EVE 402
Air Pollution Generation and Control

Chapter #5 Lectures (Part 7)

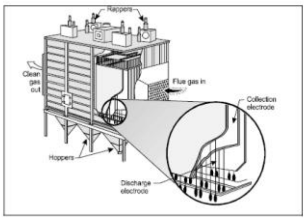
Electrostatic Precipitators (ESPs)

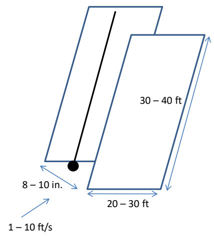
- The process of electrostatic precipitation involves
  - The ionization of contaminated air flowing between electrodes
  - The charging, migration, and collection of particles on oppositely charged plates
  - The removal of the particles from the plates
- ESPs are unique because the forces of collection act only on the particles (not the gas stream)

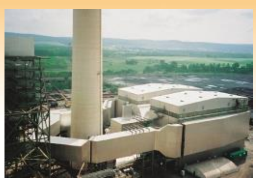
Characteristic Ranges

- Q_v: 100 – 4 x 10^6 ft^3/min
- d_p: 0.05 – 200 μm
- η: 90 – 99.9%
- ΔP: 0.1 – 0.5 in water (0.25 – 1.25 mbar)
- Temperature: up to 1200 °F (920 K)

The particles pass through a volume that has a large electrical potential (~ 50 kV) applied across a spacing of about 25 cm. The large field strength (electrical potential/distance between collection electrodes) causes the release of free electrons from the discharge electrode.



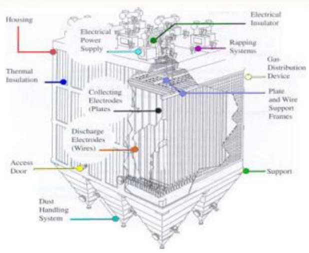




A few industrial applications for ESPs

- Refuse & sewerage sludge dryers and incinerators
- Coal- and oil-fired boilers, coal driers and coal mills
- Production plants for the cement, limestone, gypsum, pulp and paper industry (kilns, mills, driers and coolers)
- Electro-metallurgical, chemical, gas and detergent manufacturing plants
- SO_2, SO_3, acid mist and ammonia control (wet ESPs)

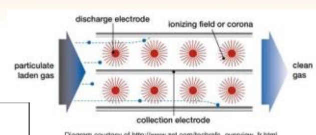
Inside an ESP

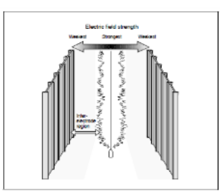


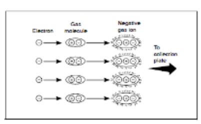
Source: http://www.neundorfer.com

At the core of the apparatus, electrodes at high voltage create a corona effect (ionizing atmosphere) surrounding them. This charges the passing particles. Once charged, particles are subjected to a transverse electrostatic force that pulls them toward the collecting plates. Plates are periodically rapped (vibrated) to make the collected particles fall down into a hopper.

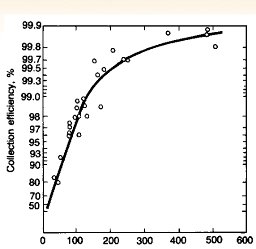
Step #1: Gas ionization







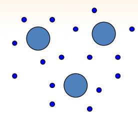
Typical efficiency of an electrostatic precipitator as a function of the corona power ratio [power (Watts) consumed per unit airflow]



Corona: the ionization of gas molecules by high-energy electrons in the region of a strong electric field

Step #2: Charging the Particles

- **Diffusion charging**: Random collisions between ions and particles ($d_p < 0.1\ \mu m$)
- **Field charging**: Direct charging due to strong electric field itself ($d_p > 1.0\ \mu m$)
- The charge on the particle is dependent on particle size, field strength, and material



Charging the Particles (2)

The total charge on a particle:

$$q = p\pi\epsilon_o E_c d_p^2$$

where,

p = dielectric factor = 3D/(D+2)

(D is the dielectric constant for the particles)

ε_o = vacuum permittivity = 8.854×10^{-12} C/V-m

E_c = strength of the charging field [V/m]

Step #3: Migration of the Particle to the Plate (Electrode)

- The speed at which the migration occurs is the *migration drift velocity* (w)
  - Depends on the electrical force on the charged particle (F_e)…

Precipitating (*collecting*) field strength

$$F_e = qE_p = p\pi\varepsilon_o E_c E_p d_p^2$$

  - …and the drag force (F_d) that develops

$$F_d = \frac{3\pi\mu_g d_p w}{K_C}$$

Step #3: Migration (2)

$$F_e = F_d \rightarrow w = \frac{p\varepsilon_o E_c E_p d_p}{3\mu_g} K_C$$

Notes:
1. The drift velocity is sensitive to changes in temperature, since $\mu_g = f(T)$
2. The actual drift velocity often differs significantly from the equation

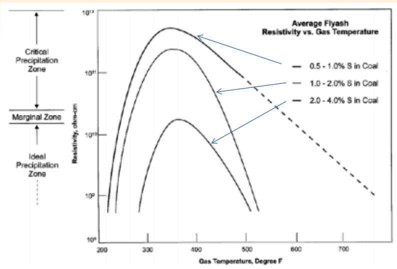
Ash Resistivity affects ESP Performance

- The degree of the ash's resistance to electrical conduction, expressed in ohms-cm
- The value of resistivity depends on the flue gas temperature, gas constituents (flue gas conditioning), and chemical composition of the ash
- $10^9 – 10^{10}$ ohm-cm is desired

Resistivity Effects

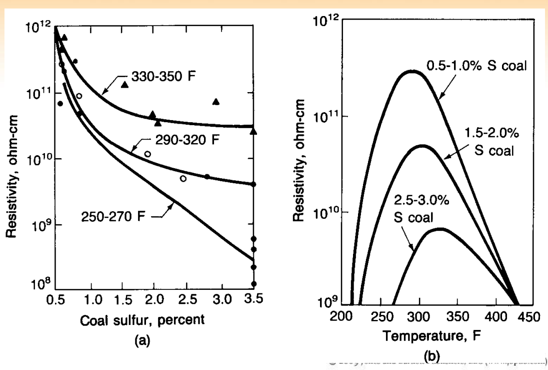
- Low Resistivity Effect ($<10^4$ ohm-cm)
  - The ash is a good conductor
  - Collected ash particles lose their charge quickly and become re-entrained into the gas stream.
- High Resistivity Effect ($>10^{10}$ ohm-cm)
  - The ash is a good insulator
  - Ionic charge is stored on the dust layer surface
  - Difficult to knock particles off the plate

The Effects of Gas Temp and Sulfur Content on Resistivity



A range of temperatures and Sulfur contents are “ideal”

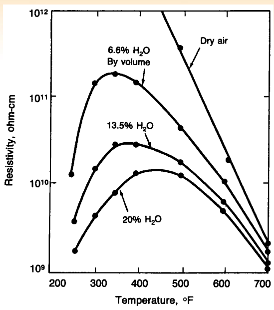
Temperature and Sulfur Content Effects (2)



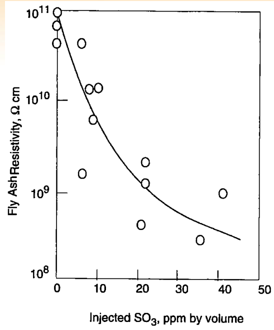
Flue Gas Conditioning

- Chemicals (conditioning agents) may be added to the flue gas to achieve resistivities in the desired range
  - Exps: SO_3(g), sodium salts, ammonium salts
- Conditioning is extremely important in the cement industry
  - Water is used; careful temp control, proper nozzle design and spacing are crucial

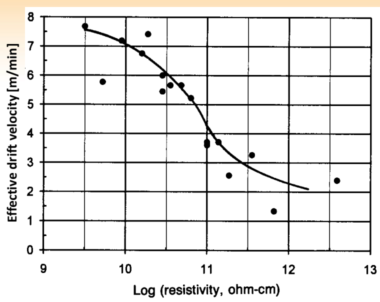
Flue Gas Conditioning (2)



Water spray for cement kiln dust



Effective drift velocity as a function of resistivity



Advantages

- ESPs are very efficient (up to 99% efficiency), even for small particles
- They are generally more economical than other particulate control devices:
  - Operating costs are reduced by low energy consumption, minimal maintenance requirements and reduced cost on spare parts
- Can be designed to handle wet and dry gas compositions for a wide range of gas temperatures
- Can handle large volumes of gas flow with low pressure drop (ΔP = 0.1 to 0.5 in. H_2O)

Disadvantages

- High initial capital costs
- Dry ESPs can only control particulate emissions, not gas composition emissions
- Once installed, ESPs take up a lot of space and cannot be easily redesigned – not flexible to varying flows
- May not work properly on high electrical resistive particles

Example (ESP)

Calculate the drift velocity in m/s at 25 °C in air for particles with a diameter of (a) 0.5 μm, (b) 1.0 μm, (c) 5 μm, (d) 10 μm, and (e) 50 μm. The charging and collecting voltages are 50,000 and 40,000 respectively, and the anode-cathode spacing in 10.0 cm. Assume a dielectric factor p of 2.50, and apply the Cunningham correction as needed.

Example (ESP)

An ESP has collecting plates 3 m tall and 1 m long in the direction of flow. The spacing between the charging electrode and the collecting plate is 7.56 cm. The device is to be used to collect particles having a dielectric constant of 4 and an effective diameter of 4 mm. The carrier gas (air at 25 °C) has a velocity of 1.2 m/s. Calculate the collection efficiency for a charging voltage of (a) 10 kV, (b) 20 kV, (c) 30 kV, (d) 40 kV, and (e) 50 kV. Omit the Cunningham correction.

Example (ESP)

An ESP is used to remove glass particles having a mean diameter of 4 mm from air flowing through the collector at 4 ft/s. The precipitator is 8 ft tall and 6 ft wide with electrodes having a spacing of 6 in and a length of 3 ft in the direction of flow. The charging voltage is 20,000 V, and the dielectric constant averages 4.75. Estimate (a) the efficiency of the precipitator, (b) the efficiency if the voltage is increased to 35,000 V, and (c) the efficiency if the length of the plates is increased to 5 ft for part (a) and (b).