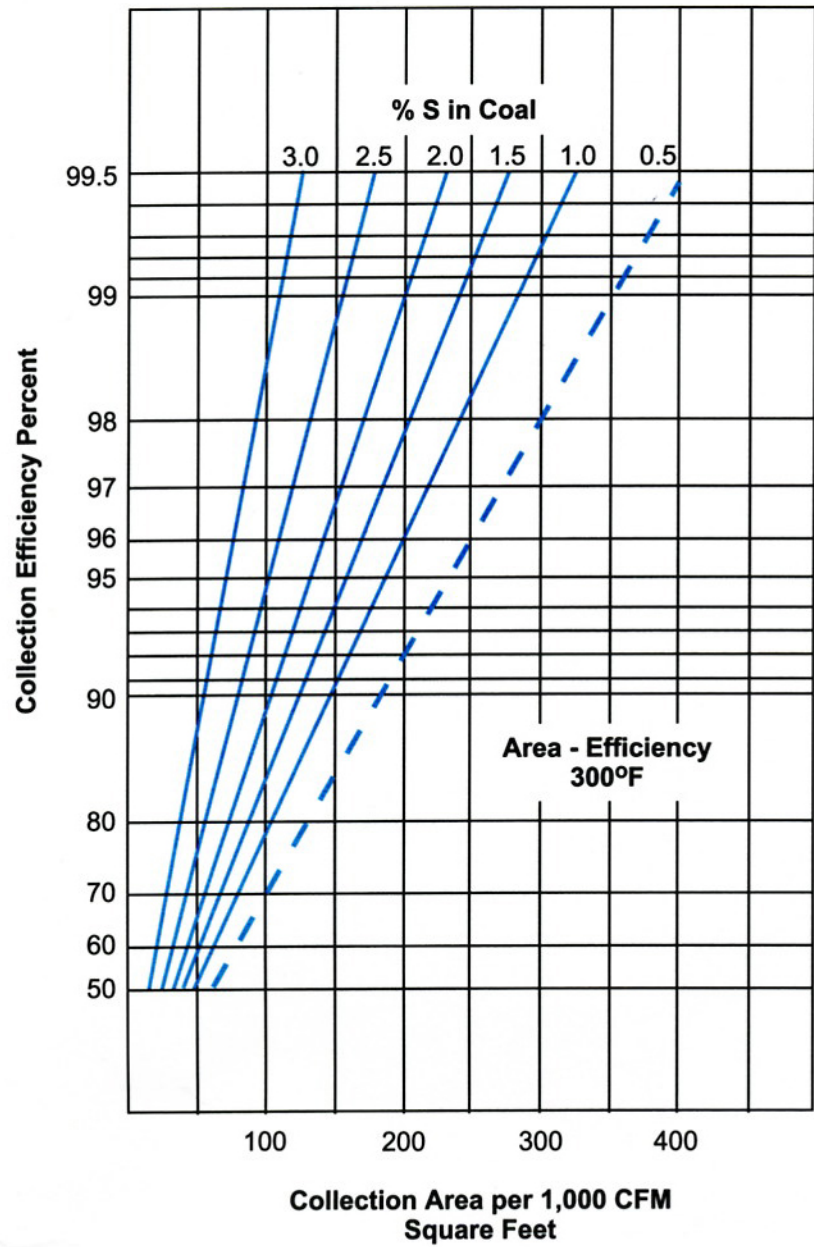
Surface Conduction \longrightarrow

Volume Conduction \dashrightarrow

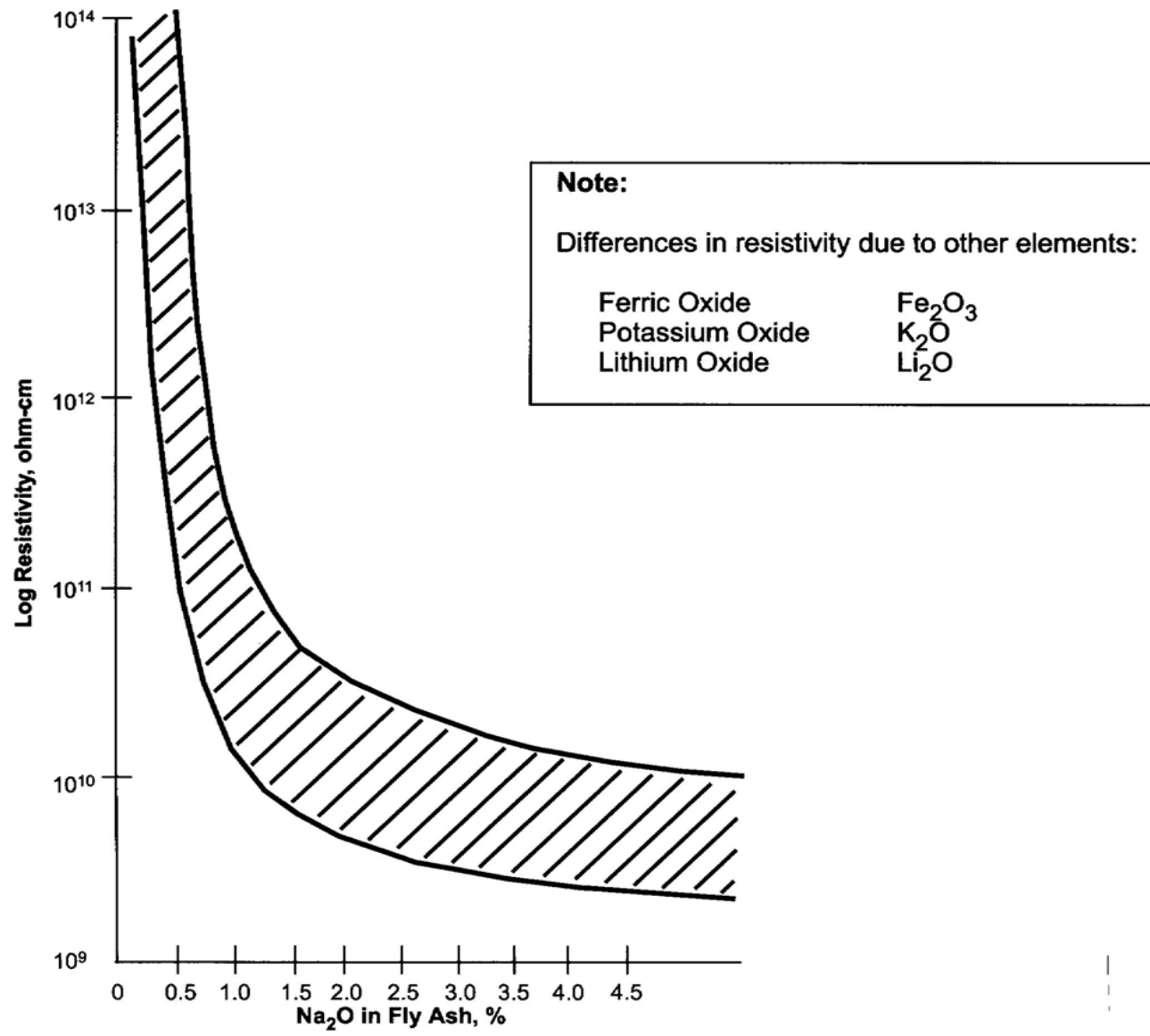
Surface Conduction Charge Carriers: H^+ , OH^- , Na^+ , K^+ , Li^+ , HSO_4^- , SO_4^{2-} ions

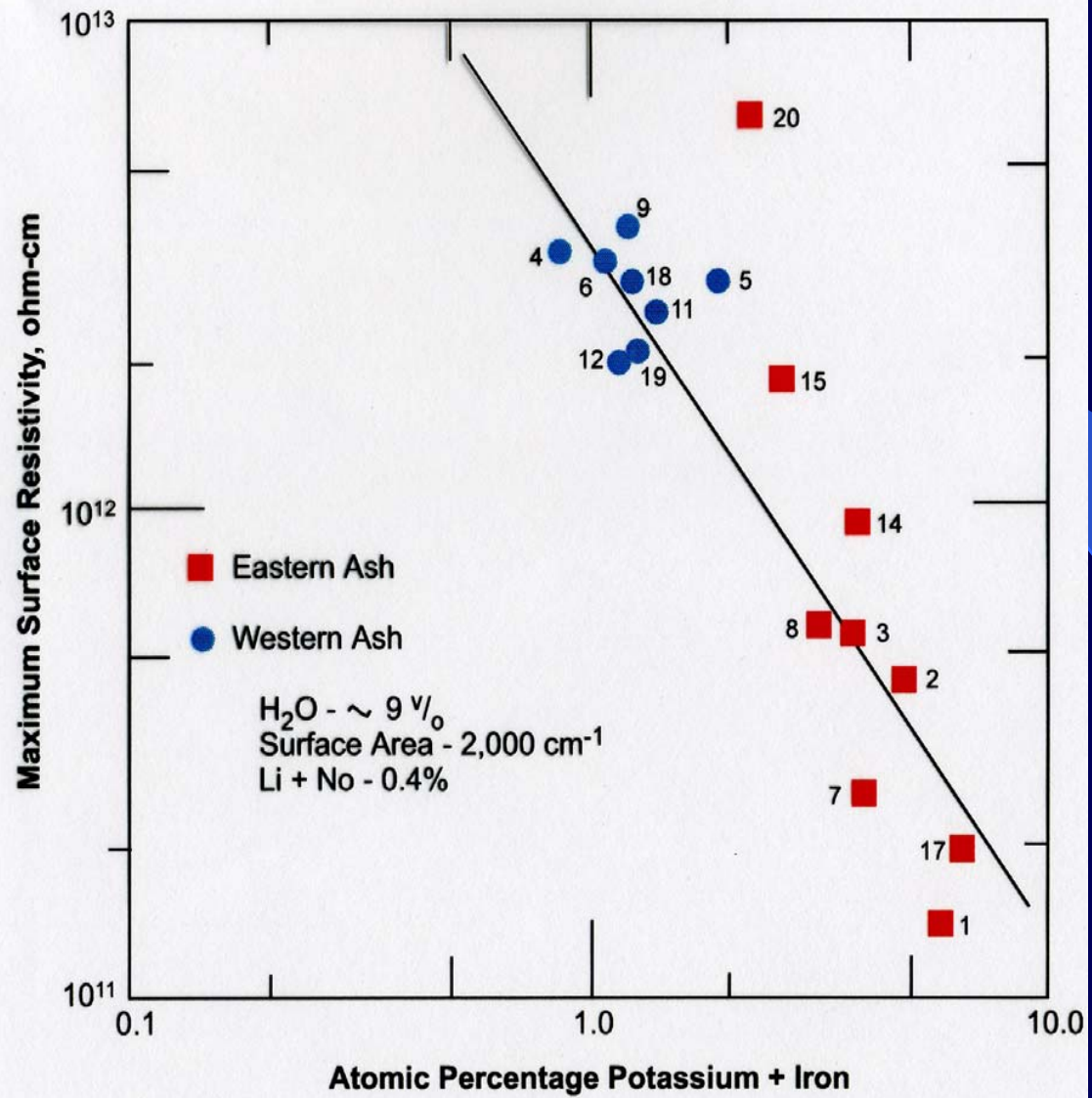
Volume Conduction Charge Carriers: Na^+ , K^+ , Li^+ ions





Resistivity of Flyash from Low Sulfur Coal @ 300°F





Elemental Analysis of Flyash

Typical Range of Constituents

<u>Component</u>	<u>Maximum %</u>	<u>Minimum %</u>
SiO ₂	61.00	41.20
Al ₂ O ₃	31.00	17.90
Fe ₂ O ₃	23.70	3.90
CaO	23.50	0.30
MgO	5.50	0.90
Na ₂ O	2.66	0.13
K ₂ O	3.90	0.28
Li ₂ O	0.07	0.01
TiO ₂	2.30	0.80
P ₂ O 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:

$\text{SiO}_2 + \text{Al}_2\text{O}_3 > 80\%$

$\text{Fe}_2\text{O}_3 < 5\%$

$\text{Na}_2\text{O} < 0.5\%$

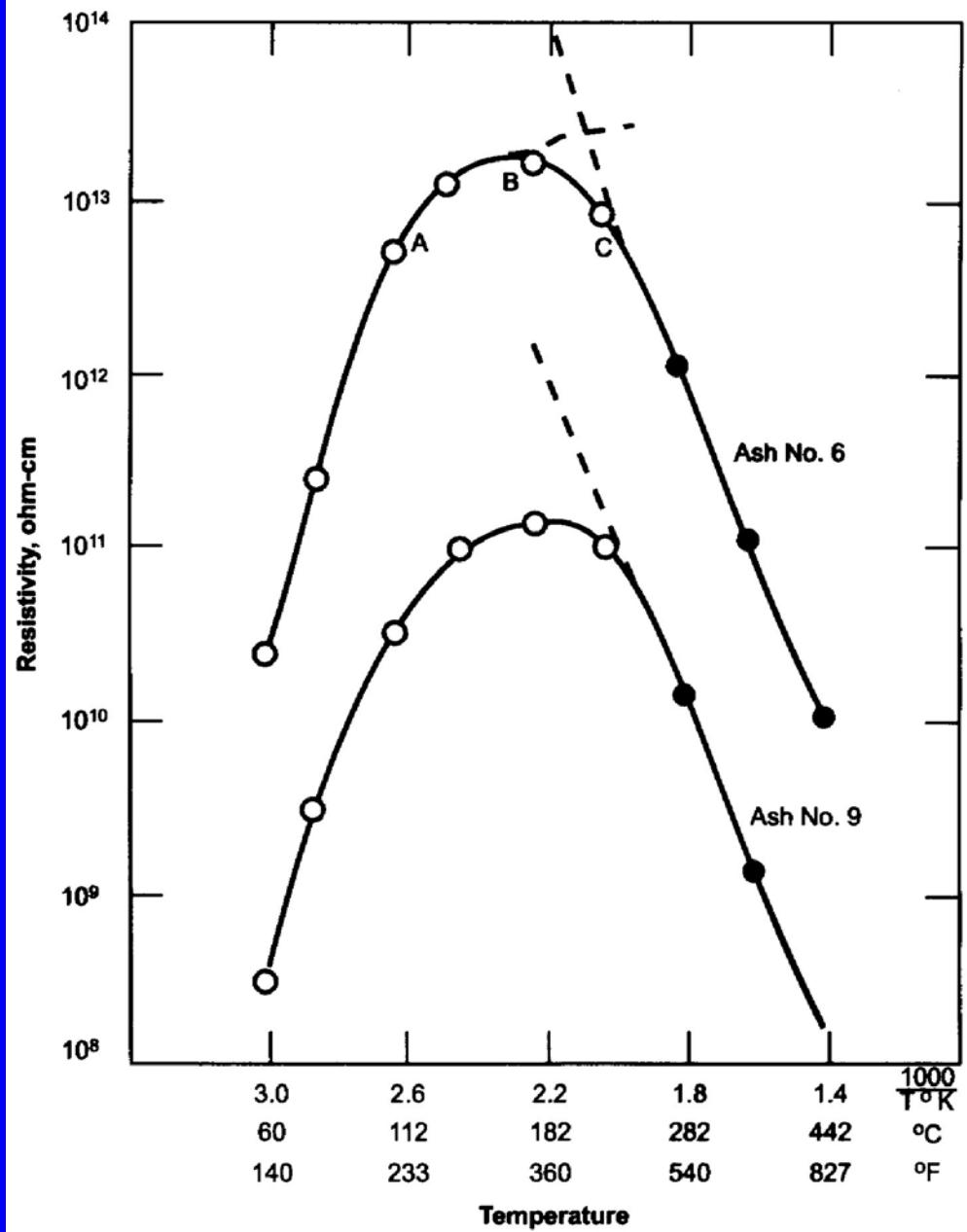
Coal Sulfur Content $< 1\%$

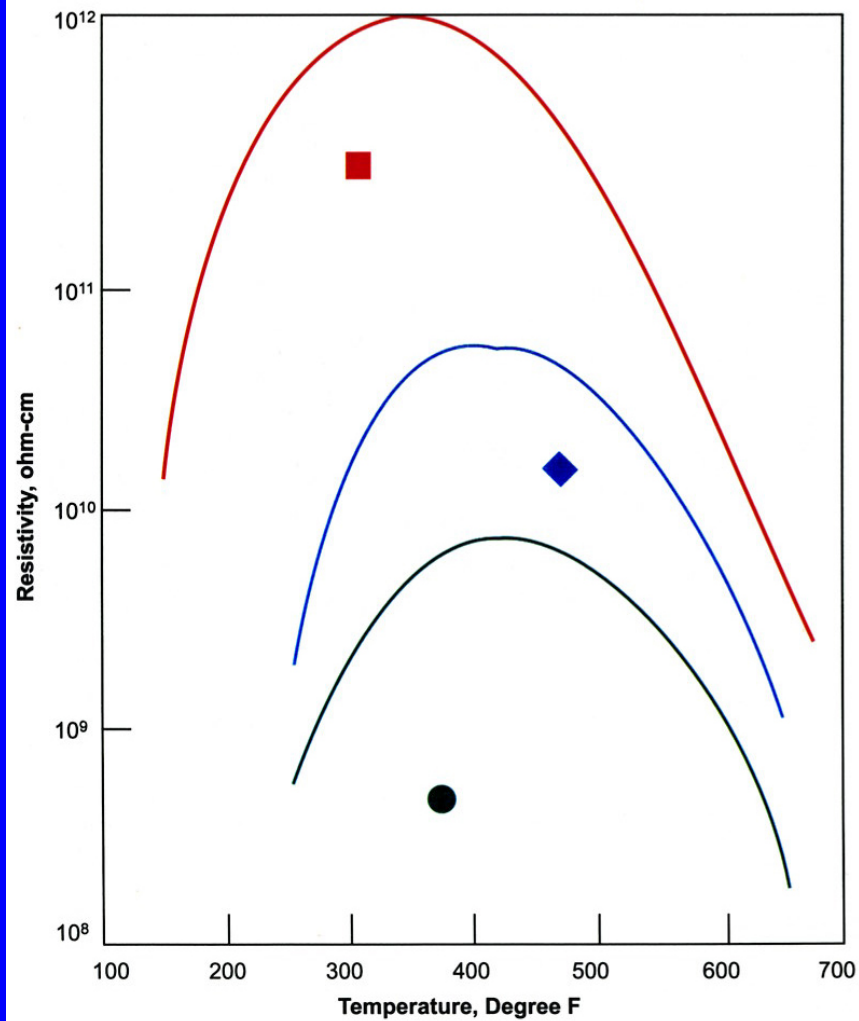
ESP Flue Gas Temperature 330 to 350°F

Chemical Analyses of Ashes in Weight Percent

Ash No.	Li ₂ O	Na ₂ O	K ₂ O	MgO	CaO	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂	TiO ₂	P ₂ O 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





- **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**

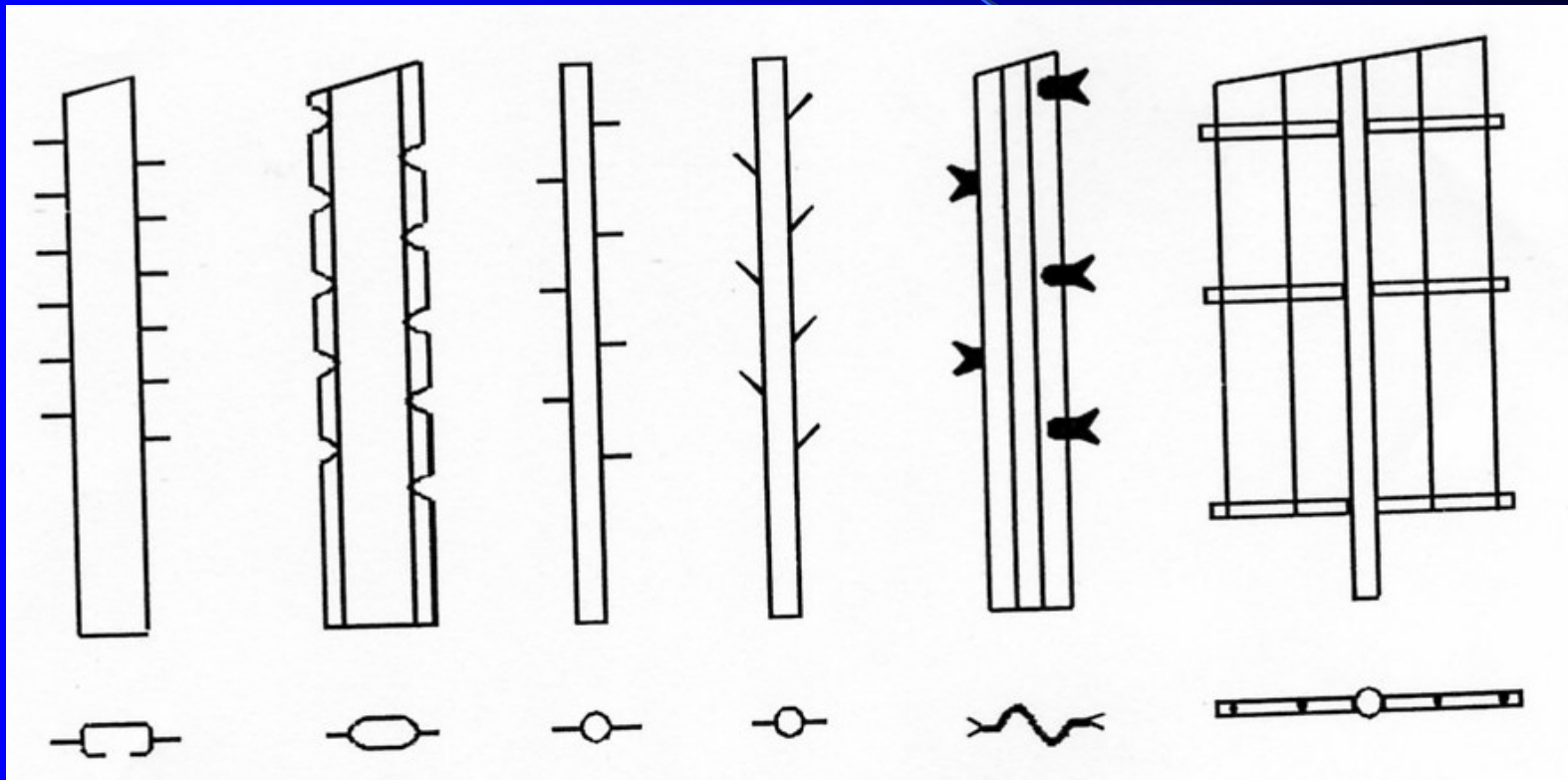


Precipitator Design Practice - U.S. OEMS

<u>Design Characteristics</u>	<u>Prior</u>	<u>Current</u>
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	All Electro-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



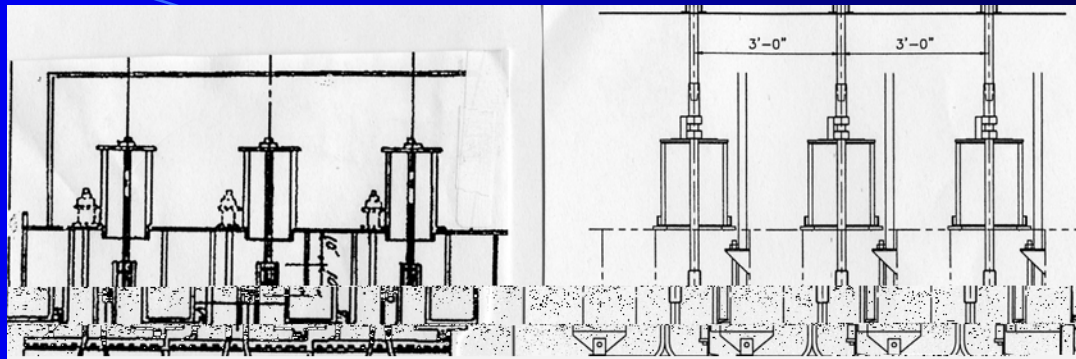
Rigid Emitting Electrode Example Mast Type



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

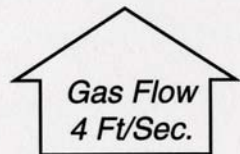
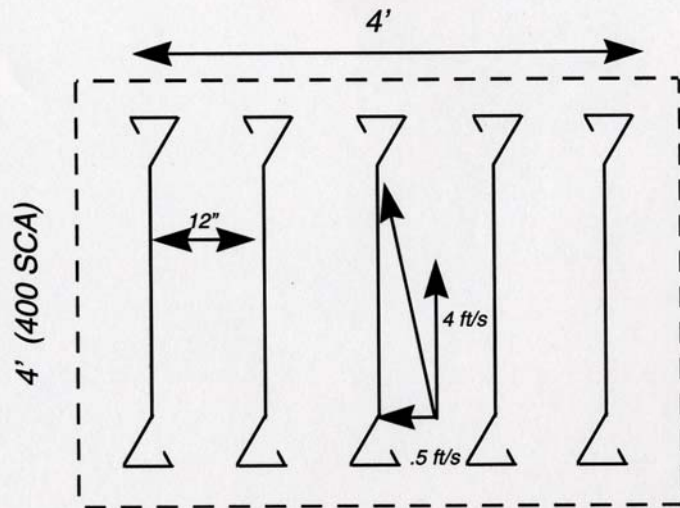
Wide Plate Spacing

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.

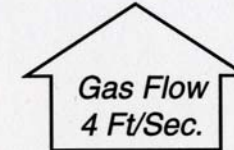
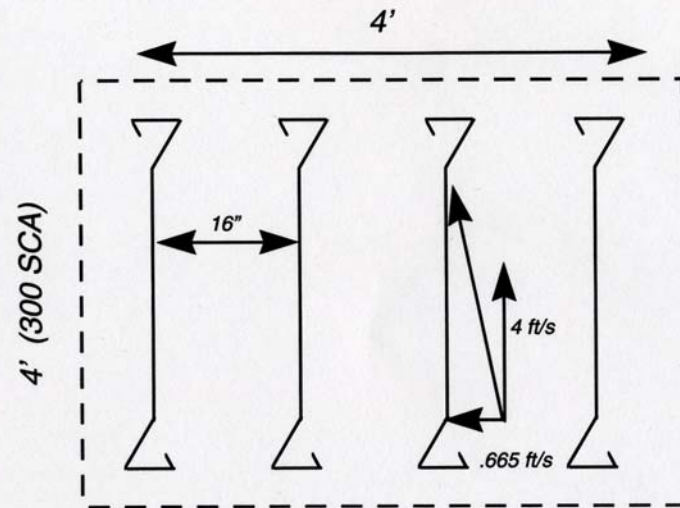
Wide Plate Spacing

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.