# Lecture 2.22

Emission Control Systems: Electrostatic Precipitators

# Agenda

- 1. Need for Particulate Emission Control
- 2. Fundamental Principles of Electrostatic Precipitation
- 3. Mechanisms of Particle Charging (Field and Diffusion Charging)
- 4. Particle Migration and Collection
- 5. Major ESP Components (Electrodes, Hoppers, Rappers)
- 6. Deutsch-Anderson Efficiency Equation
- 7. Impact of Ash Resistivity (Back Corona effect)

# Need for Particulate Emission Control

- Pulverized coal combustion generates significant amounts of fly ash, constituting 70-80% of total ash.
- Uncontrolled emission of fine particulate matter (PM10 and PM2.5) poses severe respiratory health hazards and environmental degradation.
- Stringent environmental regulations mandate collection efficiencies exceeding 99.5% for modern coal plants.
- Electrostatic Precipitators (ESPs) are the industry standard due to low pressure drop (typically 10-20 mm WC) and high collection efficiency for fine particles.
- Unlike fabric filters, ESPs can operate effectively at higher flue gas temperatures (130-170\ensuremath{^\circ}C) with minimal draft loss.

# Fundamental Principles of ESP

- An ESP relies on electrostatic forces to separate particulate matter from the flue gas stream.
- Process involves four primary steps: Corona generation, Particle charging, Particle migration, and Dust removal.
- A high negative DC voltage (typically 30 kV to 100 kV) is applied to the discharge electrodes.
- Collecting electrodes are grounded (zero potential), creating a strong, non-uniform electric field between the electrodes.
- The high electric field strength near the discharge electrode ionizes the gas, creating a corona discharge.
- Free electrons migrate toward the grounded plates, colliding with and attaching to gas molecules, forming negative ions.

# Corona Generation and Particle Charging

- Field Charging: Dominant for particles ¿ 1 µm. Negative ions follow electric field lines and collide with dust particles. Charging rate decreases as the particle's charge repels further ions (saturation charge).
- Diffusion Charging: Dominant for ultrafine particles ¡ 0.2 µm. Driven by thermal kinetic motion of gas ions colliding with particles, regardless of electric field lines.
- Saturation Charge (Q) depends on particle radius (a), permittivity, and the applied electric field (E0).
- For the critical PM2.5 to PM10 range, field charging is the primary mechanism.
- Gas ionization zone is confined to a few millimeters around the discharge wire; the rest of the inter-electrode space is the transport and charging zone.

# Particle Migration and Collection Mechanism

- Once charged, particles experience a Coulombic force (Fe = Q * E) pulling them toward the grounded collecting plates.
- This electrical force is opposed by the aerodynamic viscous drag force (Stokes' drag) of the flue gas.
- Particles reach terminal velocity, termed 'Migration Velocity' (w), where electrostatic force equals drag force.
- w = (Q * Ep) / (6 * pi * viscosity * radius), where Ep is the collection field strength.
- Migration velocity is a critical design parameter; higher w implies faster collection and allows for smaller ESP size.
- Upon reaching the grounded plate, particles lose some charge but adhere to the plate due to cohesive and Van der Waals forces.

# Major ESP Components

- Discharge Electrodes (DE): Emitting wires/rigid masts carrying high negative DC voltage. Various designs: round wire, barbed wire, star-shaped, or rigid frame.
- Collecting Electrodes (CE): Grounded steel plates, typically 10-15 meters high. Often profiled with baffles to create quiescent zones that prevent re-entrainment of dust.
- Transformer-Rectifier (TR) Sets: Step up utility voltage (e.g., 415V AC) to high voltage (e.g., 70-100kV AC) and rectify it to DC using silicon bridge rectifiers.
- Rapping System: Mechanical or electromagnetic hammers that periodically strike DEs and CEs to dislodge the accumulated ash.
- Ash Hoppers: Pyramidal bins located at the bottom of the ESP to collect dislodged ash. Usually equipped with heaters to prevent moisture condensation and ash bridging.

# Discharge and Collecting Electrodes Design

- Discharge Electrodes must have sharp edges or small radii to generate intense localized electric fields for corona onset.
- Rigid Discharge Electrodes (RDE) are preferred over weighted wires in modern plants due to higher reliability and resistance to breakage from sparking.
- Collecting Electrodes are spaced typically 300 mm to 400 mm apart. Wider spacing allows higher operating voltages and reduces specific collection area (SCA) requirements.
- CE profiles (e.g., G-profile, C-profile) are aerodynamically designed to shield the collected dust layer from the scouring action of the main gas stream.
- Precise alignment between DEs and CEs is crucial; misalignment reduces spark-over voltage, limiting the maximum operating voltage and reducing efficiency.

# Rapping Systems and Re-entrainment

- Ash layers on collecting plates must be periodically dislodged into hoppers to maintain electrical clearances and prevent voltage drop across the ash layer.
- Rapping generates high-frequency shear forces (accelerations up to 200g) on the plates, causing the ash to fall as cohesive agglomerated sheets.
- If ash falls as dispersed powder, it is re-entrained by the gas flow (Rapping Re-entrainment), severely lowering overall efficiency.
- Rapping schedules (frequency and intensity) are optimized per electrical field; inlet fields collect the most ash and are rapped frequently, while outlet fields are rapped rarely.
- Discharge electrodes also require mild rapping to remove insulating ash buildup that quenches corona emission.

# ESP Efficiency: Deutsch-Anderson Equation

- The theoretical collection efficiency of an ESP is described by the Deutsch-Anderson equation.
- Efficiency (\ensuremath{\eta}) = 1 - exp(- (A * w) / Q)
- Where A = Total collection area (m^2)
- w = Effective particle migration velocity (m/s)
- Q = Volumetric flue gas flow rate (m^3/s)
- The ratio (A/Q) is termed the Specific Collection Area (SCA).
- SCA is the primary sizing parameter for an ESP. Higher SCA yields higher efficiency but implies a larger, more expensive ESP footprint.
- The equation assumes ideal conditions: uniform gas distribution, no re-entrainment, and infinite lateral mixing.

# Ash Resistivity and Performance Issues

- Ash resistivity (ohm-cm) governs how easily collected dust dissipates its charge to the grounded plate.
- Ideal resistivity range: 10ˆ8 to 10ˆ10 ohm-cm.
- Low Resistivity (¡ 10ˆ8 ohm-cm): Particles lose charge instantly upon hitting the plate and re-entrain into the gas stream (common with high unburned carbon).
- High Resistivity (¿ 10ˆ11 ohm-cm): Typical of low-sulfur coals. Ash layer acts as an insulator.
- Back Corona (Reverse Ionization): High resistivity causes massive voltage drop across the ash layer. Dielectric breakdown of the ash layer occurs, emitting positive ions.
- Positive ions neutralize negatively charged particles in the gas stream, drastically dropping collection efficiency.

# Summary

- ESPs are essential for high-efficiency particulate removal with minimal draft loss in thermal power plants.
- Operation depends on corona generation, electrostatic charging, and migration of particles to grounded plates.
- Proper sizing is determined by the Specific Collection Area (SCA) and migration velocity via the Deutsch-Anderson equation.
- Electrode design, precise alignment, and optimized rapping systems are critical for sustained performance.
- Ash resistivity drastically impacts efficiency, with back corona being a major limitation when burning low-sulfur coals.

# Next Lecture Preview

- Topic: Gaseous Emission Control Systems
- Focus on Flue Gas Desulfurization (FGD).
- Wet scrubbers and dry sorbent injection techniques.
- Selective Catalytic Reduction (SCR) for NOx control.
- Integration of ESPs with downstream FGD systems.