Operation Of Electrostatic Precipitators (ESPs)

Introduction

Electrostatic precipitators have been used for over half a century to control particulate emissions in many industries. They have a very high collection efficiency—sometimes exceeding 99 percent—and can handle large exhaust-gas volumes at high temperatures. This makes them very attractive to industries, such as cement plants and steel mills, that produce high-temperature flue gases.

ESPs handle large exhaust gas volumes.

Electrostatic Precipitator (ESP) System Components

All ESPs (Figure 10-1) contain six essential components: **discharge electrodes, collection electrodes, electrical systems, rappers, hoppers,** and a **shell**.

All ESPs contain six essential components:

- *Discharge electrodes*
- *Collection electrodes*
- *Electrical systems*
- *Rappers*
- *Hoppers*
- *Shell*

Discharge electrodes impart an electrical charge (usually negative) to particles in a gas stream. The electrodes are usually small-diameter wires that hang vertically in the ESP or are attached to rigid frames. They can, however, be rigid masts or plates with needle strips.

Collection electrodes collect the charged particles. They can be either tubes or flat plates, and they have a charge opposite to that of the discharge electrodes.

Electrical systems (also called transformer-rectifier, or T-R, sets) are used to control the strength of the electric field between the discharge and collection electrodes.

Rappers are mechanisms that provide vibration or shock to both the collection and discharge electrodes. The vibration/shock causes the particles attached to these electrodes to fall into hoppers.

Hoppers are bins used to collect and temporarily store the particles removed during rapping. They are located at the bottom of an ESP.

The shell encloses the electrodes and supports the precipitator components in a rigid frame to maintain proper electrode alignment and configuration. The shell is covered with insulation to conserve heat and prevent corrosion. The outer shell wall is usually made of steel.

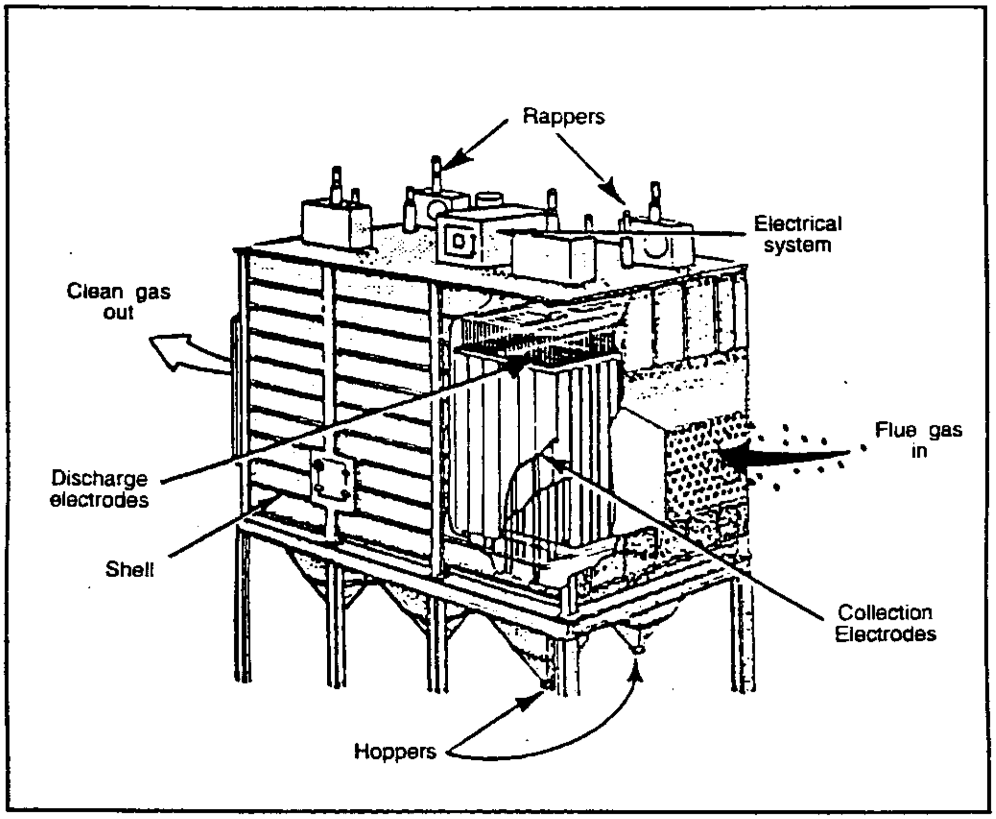

Figure 10-1. A Typical ESP

ESP System Operation

Particles are charged, attracted to oppositely charged surfaces, and removed by rapping (in dry ESPs) or water sprays (in wet ESPs)

The basic process underlying ESP operation is that pollutant particles in a gas stream are electrically charged (usually with a negative charge), which causes them to migrate toward and attach themselves to collection plates or tubes that are oppositely charged. The collection and discharge electrodes are then rapped (in dry ESPs) or sprayed (in wet ESPs), which causes the particles attached to the electrodes to fall into a collection hopper. (This lesson focuses on dry ESPs because they are more commonly used.) The basic process is accomplished in the following manner.

A high-voltage direct current is applied to a discharge wire (electrode), negatively charging it. Voltage to the wire is increased until a corona (a visible electric discharge) is produced around the wire. As the particle-laden flue gas passes through the corona, the particles contained in the flue gas become negatively charged. Because the discharge electrodes are negatively charged and the collection electrodes are positively charged, a strong electrical field is created between them. This electrical field propels the negatively charged particles toward the positively charged collection electrodes, where the particles attach themselves.

From Where Does The High-Voltage Direct Current That Is Necessary For Electrostatic Precipitation Come?

Current from a standard power source is usually low-voltage alternating current. The transformer (in the T-R set) steps up the voltage from the standard 220 to 480 volts (modern precipitators usually use 400 to 480 volts) to 20,000 to 70,000 volts. The rectifier part of the set converts this alternating current (a.c.) to direct current (d.c.).

What Is Sectionalization?

The discharge electrodes are arranged in fields, each powered by its own T-R set. This electrical partitioning, also known as **sectionalization**, is used primarily because power input requirements differ at various locations within a precipitator. To adequately charge the incoming particles, more power is needed at the inlet sections (where high dust concentrations can suppress corona current). High power is also needed at the outlet sections to collect small particles that exhibit high resistivity (resistance of a particle to accepting a charge). But, in the downstream fields, where dust loading is usually lighter, high power would create excessive sparking, so lower power is needed. If only one T-R set were used in a precipitator, power input would have to be limited (to avoid the excessive sparking), and thus, the efficiency of the entire unit would be reduced.

Partitioning (or sectionalization) allows for operation at optimum electrical conditions and allows the unit to be isolated for diagnosis and repair.

Typically, a number of fields are arranged in a series along the gas flow path (Figure 10-2). Some large ESPs are also divided into parallel chambers (Figure 10-3).

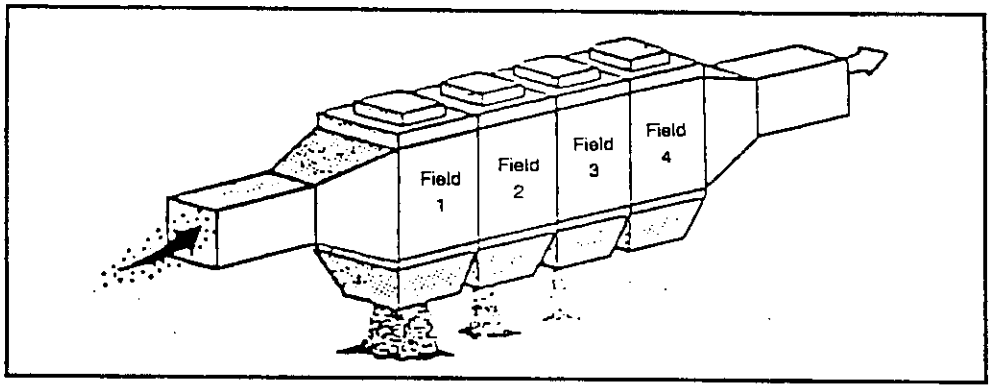

Figure 10-2. Field, Or Stage, Sectionalization

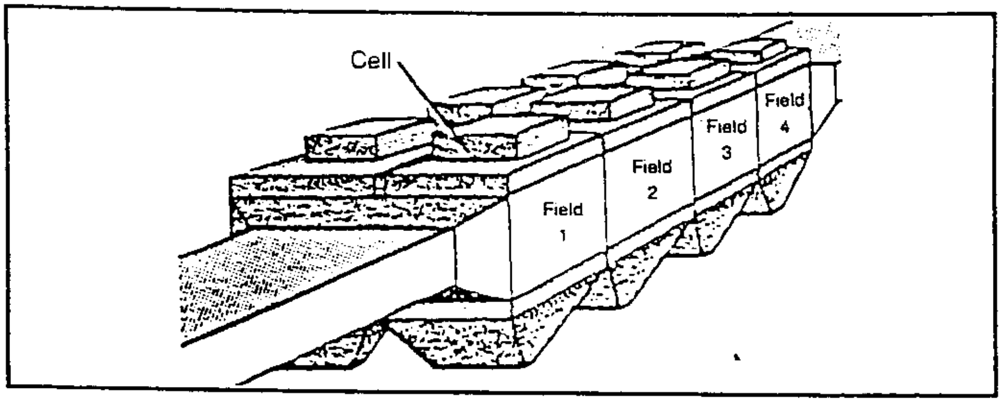

Figure 10-3. Parallel Sectionalization

Sectionalization also isolates possible internal problems to one T-R set without affecting the performance of the other power supplies.

What Meters Are Usually Found On An ESP?

The most commonly monitored electrical conditions are:
- *Primary voltage*
- *Primary current*
- *Secondary voltage*
- *Secondary current*
- *Spark rate*

Each T-R set energizes the discharge electrodes within its associated field, and each T-R set is connected to its associated discharge electrodes by an electric cable referred to as a bus line. The electrical conditions within these power supplies and within their associated fields are monitored by gauges on the T-R control cabinets. The most commonly monitored electrical conditions are the **primary voltage, primary current, secondary voltage, secondary current,** and **spark rate.** (Many older models, however, do not monitor the secondary voltage.)

The meters used to monitor these electrical conditions are **primary voltmeters, primary ammeters, secondary voltmeters, secondary ammeters,** and **sparkmeters.**

Primary voltmeters measure, in a.c. volts, the voltage coming into the transformer. They are referred to as "primary" because the power line supplying the current is connected to the primary (inlet) side of the transformer portion of the T-R set.

Primary ammeters measure, in amperes, the amount of current drawn across the transformer.

The primary voltage and current readings indicate the amount of power coming into the T-R set for a particular section of the ESP.

Secondary voltmeters measure, in d.c. volts, the operating voltage delivered to the discharge electrodes. These meters are located between the output side (hence the term "secondary") of the rectifier portion of the T-R set and the discharge electrodes.

Secondary ammeters measure, in milliamperes, the current supplied to the discharge electrodes. These meters are located on the output side of the rectifier portion of a T-R set.

The secondary voltage and current readings indicate the amount of power coming from the T-R sets and going to the discharge electrodes.

Spark meters measure the number of sparks per minute in a section of the precipitator. The sparks are localized surges of electric current that occur between the discharge and collection electrodes.

How Do These Electrical Conditions Indicate System Performance?

The ESP's performance can be evaluated by comparing the secondary currents, secondary voltages, and spark rates against baseline values. If the unit does not have secondary voltage meters, similar analyses can be conducted using the primary currents, primary voltages, secondary currents, and spark rates. To perform a valuable performance review, the inspector must analyze data from all fields of the ESP.

Performance of an ESP can be evaluated by comparing secondary currents, secondary voltages, and the spark rate to baseline values for these parameters.

The ESP should operate at maximum primary and secondary voltages. The factors that determine the actual voltages in each of the fields include the T-R set design, the internal physical dimensions, the internal faults, the dust resistivities, and the gas-stream characteristics. Although some variability in voltages is inevitable, major decreases in the voltages clearly indicate operating problems. The secondary current data and the spark rate data are useful in identifying general problems.

An ESP should operate at the maximum possible primary and secondary voltages.

Major decreases in voltage are an indication of operating problems.

Other indicators of system performance include gas temperatures, fuel sulfur content (if applicable), conditioning system operating conditions (if applicable), particle composition analyses, and rapping reentrainment spike timing. These data must be evaluated to determine the extent to which the overall resistivity is varying and to determine the extent to which resistivity varies in specific chambers of the ESP.

Conditions That Cannot Be Measured Directly

Some factors that affect system performance cannot be measured directly. These include resistivity, gas velocity, rapping, and air infiltration.

Resistivity

One important operating variable that cannot be directly measured is the **resistivity** of the dust layer on the collection plate. The resistivity can alter the electrical operating conditions of a field and can also affect the amount of material released as a puff during collection plate rapping. For ESPs operating at relatively low gas temperatures, resistivity is strongly influenced by gas temperature; changes of 20 to 30 °F are often sufficient to modify the unit's overall particle removal efficiency. Units operating at higher temperatures are less sensitive to gas temperature.

Although resistivity of the dust layer on the collection plate is an important operating variable, it cannot be measured directly.

Although it is not possible for an inspector to determine the resistivities during the inspection, it is possible to identify the general range of resistivity as low, moderate, or high. This is done by observing the field-by-field changes in voltages, currents, and spark rates.

If resistivity is moderate or high, the power input to the chamber (compared to the baseline power) can be used to measure indirectly the removal efficiency.

Power input can be calculated by multiplying the secondary current by the secondary voltage (P = I x V).

If the resistivity of particles collected in a given chamber is moderate or high, the power input to the chamber is a useful indirect index of the particle-removal efficiency. The power (P) input can be calculated by multiplying the secondary current (I) by the secondary voltage (V) for each field (P = I x V) and adding these values for the entire chamber. If the secondary voltage data are not available, the power input can be approximated by multiplying the primary voltage by the primary current and then multiplying that figure by an arbitrary adjustment factor of 0.75. If the power input for a single chamber or a number of chambers has dropped substantially (relative to the baseline values), the particle-removal efficiency has probably decreased.

If the resistivity is low, power input is not a meaningful indicator. Rapping conditions, gas flow conditions, and boiler load are used to determine the emission rates.

Gas Velocity

Gas velocity is also an important parameter that cannot be measured directly.

The gas velocity through the ESP is an important indicator of potential ESP problems, but it, too, cannot be directly measured. An increase in the velocity decreases the time available for some of the small particles to pass across the space between the discharge electrodes and collection plates. Increases in gas velocity also result in more particle reentrainment during discharge-electrode rapping and collection-plate rapping. Because it is impractical to conduct a pitot traverse of the large ducts during an inspection, the gas flow rate must be indirectly evaluated using process-related factors.

Variations in local gas velocities throughout the inlet of the ESP affect the particle-removal efficiency; however, there is no simple way to identify gas flow differences. This problem can be identified only by special field testing and scale-model flow tests.

Rapping

Optimum rapping intensity is a function of dust resistivity and a number of other factors.

Collection plates and discharge electrodes must be rapped at the correct intensity to remove the proper amount of material without causing large intermittent puffs of solids. The optimum rapping intensity depends on dust resistivity and a number of other factors; therefore, the optimum intensity regularly varies. Rapping system operations are checked by examining the transmissometer strip chart for possible rapping spikes; by checking for obvious puffing at the stack exit; and by checking the intensity, frequency, sequence, and operability of the rapping systems.

Air Infiltration

Most ESPs operate at a negative static pressure. Air infiltration is very possible and could lead to a number of serious conditions. Air infiltration is evaluated using the process-O_2 monitor and the stack-O_2 monitor. Points of audible air infiltration around hoppers, solid discharge valves, access hatches, expansion joints, and other spaces should be noted. When the O_2 monitors are not available, the inspection is limited to audible checks. Audible checks are not a complete survey, however, because it is difficult to safely approach many of the common sites of infiltration.

Air infiltration can lead to a number of serious problems.

Process-Related Conditions

In addition to checking ESP performance, the inspector often must evaluate any process-related conditions that could affect the overall particle-removal effectiveness. Any factors that affect the particle size distribution, the composition of fine particles, the concentration of sulfur trioxide (SO_3), the concentration of water vapor, and the gas flow rate should be evaluated. Such evaluations are difficult and time consuming and, therefore, are performed only in response to chronic and significant excess-emissions conditions.

Process-related factors, such as particle size distribution, composition of fine particles, concentration of SO_3, concentration of water vapor, and the gas flow rate, can affect overall removal effectiveness.

Typical Emission Points

The uncontrolled effluents or emissions from an ESP are usually emitted through a stack or vent that serves the ESP. Emissions can also occur at insulators, at access doors, and where corrosion and erosion have caused holes in the ESP and associated ductwork during start-up and close-down of the precipitator.

Typical Inspection Areas

The major inspection areas for an ESP system include:

- Stack or vent exits.
- Physical condition of the unit (corrosion and erosion).
- Internal physical condition (inspect only when out of service).
- Pressure gauges.
- Rapper operation.
- Electrical readings.
- Access ducts.
- Hoppers.
- Discharge valves.

Summary

Electrostatic precipitators use electrostatic attraction to control particulate matter and can handle large volumes of exhaust gas at low pressure drops. In an ESP, pollutant particles are electrically charged and then collected on collection electrodes. When the discharge and collection electrodes are rapped, the collected particles fall into a hopper and are removed.

The ESP's performance can be evaluated by comparing secondary currents, secondary voltages, and spark rates against baseline values. Other indicators of system performance include gas temperatures, fuel sulfur content, conditioning system operations, particle composition analyses, and rapping reentrainment spike timing.

Review Exercises

1. The basic components of a dry ESP are:

   a. Discharge electrodes
   b. Collection electrodes
   c. Electrical systems
   d. Rappers
   e. Hoppers
   f. Shell
   g. All of the above

2. In an ESP,______ are used to control the strength of the electric field generated between the discharge and collection electrodes.

   a. T-R sets
   b. Spark rates
   c. I-V curves
   d. Primary voltages

3. Rappers are commonly used for:

   a. Removing dust from discharge and collection electrodes.
   b. Removing dust from collection electrodes only.
   c. Storing discharge electrode voltage.

4. Discharge electrodes are:

   a. Used to impart a charge to particles in the "dirty" gas.
   b. Usually small diameter wires that hang vertically between collection plates.
   c. Arranged in a field, each powered by its own T-R set.
   d. All of the above.

5. The most important types of data used to evaluate an ESP are:

   a. The gas flow rate and the stack opacity.
   b. The gas inlet temperature, the gas flow rate, and the opacity.
   c. The T-R set electrical data and the opacity.
   d. The rapper intensities and the rapper frequencies.

6. The voltage on the discharge electrode is the:

   a. Primary voltage
   b. Secondary voltage
   c. None of the above

7. True or false? ESPs should operate at the maximum possible voltages.

8. If the resistivity for a given chamber is moderate or high, the ______ is/are a useful indirect index of the particulate removal efficiency.

   a. Power input to the chamber
   b. Rapping conditions
   c. Gas flow conditions
   d. Boiler load

9. If the resistivity for a given chamber is low, _______ primarily determine(s) the emission rates.

   a. Power input to chamber
   b. Rapping conditions
   c. Gas flow conditions
   d. Boiler load
   e. b, c, and d
   f. a, c, and d

10. True or false? Increases in gas velocity result in more reentrainment of particles during rapping.

Answers

1. g. All of the above
2. a. T-R sets
3. a. Removing dust from discharge and collection electrodes.
4. d. All of the above.
5. c. The T-R set electrical data and the opacity.
6. b. Secondary voltage
7. True
8. a. Power input to the chamber
9. e. b, c, and d
10. True