

Reinhold Environmental Ltd.



2006 APC Round Table & Expo Presentation

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ELECTROSTATIC PRECIPITATOR FUNDAMENTALS

- History
 - Pioneers
 - Pioneer Installations
- Basic Process
 - Five-Step Process
- Components
- ESP Size
 - Dimensions

ELECTROSTATIC PRECIPITATOR FUNDAMENTALS

- Collecting Efficiency
 - Deutsch-Anderson Equation
 - Matts-Oehnfeldt Equation
- Parameters Affecting the Performance of the ESP
 - Fuel
 - Gas Flow
 - Dust Particles

ELECTROSTATIC PRECIPITATOR FUNDAMENTALS

- Operation
 - Process Data
 - Electric Power Readings
 - Specific Dust Resistivity
 - Reentrainment
 - Other Problems

ELECTROSTATIC PRECIPITATOR FUNDAMENTALS

- Improvements
 - Process
 - ESP Equipment
 - ESP Operation
- Summary

HISTORY

Pioneers

1884 Sir Oliver Lodge (1851-1940)

“Electricity could be used to collect fumes.”

1885 A. O. Walker & W.O. Hutchings

Full-scale precipitator in a lead smelter

1907 F. G. Cottrell

Precipitator to collect sulfuric acid mist

HISTORY

Pioneer Installations

- 1907 Chemical Industry
- 1910 Non-Ferrous Industry
- 1910 Rock Products Industry
- 1916 Pulp and Paper Industry
- 1919 Ferrous Industry
- 1923 Power Industry (Detroit Edison)

BASIC PROCESS

Five Step Process

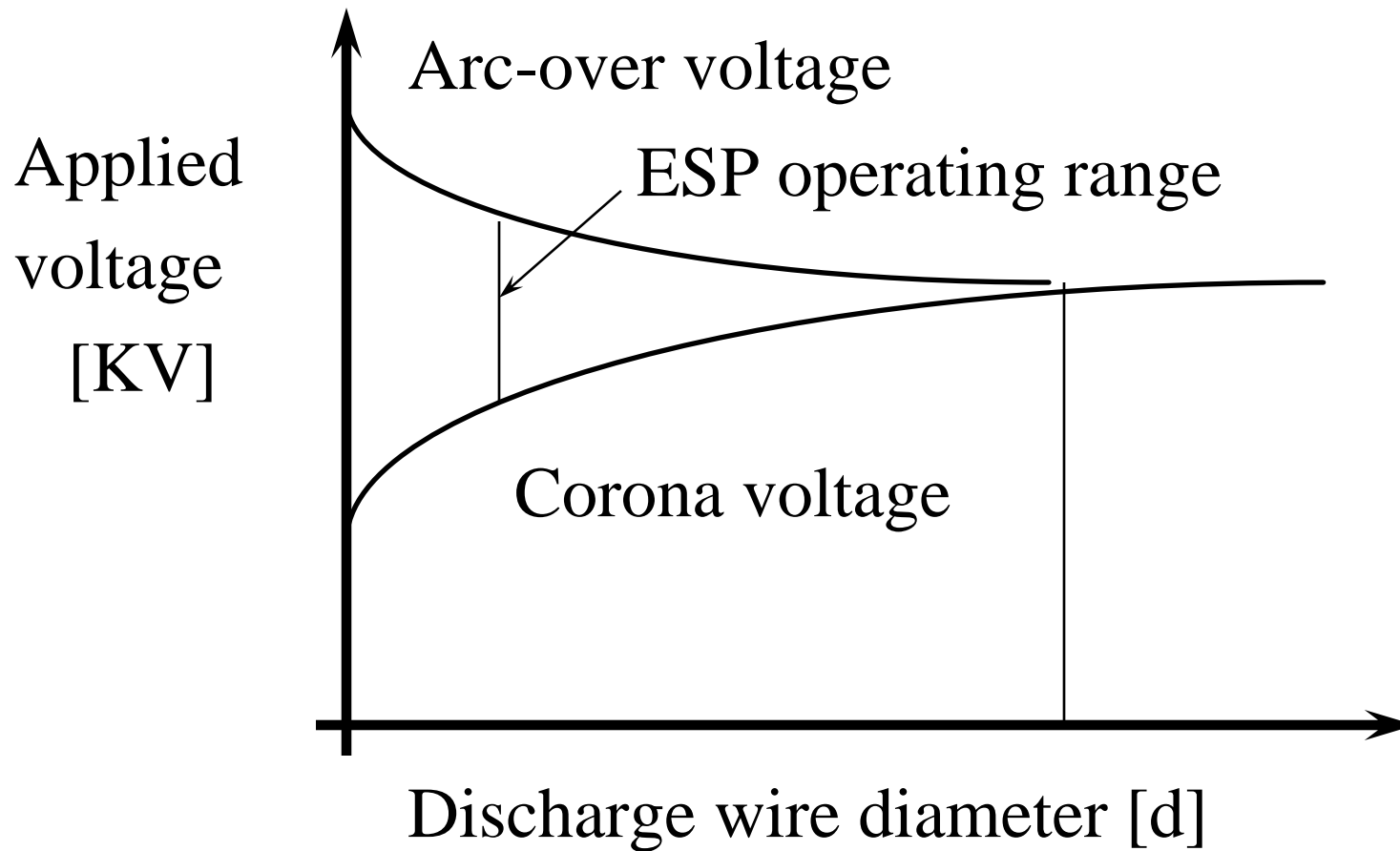
- Charging fly ash particles
- Transporting to collecting surface
- Discharging and holding on collecting surface
- Moving the fly ash to the ash hopper
- Moving from the ash hopper to disposal

BASIC PROCESS

Charging Fly Ash Particles

- Negative corona
- Field charging using corona discharge
- Diffusion or ion charging for particles
< 0.1 to 1 micrometer
- Electrical wind

BASIC PROCESS



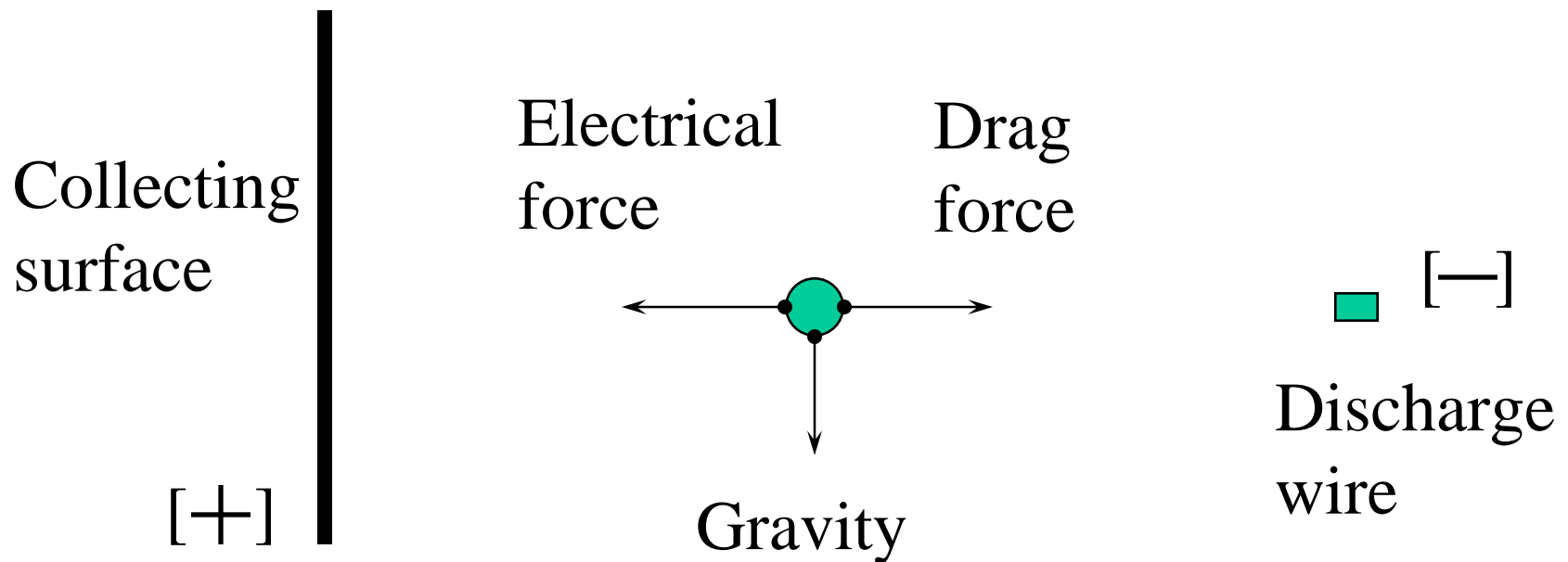
BASIC PROCESS

Transporting to Collecting Surface

- Electrical field between discharge wire and collecting surface
- Electrical current
 - as free electrons
 - as ions
 - as charged particles

BASIC PROCESS

Forces on Particle



Electrical force and drag force define migration velocity

BASIC PROCESS

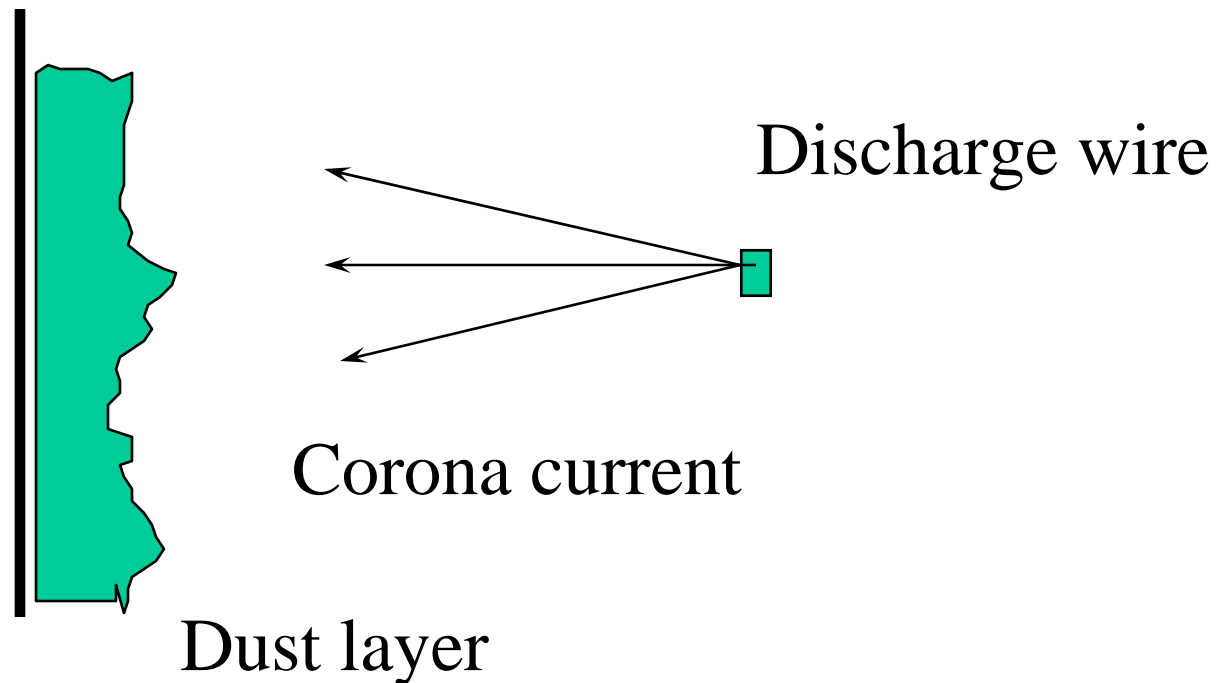
Discharging and Holding to Collecting Surface

- Precipitated fly ash builds up on collecting surface
- Current through dust layer:
 - Surface and volume resistivity
 - Voltage drop in dust layer
 - Back corona

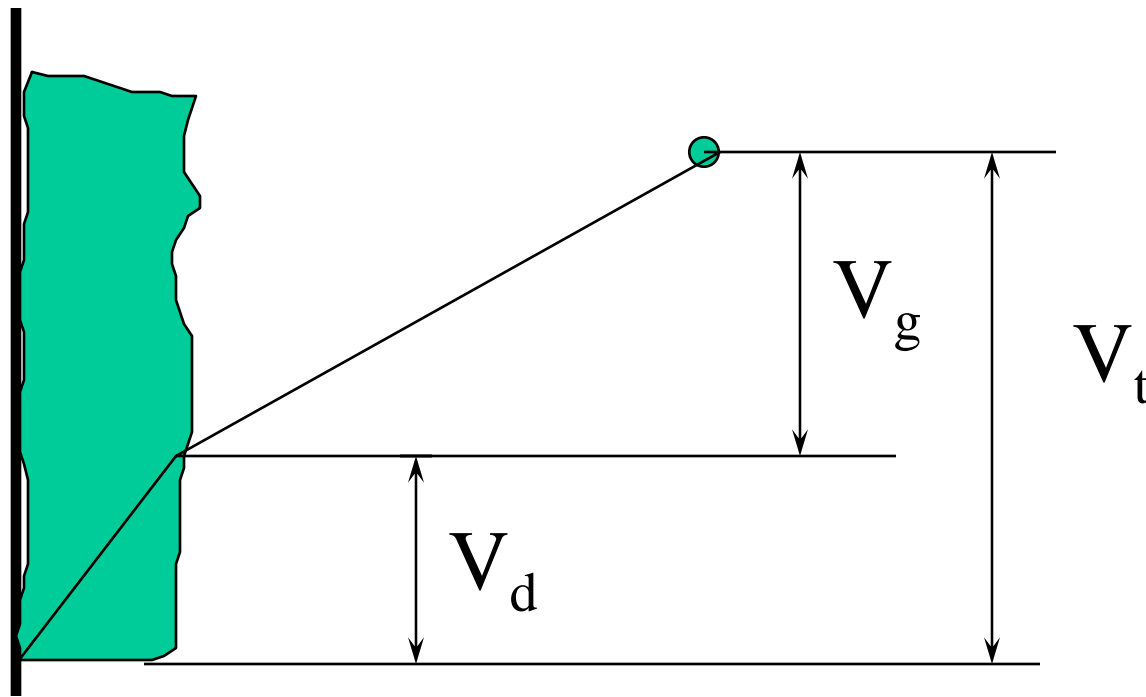
BASIC PROCESS

Dust Layer and Corona Current

Current density x resistivity = voltage drop



BASIC PROCESS



V_t = total applied voltage

V_g = voltage drop in gas space

V_d = voltage drop through dust layer

BASIC PROCESS

Moving the Fly Ash to the Ash Hopper

- Rapping system for collecting surfaces
- Rapping system for discharge electrodes
- Electric vibrators or impactors
- Rotating hammers
- Rapper control systems for sequence, frequency, and intensity
- Rapping re-entrainment

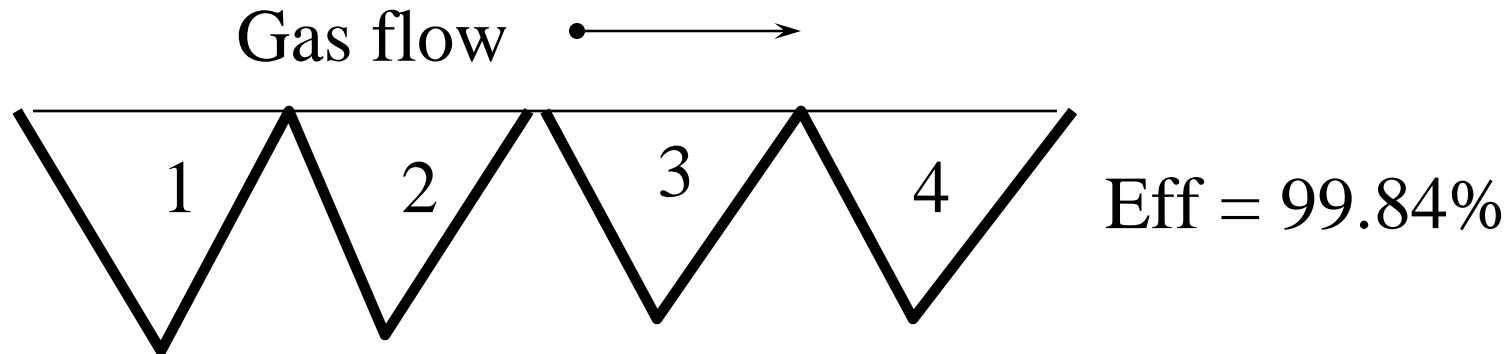
BASIC PROCESS

Moving the Fly Ash to the Ash Hopper

- Fly ash removed by rapping travels like an avalanche (two-phase flow) into the dust hopper
- Collecting surface rapping systems have to be programmed to remove the fly ash as required by the rate of precipitation
- Discharge wire rapping systems have to maintain the electrical performance of the precipitator

BASIC PROCESS

Moving the Fly Ash to the Ash Hopper

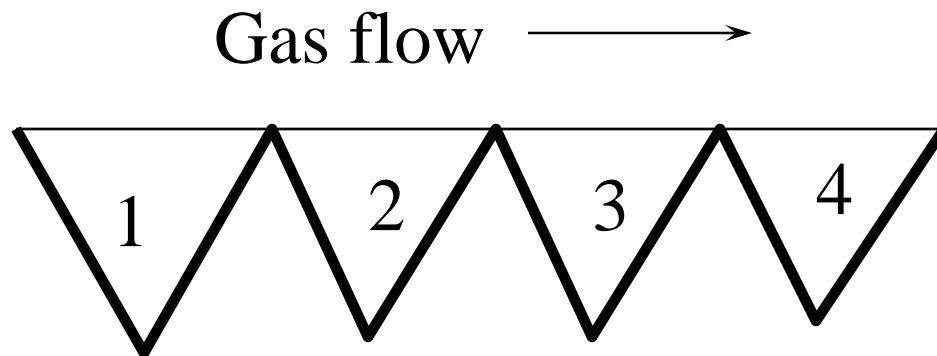


$$\text{Catch: } 57.6 + 11.52 + 2.3 + 0.46 = 71.88 \text{ Klb/hr}$$

Using the Deutsch-Anderson equation, each field of the ESP collects 80% of the fly ash entering this field

BASIC PROCESS

Moving the Fly Ash to the Ash Hopper



Eff =
99.84%

Eff. = 96.0 73.75 63.81 57.89 %

Catch: $69.12 + 2.12 + 0.48 + 0.16 = 71.88$ Klb/hr

Using the Extended Deutsch (M/O) equation, the inlet field of the ESP collects most of the fly ash entering the ESP

BASIC PROCESS

Moving from the ash hopper to disposal

- Hopper ash discharge sequence to match the precipitation rate of the electrical field(s) above the hopper
- Ash removal may not cause air infiltration

COMPONENTS

Internal and External

- Collecting plates and discharge electrodes
- Rapping systems
- Power supplies and controls
- Casing, hoppers, inlet/outlet transitions
- Access
- Hopper discharge valves

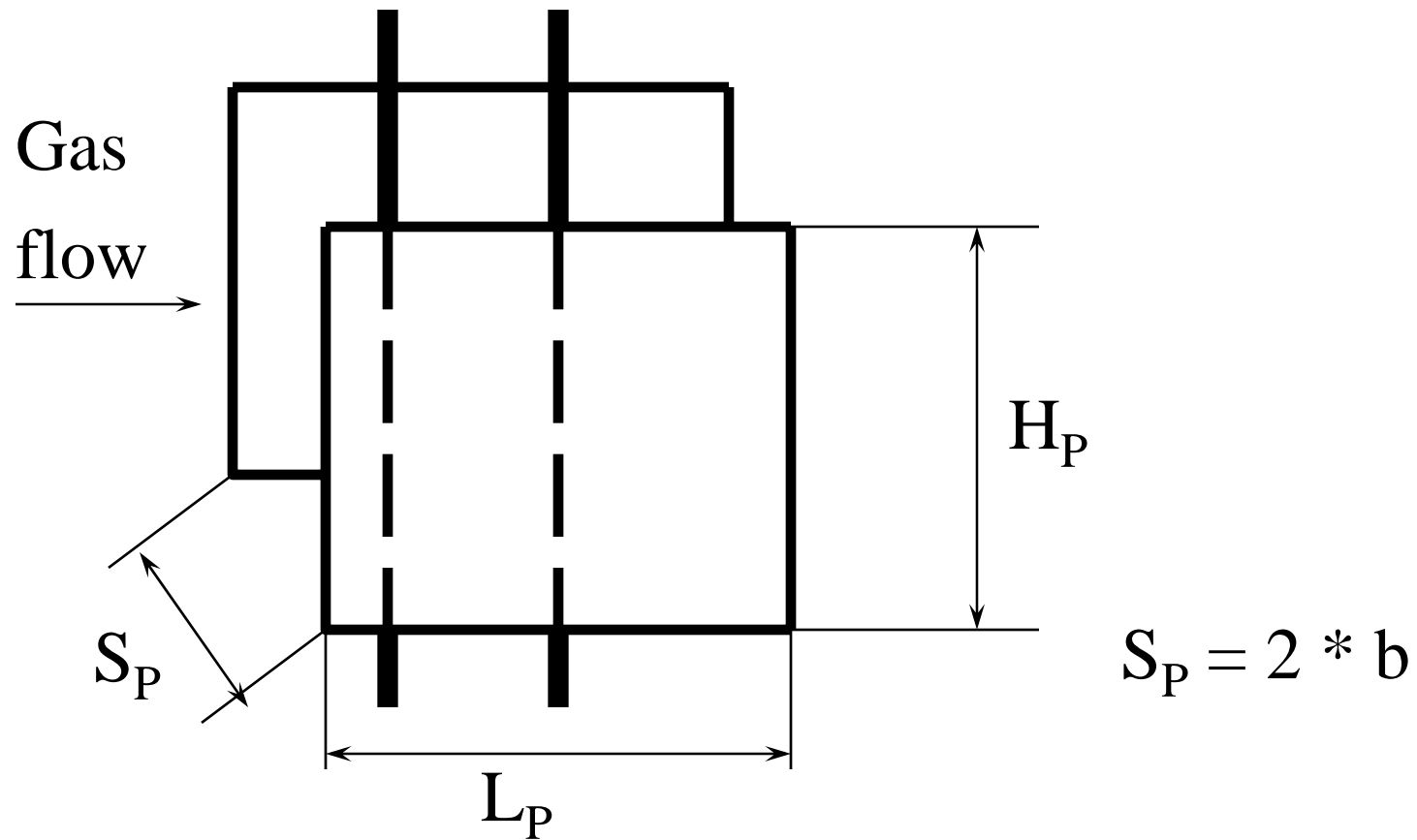
ESP SIZE

Basic Dimensions

- Number of electrical/mechanical fields in series
- Number of bus sections in parallel
- Number of transformer-rectifiers
- Collecting surface
 - Field height, length, number of gas passages
- ESP cross section
 - Field height, number of gas passages, plate-to-plate spacing
- Number of transformer-rectifiers

ESP SIZE Schematic

Collecting surfaces and discharge wires



ESP SIZE Dimensions

A_T = total plate area of ESP

$$A_T = H_P * L_P * 2 n_P * n_F$$

L_T = total field length

$$L_T = L_P * n_F$$

L_T / H_P = aspect ratio

b = plate-to-wire spacing

S_P = plate-to-plate spacing

$$S_P = 2 * b$$

A_X = cross section of ESP

$$A_X = H_P * S_P * n_G$$

COLLECTING EFFICIENCY

Fractional collecting efficiency (E) of an ESP can be defined as:

- $E = (\text{inlet} - \text{outlet}) / \text{inlet}$
- $E = \text{catch} / \text{inlet}$
- $E = \text{catch} / (\text{catch} + \text{outlet})$
- $E = 1 - (\text{outlet} / \text{inlet})$
- To obtain collecting efficiency in [%], multiply fractional collecting efficiency by 100

COLLECTING EFFICIENCY

Efficiency is a logarithmic function of :

- Gas flow
- Total collecting surface
- Migration velocity of the fly ash particles
- Log. functions commonly used:
 - Deutsch - Anderson
 - Matts - Oehnfeldt

COLLECTING EFFICIENCY

Deutsch-Anderson equation:

$$E = (1 - \exp. - (w * A/Q)) * 100$$

E = collecting efficiency [%]

w = migration velocity [ft/sec]

A/Q = specific collecting area [sec/ft]

A = total collecting surface area [ft²]

Q = gas flow [ft³/sec]

COLLECTING EFFICIENCY

Deutsch-Anderson equation:

In more familiar terms:

$$E = (1 - \exp - w * SCA / 508) * 100$$

w = migration velocity [cm/sec]

SCA = ft³ collecting surface area per
1000 acfm

$$SCA = 16.66 * ft^2 / ft^3 / sec = 16.66 * sec / ft$$

$$SCA = 16.66 * t / b$$

COLLECTING EFFICIENCY

Matts/Oehnfeldt equation:

$$E = (1 - \exp(-(w_K * A/Q)^K)) * 100$$

w_K = modified migration velocity

k = dimensionless exponent related
to particle size distribution

$$(0.4 < k < 0.6)$$

COLLECTING EFFICIENCY

Computer Programs

Computer programs are used to evaluate the future collecting efficiency of ESPs as part of the design process or prior to repairs or planned performance improvements. These programs require additional input data which cover undefined effects, such as re-entrainment, design details of collecting surfaces and discharge electrodes, alignment and wear and tear in existing installations.

PARAMETERS AFFECTING THE PERFORMANCE OF THE ESP

- Fuel
 - Ultimate analysis
 - Ash chemistry
- Gas flow
 - Gas flow rate
 - Gas analysis, temperature
- Dust Particles
 - Particle chemistry
 - Particle loading
 - Particle size distribution

PARAMETERS AFFECTING THE PERFORMANCE OF THE ESP

A review of the following items is suggested:

- ESP inlet conditions
 - Boiler operation and fuel
 - Gas velocity, dust and temperature distribution
 - In-leakage
- ESP operation
 - Electrical energization
 - Rapping system operation
 - Fly ash handling system

ESP OPERATION

Process Data

- Stack opacity [%]
- Boiler load [MW]
- Fuel rate [Klb/hr]
- ESP inlet gas temperature [deg.F]
- Gas flow [acfm]
- Dust load [lb/MMBtu]
- Dust load [gr/scft] or [gr/acft]

ESP OPERATION

Electrical Power Readings

- Primary voltage [V, ac]
- Primary current [A, ac]
- Secondary voltage [KV, dc] or [KV/in]
- Secondary current [mA , dc] or [mA/1000 ft³]
- Spark rate [SPM]
- V/I data or graphs
- Historical data
 - Air load data
 - Operating data

ESP OPERATION

Electrical Power Readings

- Secondary voltage and plate-to plate spacing:

Spacing [in]	Voltage [KV avg.]
9	45
10	50
12	55
16	80

- Increases with plate spacing
- Decreases in direction of gas flow after 1st field
- Should be about equal for bus sections in parallel

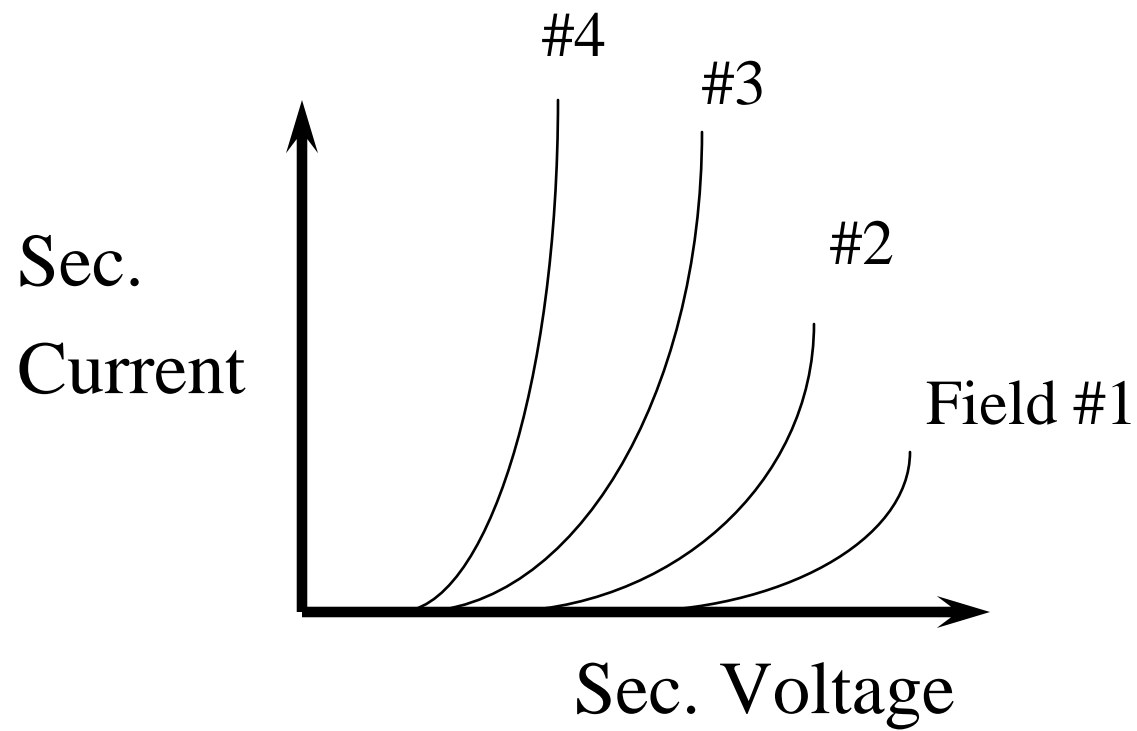
ESP OPERATION

Electrical Power Readings

- Expected readings for secondary current:
 - First field 20 - 30 mA/1000 ft² plate area
 - Second field 30 - 60 mA/1000 ft²
 - Third field 40 - 80 mA/1000 ft²
 - Fourth field 50 - 100 mA/1000 ft²
- Varies for different types of discharge electrodes
- Should be about equal for bus sections in parallel

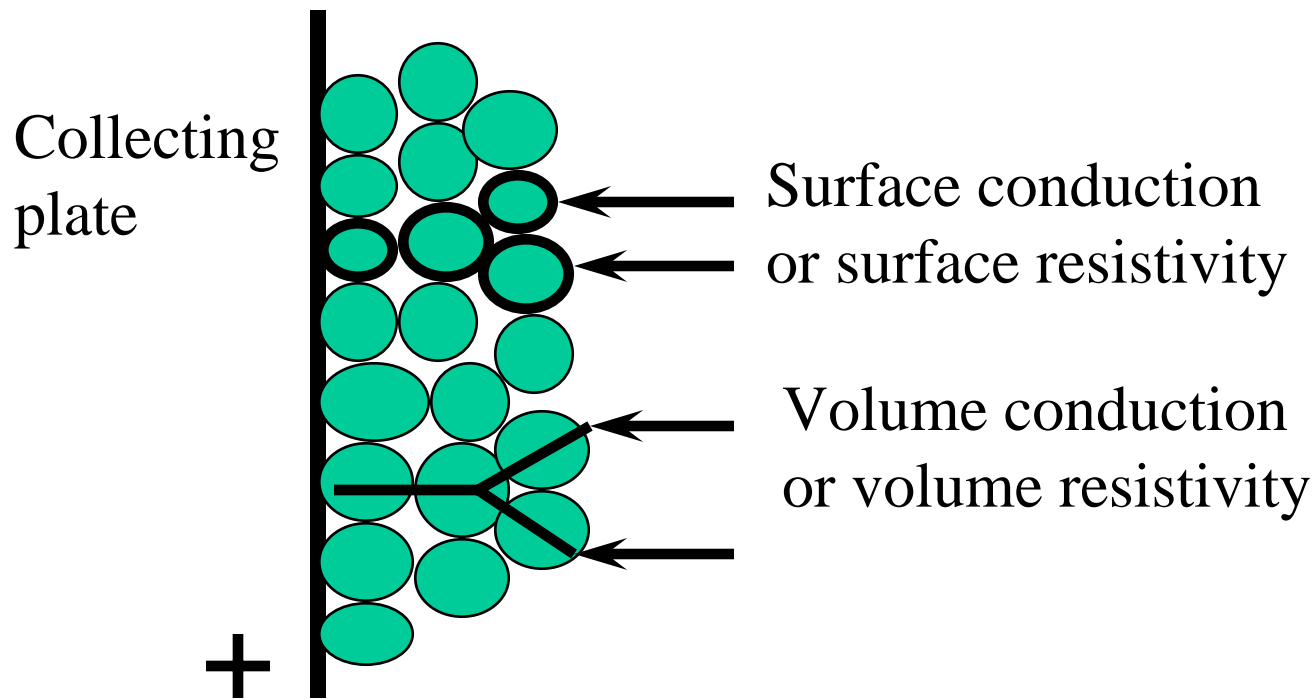
ESP OPERATION

Electrical Power Readings



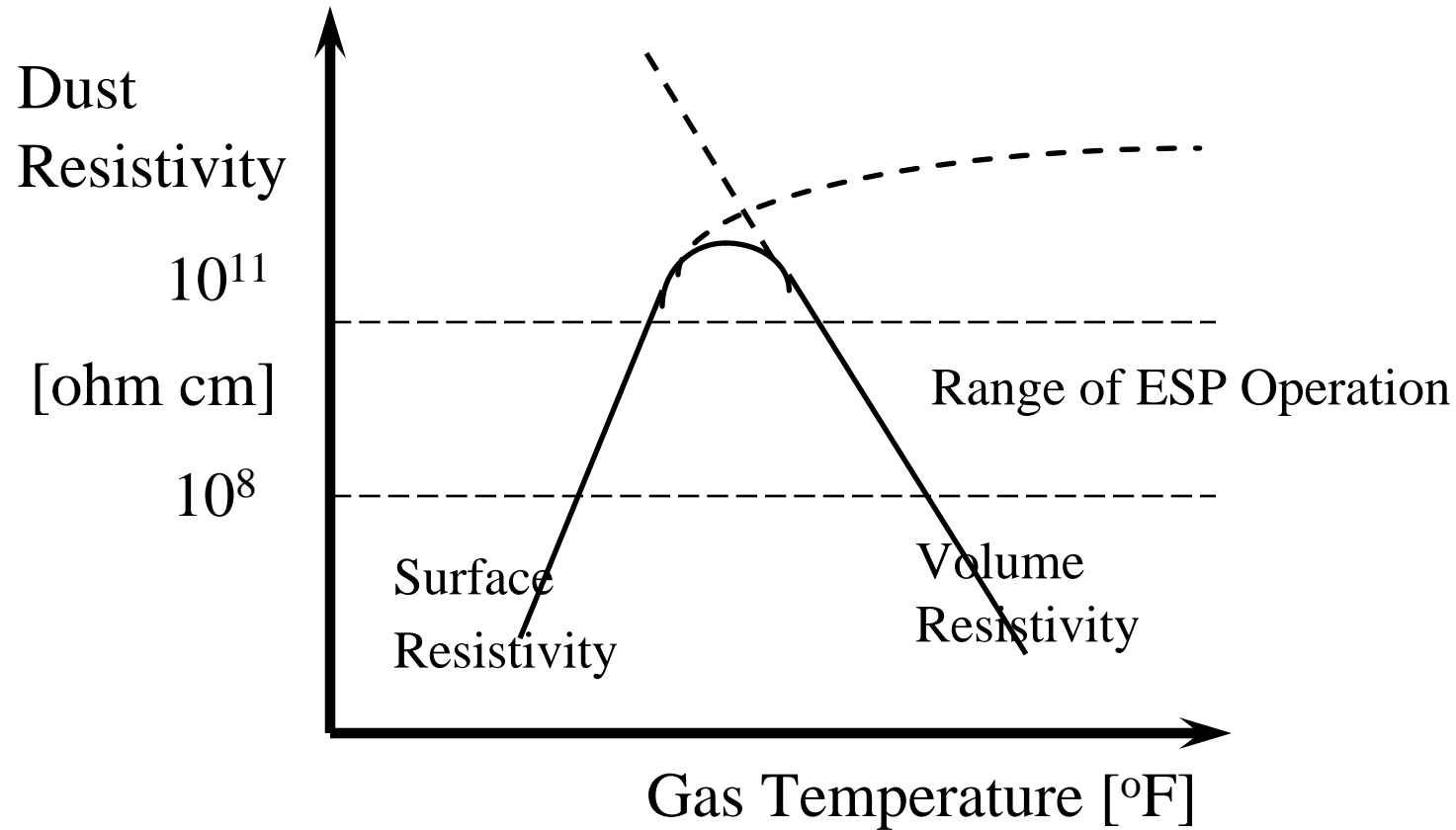
ESP OPERATION

Specific Dust Resistivity



ESP OPERATION

Specific Dust Resistivity



ESP OPERATION

Specific Dust Resistivity

- Effects of high resistivity:
 - Back corona, bi-polar charging of particles
 - Loss of collecting efficiency
 - Reentrainment
- Remedies:
 - Adjustment of corona voltage
 - Use of intermittent energization
 - Flue gas conditioning with H_2O , SO_3 or NH_3 or proprietary agents

ESP OPERATION

Reentrainment

- What is it?
 - Any dust particle collected on a surface inside of the ESP and reentrained into the gas flow
- Reentrainment from the outlet field
 - Collecting plate rapping
 - Sparking, Saltation, Erosion
 - Sneakage
 - Hopper loss
 - Electrical field loss

ESP OPERATION

Reentrainment

- Reduce reentrainment:
 - Fuel and boiler operation
 - Optimize electrical power levels
 - Optimize rapping system operation
 - Gas velocity distribution
 - Gas temperature distribution

ESP OPERATION

Reentrainment

- Summary:
 - Reentrainment accounts for 60 to 80% of the outlet loss of an ESP
 - Rapping reentrainment is 60 to 80% of the total reentrainment
 - Reentrainment mean particle size is smaller than average particle size
 - Reentrained dust has a higher opacity level
 - Reentrainment causes stack opacity spikes

ESP OPERATION

Other Problems

- Operational Problems:
 - Space charge effects
 - High dust load
 - Small particle size
 - High LOI
- Equipment Problems
 - Misalignment
 - Corrosion

IMPROVEMENTS

Process

- Coal
- Coal Mill
- Furnace
- Burners
- Air Preheater

IMPROVEMENTS

ESP Equipment

- Collecting surface
- Discharge electrodes
- Rapping system improvements
- Gas velocity distribution
- Upgraded automatic voltage controls
- Increased sectionalization
- Flue gas conditioning system

IMPROVEMENTS

ESP Operation

- Automatic voltage control operation
- Collecting plate rapper operation
- Discharge electrode rapper operation
- Ash handling system operation

SUMMARY

- History:
 - Electrostatic precipitation started with pioneering work at the end of the 19th and the beginning of the 20th century. Basic process steps have not changed much.
- Development:
 - Structural and mechanical design improvements were followed by the development of automatic voltage controls leading to control systems for the entire ESP.

SUMMARY (continued)

- Performance Improvements:
 - More difficult applications demanded a look at the upstream process and equipment leading to gas conditioning systems.
- Future Work:
 - The ESP is becoming but one part of an emission control system for industrial and utility plants which will control particles, gases and air toxics.