ESP Basics

By

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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

50 - 75 KVDC

Dust Layer

Collecting Plate Surface

Emitting Electrode

6" (150 mm)

8" (200 mm)
ESP Gas Passage – Particle Charging & Collection

Electric Field Lines

Dust Particle

Particle Path

(High Voltage) Discharge Electrode

Negative Charging Ions Follow the Electric Field Lines to the Plates

(Grounded) Collecting Electrode

GAS FLOW
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:
- \( \eta \) = 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

SCA = \frac{\text{Collecting Plate Area} \text{ ft}^2}{1000 \text{ ft}^3/\text{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
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.
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 steam.

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

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

![Graph showing the relationship between precipitation rate parameter (μ/sec) and resistivity (ohm-cm). The graph indicates a downward trend as resistivity increases.](image-url)
Factors Affecting Flyash Resistivity
Surface and Volume Conduction

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

Note:
Differences in resistivity due to other elements:
- Ferric Oxide: Fe₂O₃
- Potassium Oxide: K₂O
- Lithium Oxide: Li₂O
Maximum Surface Resistivity, ohm-cm

- Eastern Ash
- Western Ash

$H_2O - \sim 9\%$
Surface Area - 2,000 cm$^{-1}$
Li + No - 0.4%

Atomic Percentage Potassium + Iron
## Elemental Analysis of Flyash

**Typical Range of Constituents**

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<thead>
<tr>
<th>Component</th>
<th>Maximum %</th>
<th>Minimum %</th>
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<tr>
<td>SiO$_2$</td>
<td>61.00</td>
<td>41.20</td>
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<tr>
<td>Al$_2$O$_3$</td>
<td>31.00</td>
<td>17.90</td>
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<td>Fe$_2$O$_3$</td>
<td>23.70</td>
<td>3.90</td>
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<td>CaO</td>
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<td>MgO</td>
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<td>Li$_2$O</td>
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<td>TiO$_2$</td>
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<tr>
<td>P$_2$O$_5$</td>
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<tr>
<td>SO$_3$</td>
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The Major Ash Resistivity Effects Due to Mineral Compounds in the Ash are:

SiO₂, Al₂O₃, CaO, MgO - Increases Ash Resistivity

Na₂O, Li₂O - Reduces Ash Resistivity

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

SiO₂ + Al₂O₃ > 80%
Fe₂O₃ < 5%
Na₂O < 0.5%

Coal Sulfur Content < 1%
ESP Flue Gas Temperature 330 to 350°F
### Chemical Analyses of Ashes in Weight Percent

<table>
<thead>
<tr>
<th>Ash No.</th>
<th>Li₂O</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>MgO</th>
<th>CaO</th>
<th>Fe₃O₄</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>TiO₂</th>
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Note: SO₄²⁻ a) soluble sulfate
The graph illustrates the resistivity (in ohm-cm) as a function of temperature for Ash No. 6 and Ash No. 9. The resistivity values are given on a log scale, with temperatures in Kelvin, Celsius, and Fahrenheit. The data points for each ash type are marked with different symbols, and the trend lines are clearly visible.
- 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

<table>
<thead>
<tr>
<th>Design Characteristics</th>
<th>Prior</th>
<th>Current</th>
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</thead>
<tbody>
<tr>
<td>Plate-to-Plate Spacing</td>
<td>8”- 9”</td>
<td>12” - 16”</td>
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<tr>
<td>Precipitator Voltage</td>
<td>45KV</td>
<td>55-75KV</td>
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<tr>
<td>Emitting Electrode</td>
<td>Wire-Weight</td>
<td>Rigid</td>
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<tr>
<td>Control System</td>
<td>Analog</td>
<td>Microprocessor based with Host Computer</td>
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**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)

4’ (400 SCA)

12”

.5 ft/s

4 ft/s

Gas Flow 4 Ft/Sec.

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)

4’ (300 SCA)

16”

.665 ft/s

4 ft/s

Gas Flow 4 Ft/Sec.

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.