Construction, Working, Operation and Maintenance of Electrostatic Precipitators (ESPs)

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Committed to improve the Quality of Life

The information contained in this booklet represents a significant collection of technical information on construction, working, operation and maintenance of electrostatic precipitators (ESPs). This information will help to achieve increased reliability at a decreased cost. Assemblage of this information will provide a single point of reference that might otherwise be time consuming to obtain. Most of information given in this booklet is mainly derived from the literature on the subject indicated in the reference list given at the end of this booklet. For more information, please refer them. All information contained in this booklet has been assembled with great care. However, the information is given for guidance purposes only. The ultimate responsibility for its use and any subsequent liability rests with the end user. Please see the disclaimer uploaded on http://www.practicalmaintenance.net.

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Content

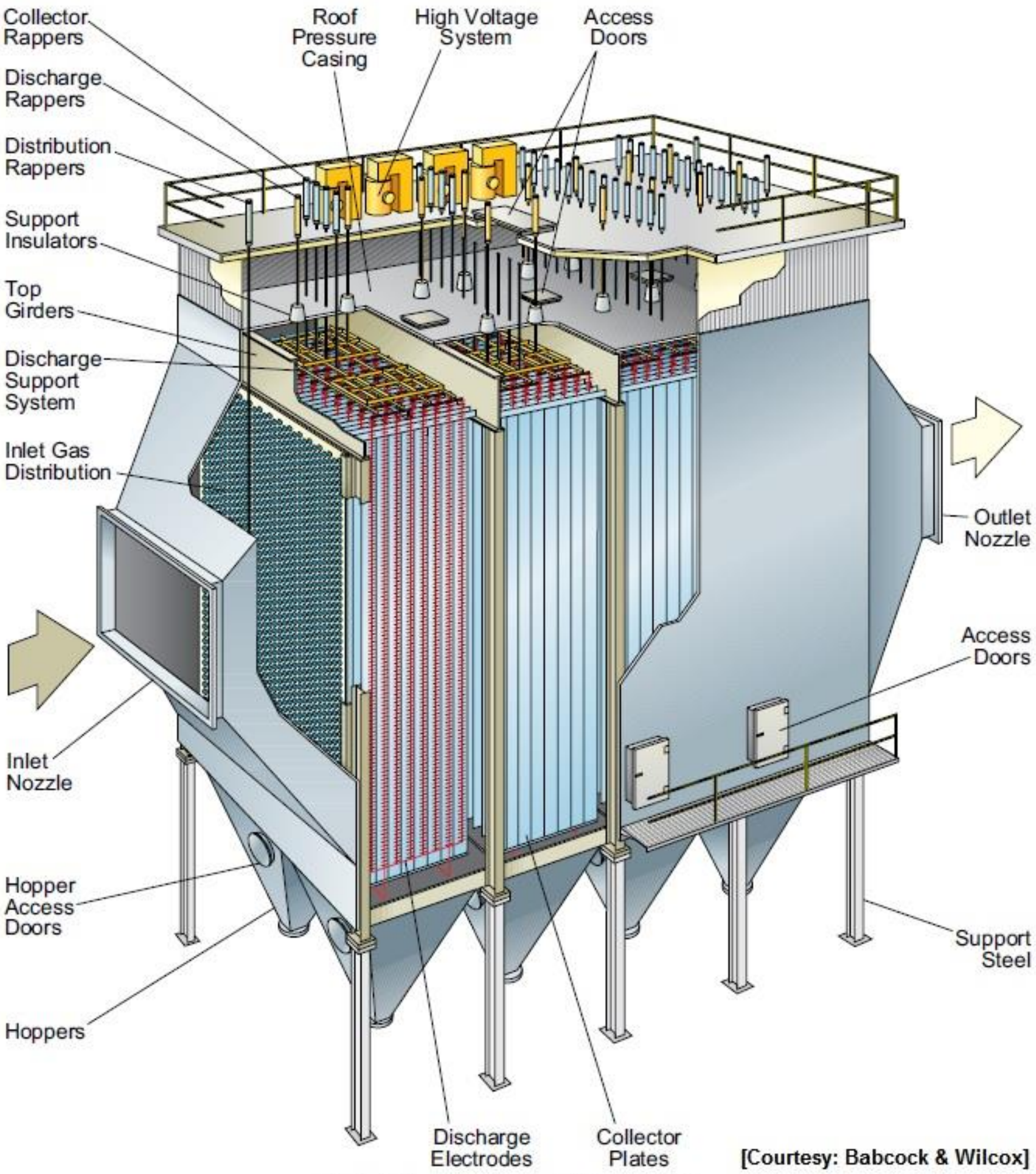
Introduction

Many industrial, power generation and chemical processes produce unwanted fine particulate material as a consequence of their operation. Electrostatic precipitation (ESP) is a highly efficient method of removing entrained particulate contaminants from exhaust gases and is extensively used in these industries to limit particulate emissions. In view of this, information on construction, working, design, erection, commissioning, operation and maintenance of electrostatic precipitators; and emission standards is given in this booklet.

Construction and Working of Electrostatic Precipitators

Information on construction and working of electrostatic precipitators (ESPs) is given in this chapter.

Construction of Electrostatic Precipitator



Typical Dry Electrostatic Precipitator

Above figure shows construction of a typical dry electrostatic precipitator. Detail information on various components is given in the chapter on Electrostatic Precipitator Components.

Working of Electrostatic Precipitator

An ESP works because of electrostatic attraction (like charges repel; unlike charges attract).

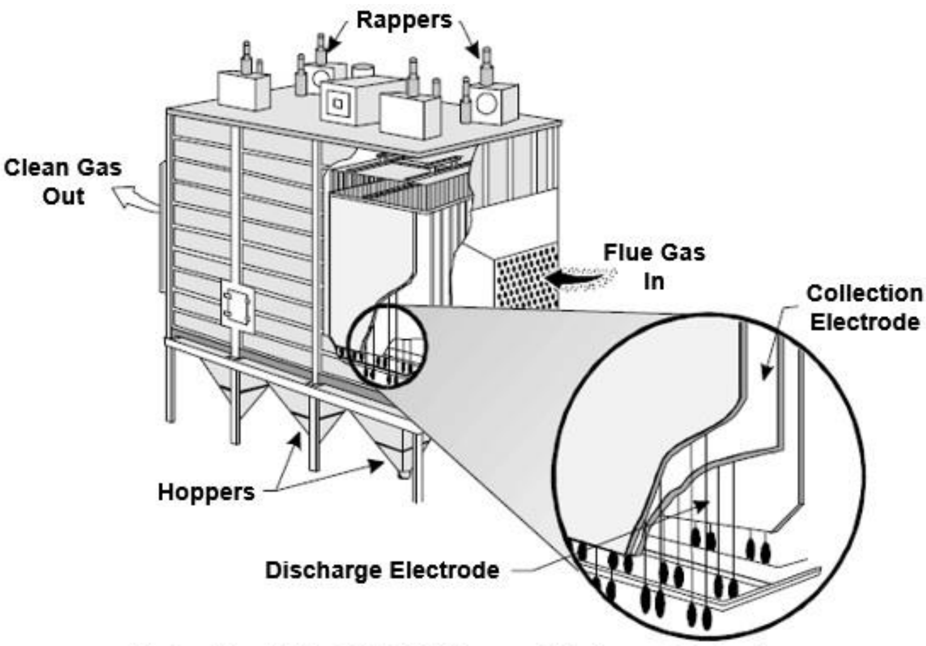
An ESP uses a high voltage electrostatic field to separate dust, fume or mist from a gas stream. The precipitator consists of vertical parallel plates (collecting plates/electrodes) forming gas passages 12 to 16 in. (30.5 to 40.6 cm) apart. Discharge electrodes are electrically isolated from the plates and suspended in rows between the gas passages.

Every particle either has or can be given a charge - positive or negative. A high voltage system provides power to the discharge electrode to generate an electrical field. The particulate, entrained in the gas, is charged while passing through the electrical field. The particulate is then attracted to the grounded collector plate, and forms a dust layer on the plate.

Periodic rapping separates the accumulated dust layer from both the collector plates and discharge electrodes (in case of wet ESP by spraying it with a liquid). The dust layer released by the rapping collects in hoppers and is removed by material / ash handling system. At many places in this article, ash is used instead of particulate matter since major application of an ESP is for ash collection.

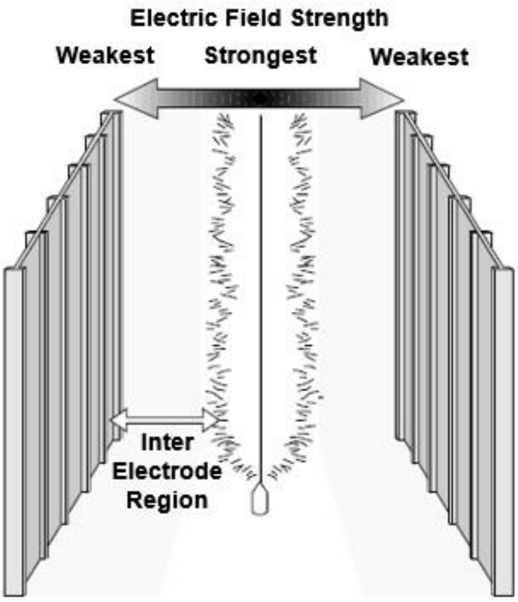
In short, charging, collecting and removing is the basic idea of an ESP. Detail information on working of an ESP is as under.

Particle Charging



Typical Dry ESP with Thin Wires as Discharge Electrodes

Above figure shows typical dry ESP having thin wires as discharge electrodes, which are evenly spaced between large plates called collection electrodes, which are grounded. An electrode is something that can conduct or transmit electricity. A negative, high-voltage, pulsating, direct current is applied to the discharge electrode creating a negative electric field. (Electrical coronas can be established at the corona electrode with either negative or positive polarity. However, generally negative corona is generated/used in industrial ESPs because negative corona systems operate at higher voltages before spark-over than positive corona under flue gas conditions in most industrial applications.) The electric field in an ESP can be mentally divided into three regions as shown in the following figure.

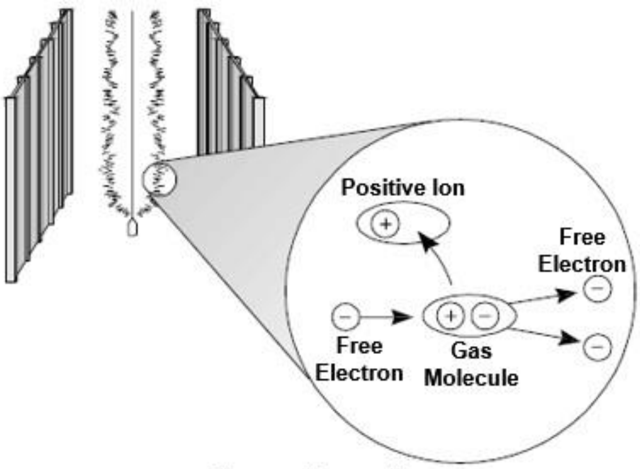


ESP Electric Field

The field is strongest near the discharge electrode, weaker in the areas between the discharge and collection electrodes called the inter-electrode region, and weakest near the collection electrode. The particle charging process begins in the region around the discharge electrode.

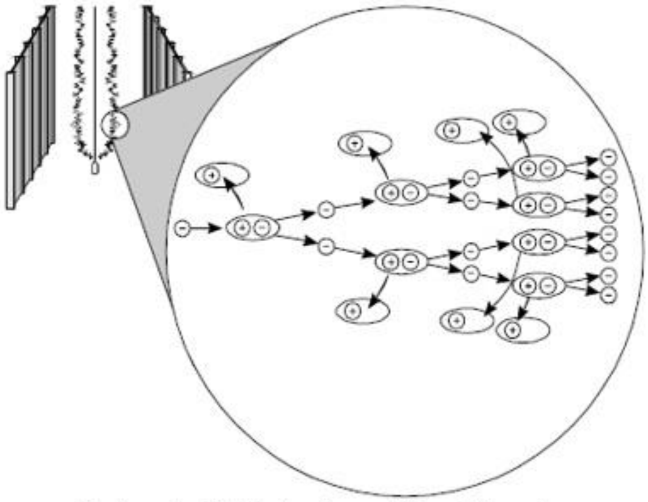
Free Electron Generation

Several things happen very rapidly (in a matter of a millisecond) in the small area around the discharge electrode. The applied voltage is increased until it produces a corona discharge (electrical breakdown of the gas so that it gets transformed from insulating to conducting state), which can be seen as a luminous blue glow around the discharge electrode.



Corona Generation

The free electrons created by the corona rapidly moves away from the negative electric field because it repulses them. They move faster and faster away from the discharge electrode. This acceleration causes them to literally crash into gas molecules, bumping off electrons from the molecules. As a result of losing an electron (which is negative), the gas molecules become positively charged, that is, they become positive ions as shown in above figure. Thus gas molecules are ionized, and electrons are liberated. This activity occurs very close to the discharge electrode.



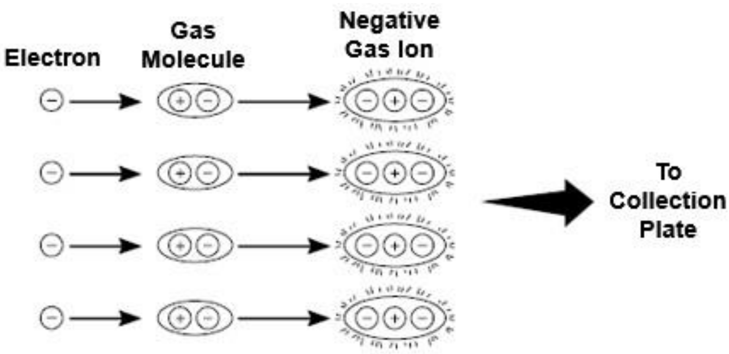
Avalanche Multiplication of Gas Molecules

As shown in above figure, this process continues, creating more and more free electrons and more positive ions. The name for all this electron generation activity is **avalanche multiplication**.

The positive ions move toward the negative discharge electrode (unlike charges attract). As the positive ions (positive gas molecules) are hundreds of times bigger than the tiny electrons, they move slowly, but they do pick up speed and many of them collide right into the metal discharge electrode or the gas space around the wire causing additional electrons to be knocked off. This is called **secondary emission**.

Ionization of Gas Molecules

As the electrons leave the strong electrical field area around the discharge electrode, they start slowing down. In the inter-electrode area, they are still repulsed by the discharge electrode but to a lesser extent. They collide with the gas molecules in the inter electrode region also, but instead of violently colliding with them, the electrons bump up to gas molecules and are captured by them as shown in the following figure. This imparts a negative charge to the gas molecules, creating negative gas ions.



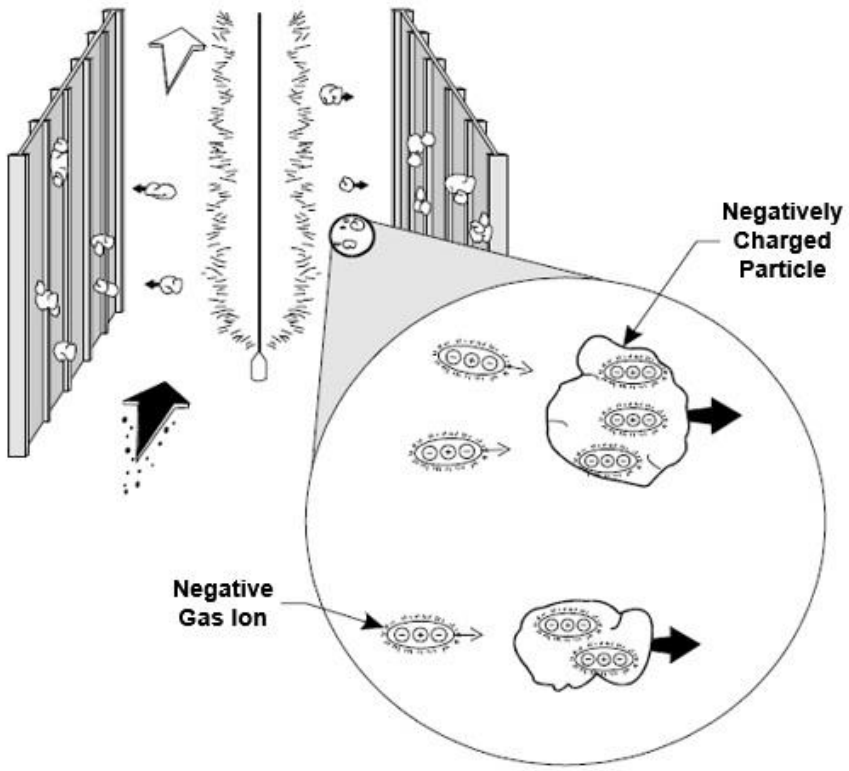
Formation of Negative Gas Ions in Inter Electrode Region

Because the ions are negative, they move in the direction opposite the strong negative field along the path of invisible electric field lines toward the collection electrode.

These negative gas ions play a key role in capturing the dust particles as explained in the following section.

Charging of Particles

The particles are traveling along in the gas stream. As they encounter (get in the way of) the negatively charged gas ions moving along the path of invisible electric field lines toward the collection electrode, the gas ions stick to the particles, imparting a negative charge to them. At first the charge is fairly insignificant as most particles are huge compared to a gas molecule. But many gas ions can fit on a particle, and they do. Small particles (less than 1 μm diameter) can absorb “tens” of ions. Large particles (greater than 10 μm) can absorb "tens of thousands" of ions. Eventually, there are so many ions stuck to the particles, the particles emit their own negative electrical field. When this happens, the negative field around the particle repulses the negative gas ions and no additional ions are acquired. This is called the saturation charge.



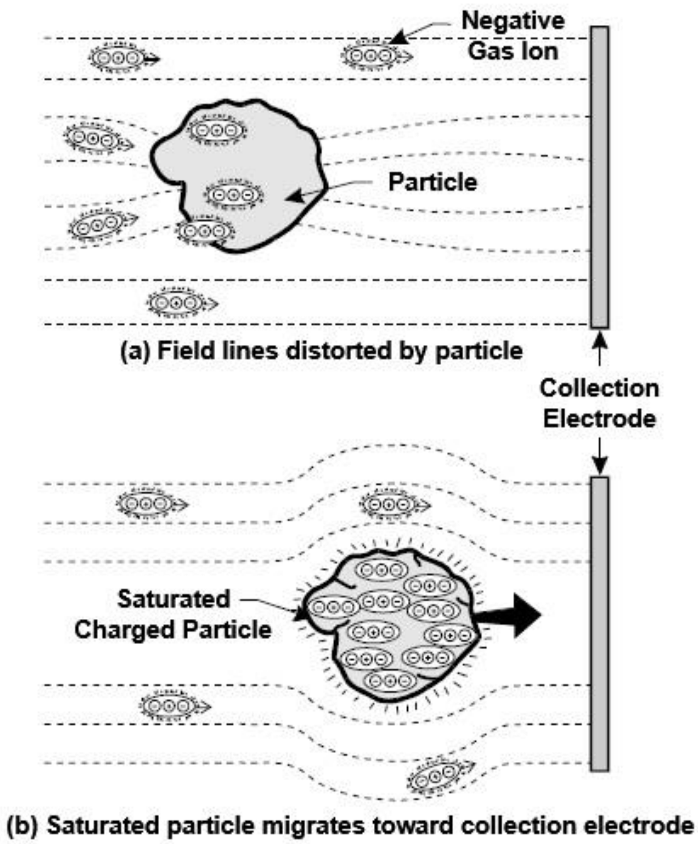
Particle Charging

Now the negatively charged particles are feeling the inescapable pull of electrostatic attraction. Bigger particles have a higher saturation charge (more molecules fit) and consequently they are pulled more strongly to the collection plate. In other words, they move faster than smaller particles. Regardless of size, the particles encounter the grounded collection plate and stick to it because of adhesive and cohesive forces as shown in above figure.

As more and more particles accumulate, they create a dust layer. This dust layer builds until it is somehow removed.

Particle Charging Mechanisms

Particles are charged by negative gas ions by one of the two mechanisms: field charging or diffusion charging. In field charging (the mechanism described above), particles capture negatively charged gas ions as the ions move toward the grounded collection plate. Diffusion charging, as its name implies, depends on the random motion of the gas ions to charge particles.



Field Charging

As shown in above figure, in **field charging**, particles cause a local dislocation of the electric field as they enter the field. The negative gas ions traveling along the electric field lines collide with the particles and impart a charge to them [as shown at (a)]. The ions continue to collide a particle until the charge on that particle is sufficient to divert the electric lines away from it [as shown at (b)]. This prevents new ions from colliding with the charged dust particle. When a particle no longer receives an ion charge, it is said to be saturated. The saturated charged particles then migrate towards the collection electrode and are collected.

Diffusion charging occurs due to the random Brownian motion of the negative gas ions. The movement of the gas ions in random motion is related to the temperature. Higher the temperature, more the movement. The negative gas ions collide with the particles because of their random thermal motion and impart a charge on the particles. In case of very small particles (sub micrometer), they do not cause local dislocation of the electric field (as in the field charging). Thus, diffusion charging is the only mechanism by which very small particles become charged. The charged particles then migrate to the collection electrode.

Each of these two charging mechanisms occurs to some extent depending on particle size. Field charging mechanism dominates for particles with a diameter greater than 1.0 micrometer and diffusion charging mechanism dominates for particles with a diameter less than 0.1 micrometer. A combination of these two charging mechanisms occurs for particles ranging between 0.2 and 1.0 micrometer in diameter.

A third type of charging mechanism, which is responsible for very little particle charging is **electron charging**. With this type of charging, fast moving free electrons that have not combined with gas ions hit the particle and impart a charge.

Electric Field Strength

Because of the high electric field applied to the ESP, in the inter-electrode region, negative gas ions migrate toward the grounded collection electrode. This forms a **space charge**, which is a stable concentration of negative gas ions in the inter-electrode region. Increasing the applied voltage to the discharge electrode will increase the field strength and ion formation until **spark-over** occurs. Spark-over refers to internal sparking between the discharge and collection electrodes. It is a sudden rush of localized electric current through the gas layer between the two electrodes. Sparking causes an immediate short-term collapse of the electric field.

For optimum efficiency, the electric field strength should be as high as possible. More specifically, ESPs should be operated at voltages high enough to cause some sparking, but not so high that sparking and the collapse of the electric field occur too frequently.

The optimum ESP voltage is achieved by an automatic voltage control (AVC). The automatic voltage control varies the power to the transformer-rectifier (T-R) set in response to signals received from the precipitator and from the transformer-rectifier itself.

The ideal AVC would produce the maximum collecting efficiency by holding the voltage on the precipitator electrodes at a value just below their ever-changing spark-over voltage. Since there is no way of determining the spark-over voltage at any given time without allowing a spark to occur, the AVC commands increasing output from the T-R set until a spark occurs.

This spark signals the AVC to reset its command lower. The AVC again commands an increasing output from this new starting point, and the cycle is repeated.

The average spark-over rate for optimum precipitator operation is between 50 and 100 sparks per minute. At this spark rate, the gain in efficiency associated with increased voltage compensates for decreased gas ionization due to reduction of the electric field.

Particle Collection

When a charged particle reaches the grounded collection electrode, the charge is slowly leaked to the grounded collection plate. A portion of the charge is retained and contributes to the inter-molecular adhesive and cohesive forces that hold the particles onto the plates. Adhesive forces cause the particles to physically hold on to each other because of their dissimilar surfaces. Newly arrived particles are held to the collected particles by cohesive forces; particles are attracted and held to each other molecularly. The dust layer is allowed to build up on the plate to a desired thickness and then the particle removal cycle is initiated.

Particle Removal

Dust that has accumulated to a certain thickness on the collection electrode is removed by a process depending on the type of collection electrode.

Tube type of collection electrodes are usually cleaned by water sprays, while plates type of collection electrodes can be cleaned either by water sprays or a process called rapping.

Rapping is a process whereby deposited, dry particles are dislodged from the collection plates by sending mechanical impulses, or vibrations, to the plates. Precipitator plates are rapped periodically while maintaining the continuous flue gas cleaning process. In other words, the plates are rapped while the ESP is on-line; the gas flow continues through the precipitator and the applied voltage remains constant.

Plates are rapped when the accumulated dust layer is relatively thick (0.08 to 1.27 cm or 0.03 to 0.5 in.). This allows the dust layer to fall off the plates as large aggregate sheets or clumps that fall by gravity into the hopper and eliminate dust reentrainment.

As the clumps fall downward, they are swept toward the outlet of the precipitator by the horizontally moving gas stream. If the clumps are too small, gravity settling is too slow to allow the clumps to reach the hopper before the gas stream carries them out of the collector. For this reason, gravity settling is an important step in particulate matter control in electrostatic precipitators.

Dislodged dust falls from the plates into the hopper. Dust should be removed as soon as possible to avoid (its) packing. Packed dust is very difficult to remove. Most hoppers are emptied by some type of discharge device and then transported by a conveyor.

In a precipitator using liquid sprays to remove accumulated liquid or dust, the sludge collects in a holding basin at the bottom of the vessel. The sludge is then sent to settling ponds or land filling areas.

Spraying occurs while the ESP is on-line and is done intermittently to remove the collected particles. Water is generally used as the spraying liquid although other liquids could be used if absorption of gaseous pollutants is also being accomplished.

Types of Electrostatic Precipitators

ESPs can be grouped/classified, according to a number of distinguishing features in their design. These features include the following:

- The structural design and operation of the discharge electrodes (rigid-frame, wires or plate) and collection electrodes (tubular or plate)
- The method of charging (single-stage or two-stage)
- The temperature of operation (cold-side or hot-side)
- The method of particle removal from collection surfaces (wet or dry)

Tubular and Plate ESPs

Tubular precipitators consist of cylindrical collection electrodes (tubes) with discharge electrodes (wires) located in the center of the cylinder. Dirty gas flows into the tubes, where the particles are charged. The charged particles are then collected on the inside walls of the tubes. Collected dust and/or liquid is removed by washing the tubes with water sprays located directly above the tubes. Tubular precipitators are generally used for collecting mists or fogs, and are most commonly used when collecting particles that are wet or sticky.

Plate electrostatic precipitators primarily collect dry particles and are used more often than tubular precipitators. Plate ESPs can have wire, rigid-frame, or occasionally, plate discharge electrodes. Charged particles are collected on the plates as dust, which is periodically removed by rapping or water sprays.

Single-stage and Two-stage ESPs

A single-stage precipitator uses high voltage to charge the particles, which are then collected within the same chamber on collection surfaces of opposite charge. Because particle charging and collection occurs in the same stage, or field, the precipitators are called single-stage ESPs. Most ESPs that reduce particulate emissions from boilers and other industrial processes are single-stage ESPs (these units are emphasized in this booklet). Single-stage ESPs use very high voltage (50 to 70 kV) to charge particles.

In a two-stage precipitator, particles are charged by low voltage in one chamber, and then collected by oppositely charged surfaces in a second chamber. The direct-current voltage applied for charging the particles is approximately 12 to 13 kV. Two-stage precipitators were originally designed for air purification in conjunction with air conditioning systems. (They are also referred to as electronic air filters).

Cold-side and Hot-side ESPs

Electrostatic precipitators are also grouped according to the temperature of the flue gas that enters the ESP: cold-side ESPs are used for flue gas having temperatures of approximately 204°C (400°F) or less; hot-side ESPs are used for flue gas having temperatures greater than 300°C (572°F).

In describing ESPs installed on industrial and utility boilers, cold side and hot side also refer to the placement of the ESP in relation to the combustion air preheater. A cold-side ESP is located behind the air preheater, whereas a hot-side ESP is located in front of the air preheater.

However, hot-side ESPs used on coal-fired boilers have some disadvantages. Because the temperature of the flue gas is higher, the gas volume treated in the ESP is larger. Consequently, the overall size of the precipitator is larger making it costlier. Other major disadvantage includes structural and mechanical problems that occur in the precipitator shell and support structure as a result of differences in thermal expansion.

Hot-side ESPs are also used in industrial applications such as cement kilns and steel refining furnaces. In these cases, combustion air preheaters are generally not used and hot side just refers to the high flue gas temperature prior to entering the ESP.

Wet and Dry ESPs

Wet ESPs are used for industrial applications where the potential for explosion is high (such as collecting dust from a closed-hood Basic Oxygen Furnace in the steel industry), or when dust is very sticky, corrosive, or has very high resistivity. The water flow may be applied continuously or intermittently to wash the collected particles from the collection electrodes into a sump. The advantage of using a wet ESP is that it does not have problems with rapping reentrainment or with back corona.

Most ESPs are operated dry and use rappers to remove the collected particulate matter. The term dry is used because particles are charged and collected in a dry state and are removed by rapping as opposed to water washing which is used with wet ESPs.

Advantages and Disadvantages of ESPs

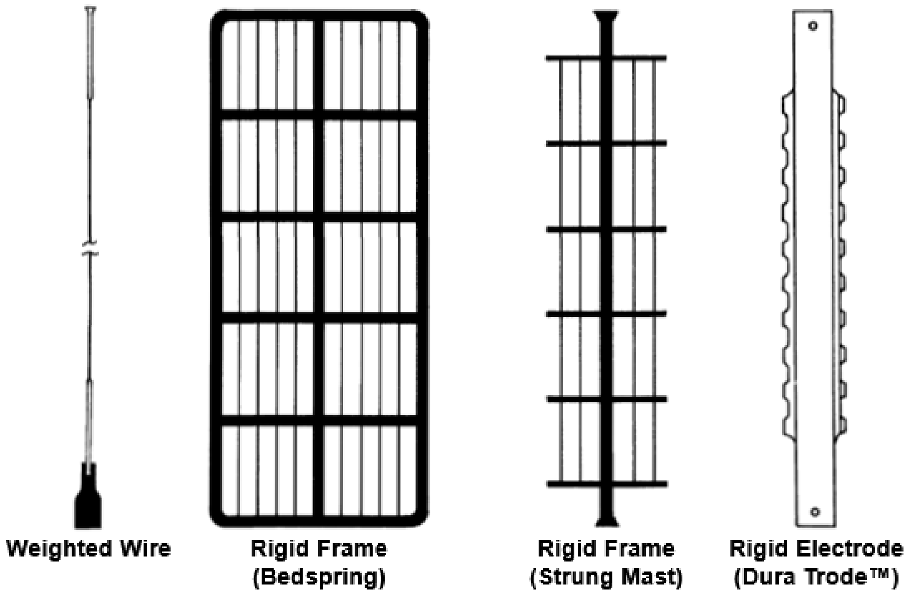
ESPs in general, because they act only on the particulate to be removed, and only minimally hinder flue gas flow, have very low pressure drops [typically less than 13 millimeters (mm), (0.5 in.) water column]. As a result, energy requirements and operating costs tend to be low. They are capable of very high efficiencies, even for very small particles. They can be designed for a wide range of gas temperatures, and can handle high temperatures, up to 700°C (1300°F). Dry collection and disposal allows for easier handling. Operating costs are relatively low. ESPs are capable of operating under high pressure [to 1,030 kPa (150 psi)] or vacuum conditions. Relatively large gas flow rates can be effectively handled. They have long useful life.

However, ESPs generally have high capital costs. Certain particulates are difficult to collect due to extremely high or low resistivity characteristics. There can be an explosion hazard when treating combustible gases and/or collecting combustible particulates. Relatively sophisticated maintenance personnel are required, as well as special precautions to safeguard personnel from the high voltage. Dry ESPs are not recommended for removing sticky or moist particles. Ozone is produced by the negatively charged electrode during gas ionization.

Electrostatic Precipitator Components

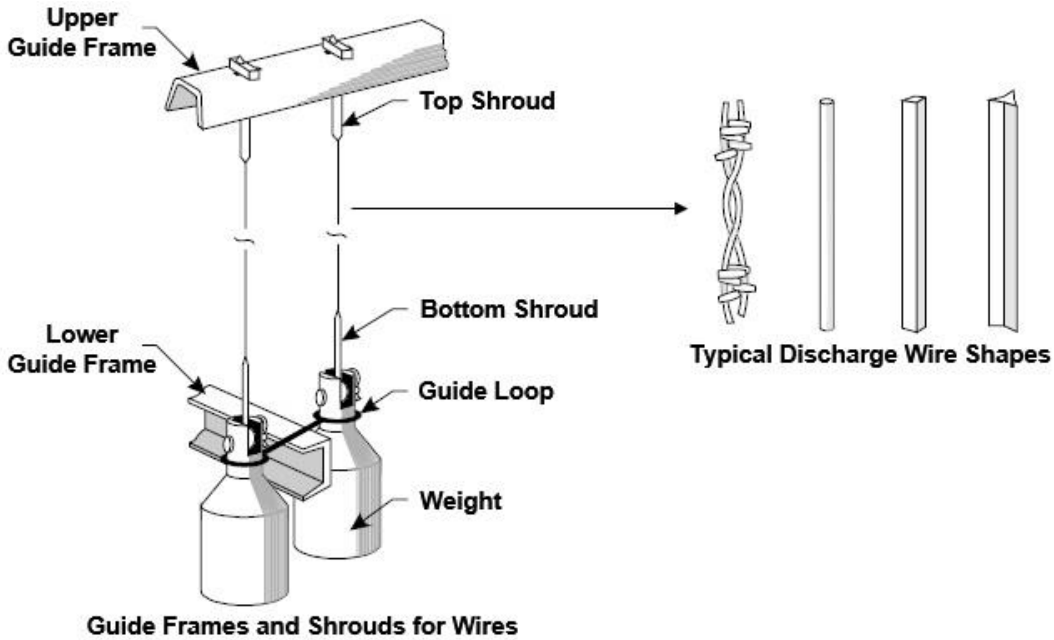
All electrostatic precipitators, regardless of their particular designs, contain: discharge electrodes, collection electrodes, rappers, high voltage electrical systems, hoppers and shell.

Discharge Electrodes



Discharge Electrode Types

Discharge electrodes are either small-diameter metal wires that hang vertically in the electrostatic precipitator (called weighted wires), a number of wires attached together in rigid frame, or a rigid electrode made from a single piece of fabricated metal. The shape of an electrode determines the current voltage characteristics; the smaller the wire or the more pointed its surface, the greater the value of current for a given voltage.



Wire Discharge Electrodes

The discharge electrodes in most U.S. precipitator designs (prior to the 1980s) are thin, round wires varying from 0.13 to 0.38 cm (0.05 to 0.15 in.) in diameter. The most common size diameter for wires is approximately 0.25 cm (0.1 in.). The discharge electrodes are hung vertically, supported at the top by a frame and held taut and plumb by a weight at the bottom. The wires are usually made from high-carbon steel, but have also been constructed of stainless steel, copper, titanium alloy, and aluminum. The weights are made of cast iron.

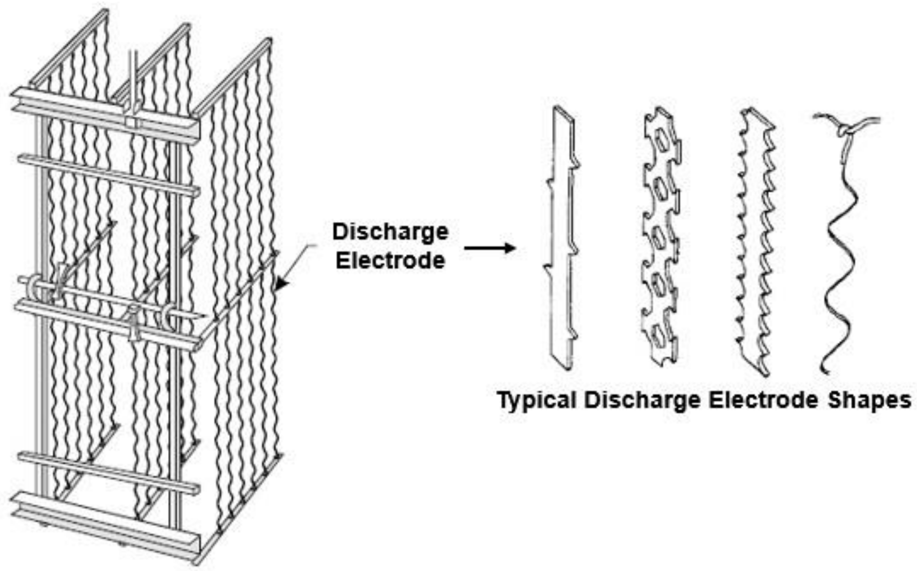
As shown in above figure, the weights at the bottom of the wire are attached to guide frames to help maintain wire alignment and to prevent them from falling into the hopper in the event that the wire breaks.

Weights that are 11.4 kg (25 lb) are used with wires 9.1 m (30 ft) long, and 13.6 kg (30 lb) weights are used with wires from 10.7 to 12.2 m (35 to 40 ft) long.

The bottom and top of each wire are usually covered with a shroud of steel tubing. The shrouds help minimize sparking and consequent metal erosion by sparks at these points on the wire.

The top support must allow rotation of the wire in two planes to avoid fatigue due to bending of the wire.

Most U.S. designs have traditionally used thin, round wires for corona generation. Some designers have also used twisted wire, square wire, barbed wire, or other configurations, as illustrated in above figure.



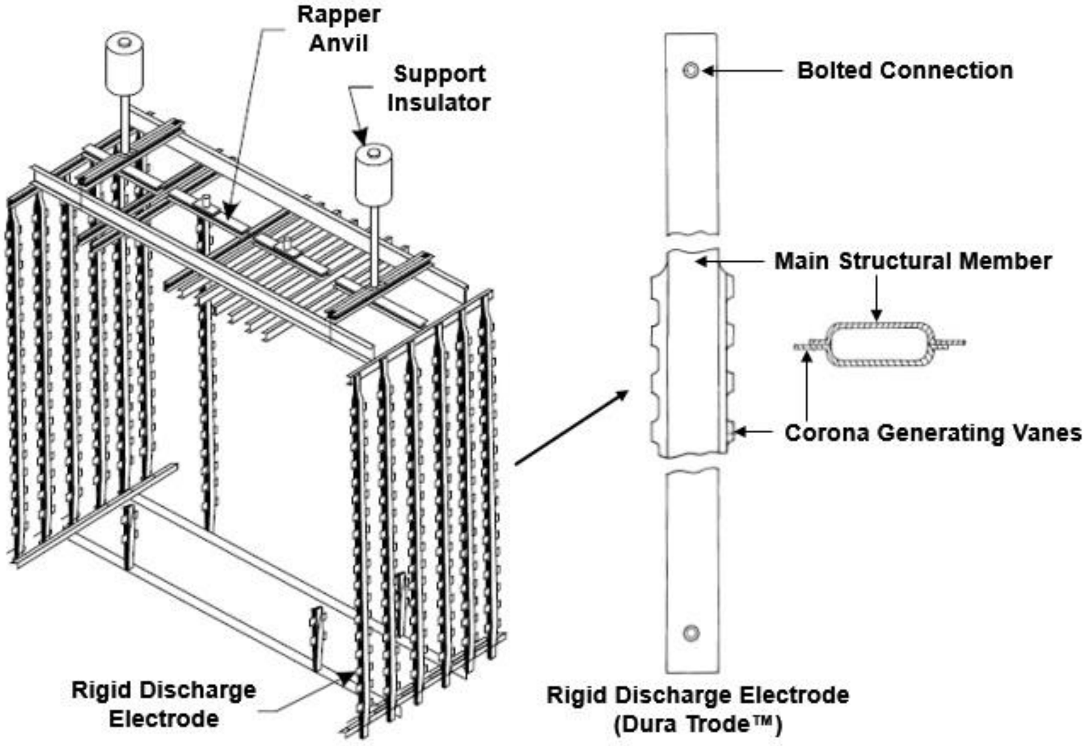
Rigid Frame Discharge Electrode Design

European precipitator manufacturers and most of the newer systems (since the early 1980s) made by U.S. manufacturers use rigid support frames or masts for discharge electrodes. The frames may consist of coiled-spring wires, serrated strips, or needle points mounted on a supporting strip. Coiled-spring wires are formed as a spring and then pulled for installation. The spring tension helps restrict the lateral motion. Above figure shows a typical rigid frame discharge electrode.

The low initial cost of a weighted wire design is typically offset by high maintenance costs resulting from wire breakage. The reverse is true of rigid frame designs; in this case, the high initial costs are usually offset by low maintenance costs.

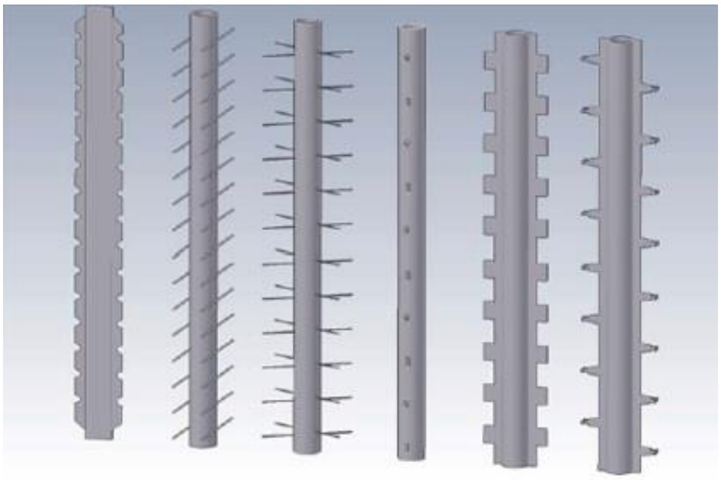
One major disadvantage of the rigid frame design is that a broken wire cannot be replaced without removing the whole frame.

Another type of discharge electrode is a rigid electrode. It does not utilize wires but creates a corona on spikes welded or otherwise attached to a rigid mast support as shown in the following figure.



Typical Rigid Discharge Electrode

When high-current sparks or continuous sparking must be tolerated, the use of inherently rigid and unbreakable rigid discharge electrode provides much better protection against erosion of the discharge electrode than the smaller size weight wire or rigid frame electrodes.



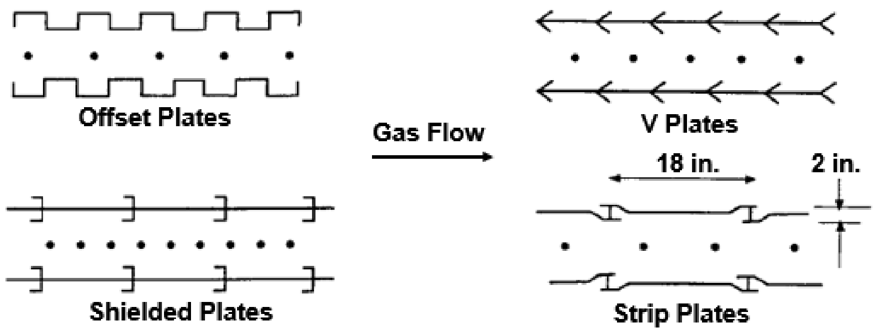
Various Forms and Shapes of Rigid Discharge Electrodes

As shown in above figure, rigid discharge electrodes, sometimes also called "Mast Electrodes" or "Pipe and Spike electrodes" are manufactured in many forms and shapes. They are inherently rigid, unbreakable, easy to fabricate and handle. In case of bolted connection with single bolt, their alignment is simplified since each electrode automatically hangs plumb from the single bolt connection.

Collection Electrodes

Collection electrodes collect charged particles. Collection electrodes are either flat plates or tubes with a charge opposite that of the discharge electrodes. Collecting plates are suspended from the precipitator casing and form the gas passages of the precipitator.

The plates are generally made of carbon steel. However, plates are occasionally made of stainless steel or an alloy steel for special flue gas stream conditions where corrosion of carbon steel plates would occur. The plates range from 0.05 to 0.2 cm (0.02 to 0.08 in.) in thickness. For ESPs with wire discharge electrodes, plates are spaced from 15 to 30 cm apart (6 to 12 in.) and for ESPs using rigid frame electrodes, collection plates are spaced 30 to 38 cm (12 to 15 inches) apart. Plates are usually between 6 and 12 m (20 to 40 ft) high.



Typical Shapes of Flat Collecting Plate Electrodes

As shown in above figure, collection plates are constructed in various shapes. These plates are solid sheets that are sometimes reinforced with structural stiffeners to increase plate strength. In some cases, the stiffeners act as baffles and provide a "quiet zone" for the dislodged dust to fall while minimizing dust reentrainment.

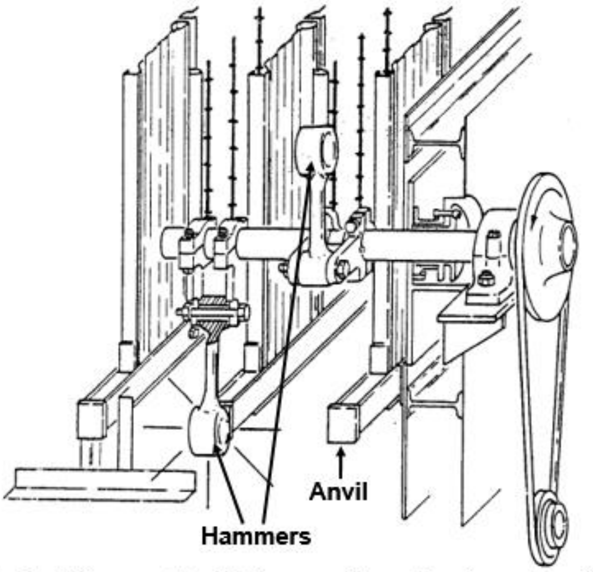
When assembled, collecting plates should be straight and parallel with the discharge electrodes. Correct alignment requires that care be exercised during fabrication, shipping, storage in the field, and erection. Most damage occurs while plates are being unpacked and raised. If an ESP is installed properly, collecting plates pose no maintenance problems during normal operation.

Pennar Industries Limited, India is one of the leading supplier of collection plates/electrodes. For more information on their products, please see their website (www.pennarindia.com).

Rappers

Dust which accumulates on collecting electrode surfaces and on discharge electrodes must periodically be dislodged by rapping the collecting plates and discharge electrodes. Rapping removes dust to the hoppers for disposal and maintains both the discharge and collecting electrodes in an "operationally" clean condition for proper operation. Without periodic rapping, the dust layer would thicken rapidly and ESP performance would be reduced. Dust deposits are generally dislodged by mechanical impulses (hammer/anvil or magnetic impulse systems) or vibrations (air or electromagnetic vibrators) imparted to the electrodes.

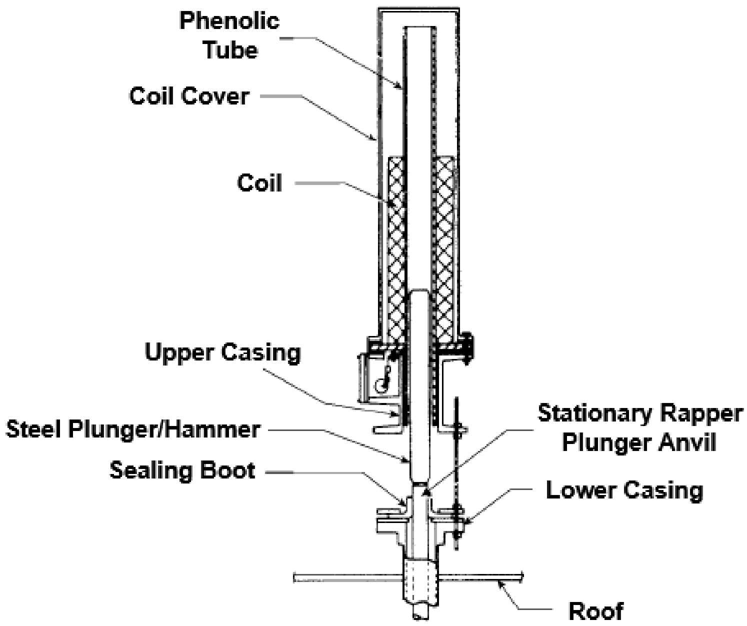
The collection electrodes are rapped by hammer/anvil or magnetic impulse systems. While rigid frame discharge electrodes are rapped by tumbling hammers and wires are rapped by vibrators. As stated previously, liquid sprays are also used (instead of rapping) to remove collected particles form both tubes and plates.



Typical Hammer/Anvil Rappers (for collection plates)

As shown in above figure, hammer/anvil system uses hammers mounted on a rotating shaft. As the shaft rotates, the hammers drop (by gravity) and strike anvils that are attached to the collection plates. European precipitator manufacturers use hammer and anvil rappers for removing particles from collection plates.

Rapping intensity is controlled by the weight of the hammers and the length of the hammer mounting arm. The frequency of rapping can be changed by adjusting the speed of the rotating shafts. Thus, rapping intensity and frequency can be adjusted for the varying dust concentration of the flue gas.



Typical Magnetic Impulse Rapper (for collection plates)

As shown in above figure, many U.S. designs consists of magnetic impulse rappers to remove accumulated dust layers from collection plates. A magnetic impulse rapper has a steel plunger (about 20 lb) that is raised by a current pulse in a coil. The raised plunger then drops back, due to gravity, striking a stationary rod (rapper plunger anvil) connected to a number of collection plates within the precipitator.

Rapper frequency and intensity are easily regulated by an electrical control system.

Magnetic impulse rappers usually operate more frequently, but with less intensity, than rotating hammer and anvil rappers.

Unlike a rotating hammer/anvil system (European) design, the magnetic impulse rapper has no moving parts in the gas stream and is not exposed to the erosive effects of the flue gas and dust. The roof mounted magnetic impulse rapper design permits on-line inspection and servicing.

Rigid frame discharge electrodes are rapped by tumbling hammers. The tumbling hammers operate similarly to the rotating hammers used to remove dust from collection electrodes. The hammers are arranged on a horizontal shaft. As the shaft rotates, the hammers hit an impact beam (instead of against anvil in case of collecting electrodes) which transfers the shock, or vibration, to the discharge electrodes, causing the dust to fall.

Wire discharge (weighted wire) electrodes must also be rapped to prevent excessive dust deposit buildup that will interfere with corona generation. This is usually accomplished by the use of air or electromagnetic vibrators that gently vibrate the discharge wires.

The acceleration of the rappers can be as low as 5 g, but rappers from 30 g to 50 g are required for most fly ash precipitators.

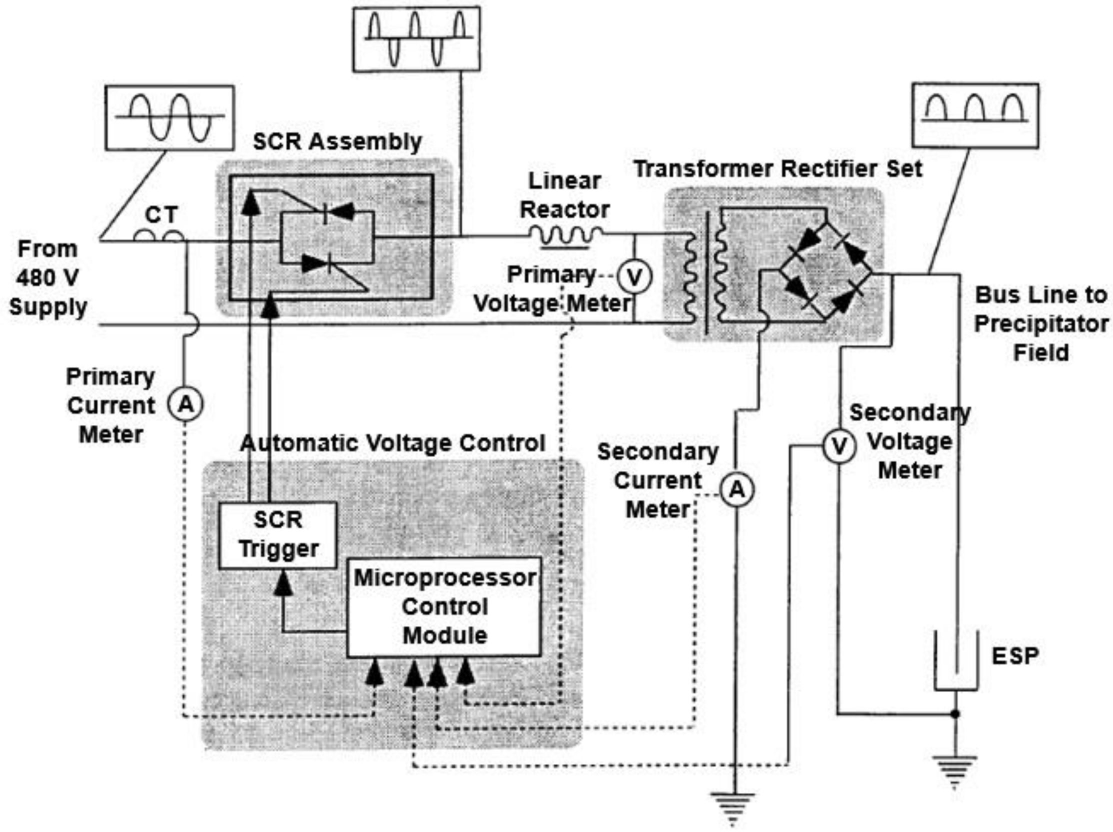
Upgrade from Hammer/anvil to Magnetic Impulse Systems

To meet more stringent emission requirements without increasing the ESP footprint, rapping system may be upgraded from hammer/anvil to magnetic impulse systems because in case of a hammer/anvil system, ample space exists inside the precipitator that could be used for additional collecting plate area to improve the precipitator performance and collection efficiency.

The other advantage of the magnetic impulse system is that it can be maintained without taking precipitator off-line since in case of magnetic impulse system, the rappers are mounted on the roof of the precipitator.

High Voltage Equipment

High voltage equipment determines and controls the strength of the electric field generated between the discharge and collection electrodes. This is accomplished by using power supply sets consisting of three components: a step-up transformer, a high-voltage rectifier and control metering & protection circuitry (automatic circuitry). The power system maintains voltage at the highest level without causing excess spark-over between the discharge electrode and collection plate. These power sets are also commonly called transformer rectifier (T-R) sets.



Schematic Diagram of Power Supply Circuit Associated with Precipitators

In a transformer rectifier (T-R) set, the transformer steps up the voltage from 400 volts to approximately 50,000 volts. The rectifier converts alternating current to direct current because direct current (or unidirectional current) is required for electrical precipitation. Most modern precipitators use solid-state silicon rectifiers and oil-filled, high-voltage transformers. The control circuitry in a modern precipitator is usually a Silicon Controlled Rectifier (SCR) automatic voltage controller with a linear reactor in the primary side of the transformer. The automatic voltage control system is designed to maintain optimum voltage and current in response to changes in the characteristics and concentrations of the dust. The function of the linear reactor (also called current limiting reactor, CLR) is to protects SCR's and silicon diode rectifiers from excessively steep current rise during transient overload (sparking) conditions to prolong life and reliability of the system. It also provides a means of shaping the wave form of the power supply output. Meters are included in the control circuitry to monitor the variations in the electrical power input. A simplified drawing of the circuitry is shown in above figure.

The T-R sets should be matched to ESP load. It is not the installed power that counts; it is the actual power under load that does the job. The ESP will perform best when all T-R sets operate at 70 to 100 percent of the rated load without excessive sparking or transient disturbances, which reduce the maximum continuous load voltage and corona power inputs. Over a wide range of gas temperatures and pressures in different applications, practical operating voltages range from 15 to 80 kV at average corona current densities of 10 to 70 mA/1000 ft of collecting area.

The following are the most common T-R set output ratings:

70 kVp, 45 kV avg. 250 to 1500 mA D.C.; 16 to 100 kV, 9 to 10 in. ducts
78 kVp, 50 kV avg. 250 to 1500 mA D.C.; 18 to 111 kV, 10 to 12 in. ducts
86 kVp, 55 kV avg. 250 to 1500 mA D.C.; 20 to 122 kV, 12 in. ducts (from some vendors)

At currents over 1500 mA, internal impedances of the T-R sets are low, which makes stable automatic control more difficult to achieve. Hence, design should call for the highest possible impedance that is commensurate with the application and performance requirements. The high internal impedance of the smaller T-R sets facilitates spark quenching as well as providing more suitable wave forms. However, with smaller T-R sets, this often means more sectionalization. But smaller electrical sections localize the effects of electrode misalignment and permit higher voltages in the remaining sections.

In normal fly ash ESP's, corona current requirements generally increase from inlet to outlet, the latter being perhaps 3 to 5 times the inlet current. Operating voltages are usually higher on inlet sections compared with outlets. In high resistivity ash cases, relatively low voltages and current densities may prevail on all T-R sets. Applications requiring extra high voltages include high density gases (above atmospheric pressures), corona quench situations (high inlet concentrations of fine particles) and wide ducts (400 to 600 mm).

Voltage Control Set Point Terminology

Spark is a small, self-extinguishing electrical discharge that does not greatly increase current flow.

Arc is a fully ionized continuous electrical discharge between the discharge electrode and a ground.

Setback is a voltage control setting that determines the amount of voltage reduction for the next half cycle (due to sparking).

Quench is a voltage control setting that determines the number of half cycles that the power is completely removed from the TR set (due to arcing).

Slow ramp is a voltage control setting that determines the slow ramp up in power to the TR set.

Fast Ramp is a voltage control setting that determines the fast ramp up in power to the TR set.

Generic Guidelines for Setting Voltage Controller Options

ESP efficiency is directly related to the applied field voltage. That is, collection efficiency will increase with average field voltage. In general, the highest voltage that can be applied to any field is the voltage at which sparking occurs since sparking represents a breakdown in the electric field. When a spark occurs, the strength of the electric field strength is momentarily reduced. While excessive sparking reduces collection efficiency, some degree of sparking is necessary to ensure that the field is operating at the highest possible applied voltage.

The function of the voltage controller is to achieve the highest possible operating voltage for various ash and load combinations. The voltage controller operates in a cycle in which the input voltage is increased until one of the following conditions occurs:

- A spark or arc occurs
- Current limit is reached
- Voltage limit is reached
- Maximum conduction angle is reached

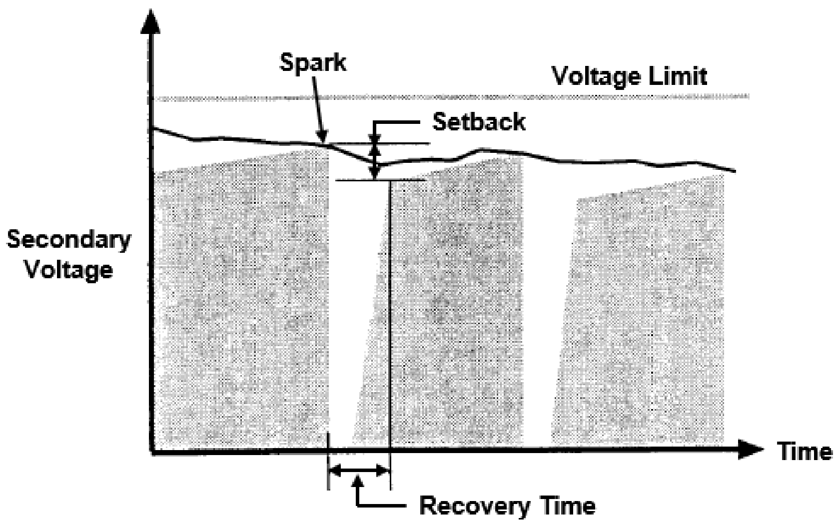
Sparks, and the spark rate of a given field, are controlled by the use of voltage control adjustments typically called the "setback" and "ramp rate". Since sparks are self-extinguishing, the voltage does not need to be completely removed from the field.

Since the spark is gone by next half cycle, the controller really doesn't have to protect against any large fault currents. But if it takes no control action, another spark will occur on the next half cycle (voltage controller will never reach its optimum voltage because each time a spark occurs, the electrostatic field is completely discharged). Usually only a small drop in voltage is necessary to prevent a repeat spark. As shown in the following figure, "setback" refers to the maximum reduction in applied voltage for the spark cycle. Typically, a setback of 10-15% will be sufficient. Immediately following a spark, voltage increases from the setback voltage until another spark occurs. The ramp rate includes a "fast ramp" setting, which quickly brings the voltage close to the previous spark point, and a "slow ramp" setting, which slowing approaches the spark point.

Voltage controller setback and ramp rate are interrelated. A higher setback and a slower ramp will reduce the spark rate but decrease collection efficiency. It is usually more effective to limit the setback and extend the slow ramp period. Setback and ramp rate settings are plant specific and may require multiple iterations. However, the following are general guidelines on effective spark rate settings:

- Inlet fields: 20 sparks per minute
- Intermediate fields: 10 sparks per minute
- Outlet fields: Zero or near zero sparks per minute

Most voltage controllers also include settings for arcing. Arcing is a continuous breakdown in the electrical field between the discharge electrode and a ground. Arcs should be rare unless there are significant clearance problems within the ESP or an internal problem like a swinging wire. Arcs can be destructive, especially when they occur often.



Spark Generation Profile

Voltage controller operation for arcing is similar to sparking although the power to the T-R set must be turned completely off to extinguish an arc. Most voltage controllers have a "quench time" setting that controls the number of half cycles in which the power is turned off. The number of half cycles off should be minimized (two at most). A "fast ramp" then quickly increases the voltage to the "spark setback" level where the "slow ramp" then increases it back to the spark/arc over voltage. It is recommended that the fast ramp be set as high as possible (3-5 seconds) and the slow ramp be the same as the setting for sparking.

Voltage controller settings vary because of design differences and coal variability, although the above guidelines should provide a starting point for plant technicians.

Meters

Power input is the most important measure of the ESP performance. Thus, any new ESP should be equipped with the following:

- Primary voltage meter
- Primary current meter
- Secondary voltage meter
- Secondary current meter
- Spark meter (optional)

Note: The terms primary and secondary refer to the side of the transformer being monitored by the meter.

The primary voltage meter measures the input voltage, in A.C. volts, coming into the transformer. The input voltage ranges from 220 to 480 volts; however, most modern precipitators use 400 to 480 volts. The meter is located across the primary winding of the transformer.

The primary current meter measures the current drawn across the transformer in amperes. The primary current meter is located across the primary winding (wires wound in the coil) of the transformer.

The primary voltage and current readings give the power input to a particular section of the ESP.

Secondary voltage meter measures D.C. volts, the operating voltage delivered to the discharge electrodes. The meter is located between the output side of the rectifier and the discharge electrodes.

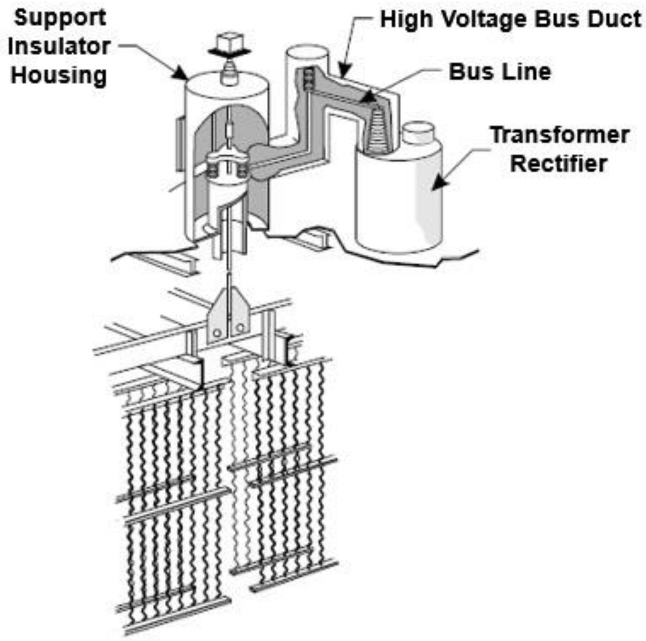
Secondary current meter measures the current supplied to the discharge electrodes in milli-amperes. The secondary current meter is located between the rectifier output and the microprocessor control module of the automatic voltage control.

The combination of the secondary voltage and current readings gives the power input to the discharge electrodes.

Spark meter measures the number of sparks per minute in the precipitator section. Sparks are surges of localized electric current between the discharge electrodes and the collection plate.

Above meters are considered essential for performance evaluation and troubleshooting.

High-Voltage Bus Lines



High-Voltage System

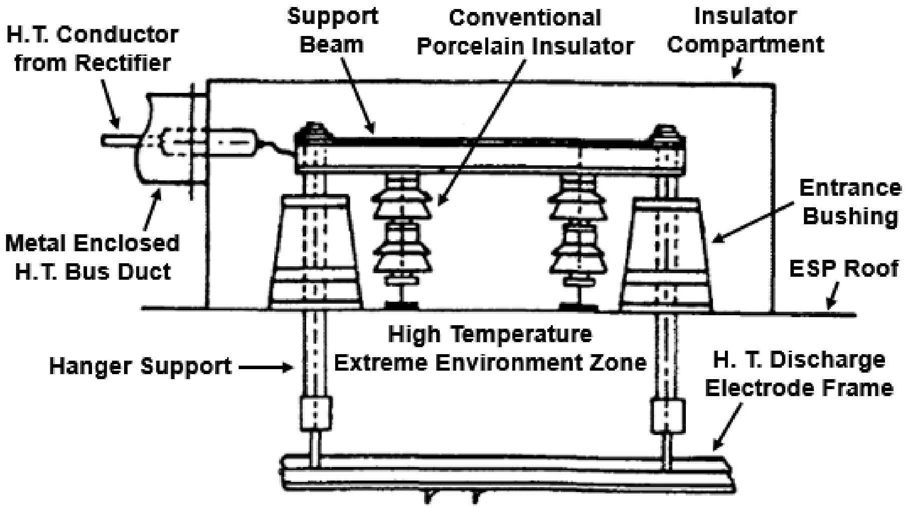
The transformer rectifier set is connected to the discharge electrodes by a bus line. As shown in above figure, a bus line is electric cable that carries high voltage from the transformer rectifier to the discharge electrodes. The bus line is encased in a pipe, or bus duct, to protect the high-voltage line from the environment and to prevent the line from becoming a potential hazard to humans. The high-voltage bus lines are separated, or isolated, from the ESP frame and shells by insulators. The insulators are made of non-conducting plastic or ceramic material (porcelain, fused alumina, or other refractory material).

High Tension Insulators for Discharge Electrode Support System

The discharge electrode support system has two primary functions: to provide the necessary high voltage electrical insulation and to give mechanical support to the discharge electrode frame.

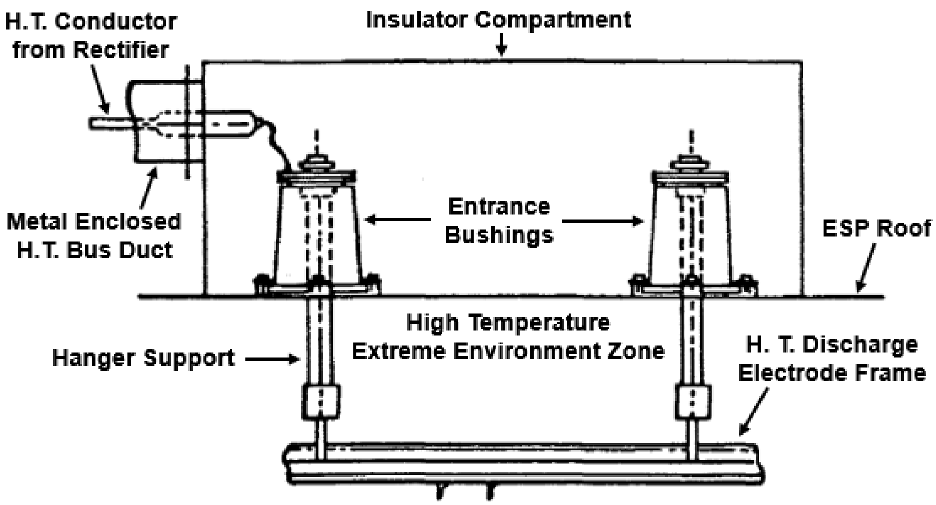
Several types of support systems are currently being used in utility precipitators. One type consists of support insulators in conjunction with entrance bushings as shown in the following figure.

In this design, the high voltage insulators are located on the roof of the precipitator. A support/bus beam is mounted atop the insulators, and the discharge electrode assembly is suspended from the support/bus beam by hanger rods. Conventional porcelain insulators support the mechanical load of the internal framework and are located in a relatively low temperature zone that is comparatively free of contaminants. Entrance bushings, sometimes referred to as "flower pots" are made of a clay refractory and are cemented in place with a refractory cement. Alumina entrance bushings are sometimes found on modern designs.



Support Insulators and Support Beam - to Support Discharge Electrode Frame

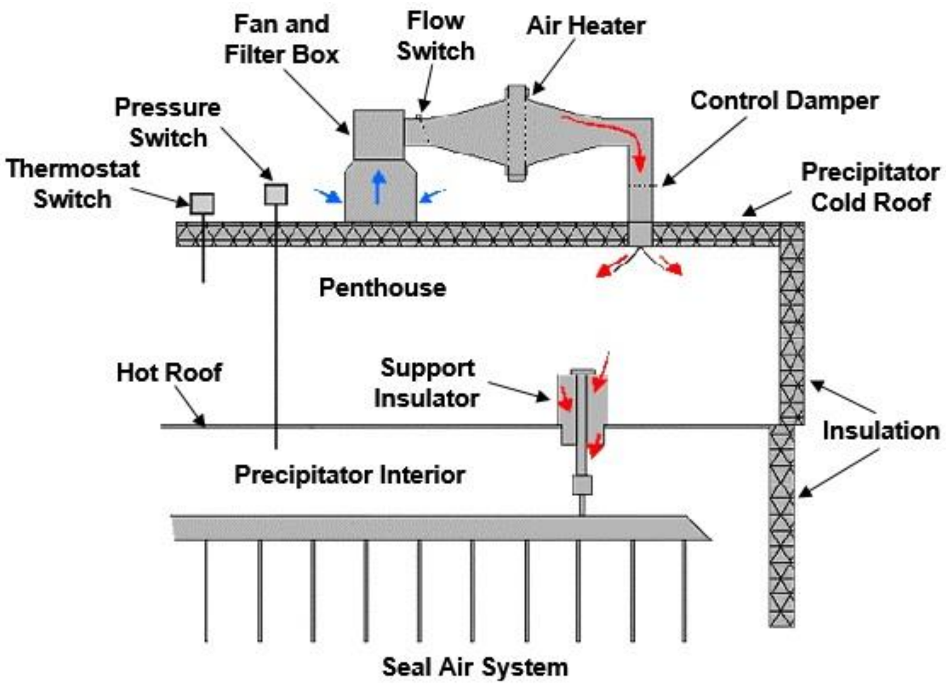
Following figure shows a support system in which the discharge electrode assembly is suspended by hanger rods that are supported directly by entrance bushings. In this arrangement, the bushings are constructed of alumina or some similar material and possess high mechanical strength and good thermal shock resistance.



Entrance Bushings - to Support Discharge Electrode Frame

Generally, the requirements for any support insulator are that the material must have sufficient strength to support the weight of the discharge electrode system. It also must be electrically strong to withstand operational voltages of up to 110 kV in the case of 400 mm spaced collectors.

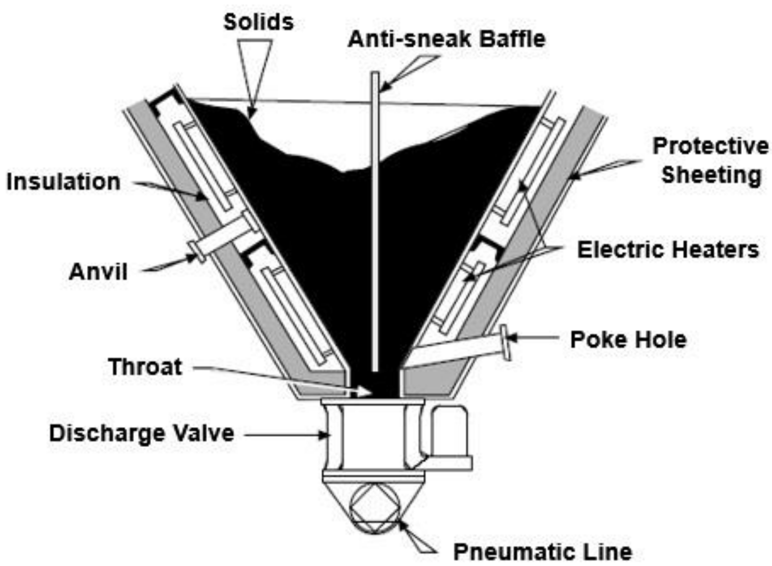
As shown in above figures, high voltage support system insulators are contained in a metal housing, either individually or in groups, to protect them from the environment. In some designs, all the high voltage support and/or entrance bushings (also called lead through insulators) are housed in a common top housing, penthouse, or weather enclosure. As shown in following figure, the insulator housings are usually supplied with clean dry air (commonly called seal air) to prevent flue gas entering from the precipitators because any excessive flue gas component (ash) buildup or condensation will create a conductive path on the insulator surface leading to surface leakage/current that could cause sparking or grounding of the entire bus section. Surface current appears as additional specific power adsorption by T-R set that does not perform any useful function/work.



In order to keep the insulators free of fly ash, if the precipitator is operating under positive pressure, the insulator housing / penthouse is normally pressurized with clean dry air so that the pressure in the housing is slightly higher than the operating pressure of precipitator. As shown in above figure, the air is also heated to prevent condensation from forming on the insulator surfaces. If the precipitator is operating under negative pressure, air is admitted through vents in the housing by natural circulation.

To prevent moisture from forming on the insulators, heaters are usually provided as a part of the forced seal air / ventilation system described above (which would provide clean, warm air to all the insulators) or as separate heating elements for each insulator or each insulator compartment.

Hoppers



Components of an ESP Hopper

When the electrodes are rapped, the dust falls into hoppers and is stored temporarily before it is disposed of. Dust should be removed as soon as possible to avoid packing, which would make removal very difficult. Typically, hoppers are rectangular in cross-section and are usually designed with a 50 to 70° (60° is common) slope to allow dust to flow freely from the top of the hopper to the bottom discharge valve. Discharge diameters are generally 8" to 12".

Hoppers should be well insulated. A minimum of 5-6" of insulation is recommended if the insulation is directly against the hopper wall or 2-3" with at least a 4" air gap for a precipitator operating between 280 and 350°F. Air channels should be baffled to prevent cooling that can result from a “chimney effect” (warm air rises; cold air replaces it). Particular attention should be paid to the critical throat, since this is where most bridging problems occur.

Some manufacturers add devices to the hopper to promote easy and quick discharge. These devices include electric heaters, poke holes, anvil (strike plates) and vibrators.

Heaters in the discharge throat and up to one-third the height of the hopper have proved to be especially beneficial. In view of this it is recommended that hopper heaters should be placed on all four walls of the hopper and designed to maintain the ash temperature and the interior surface temperature of the hopper between 300 and 350°F (heating density of between 20 and 25 watts / ft^2).

Hopper heaters should also be started well in advance of fuel firing to get the metal temperature high enough before they start collecting ash (heaters are usually energized at least eight hours before start-up). The need for hopper heater operation is precipitator and ash specific. Since these devices consume significant amounts of power, the minimum hopper heater use should be experimentally determined, observing ash consistency and interior metal surface corrosion. In some climates, winter operation may require their use, while summer operation may not.

Enough “poke hole” ports should be provided to allow for cleaning a blockage at the discharge.

Anvils are simply pieces of flat steel that are bolted or welded to the center of the hopper wall. If dust becomes stuck in the hopper, rapping the anvils several times with a mallet may free it. Maintenance staff will eventually learn to determine whether or not the hopper is full by the sound the hopper makes when the anvil is hit.

If vibrators are used, their operation controls should be interlocked with the ash removal system so that rapping cannot occur unless the hopper is being evacuated. Vibrators that operate before the discharge valve opens may actually compact the ash and make its removal more difficult. For this same reason, vibrators should also not be used to clear plugged hoppers.

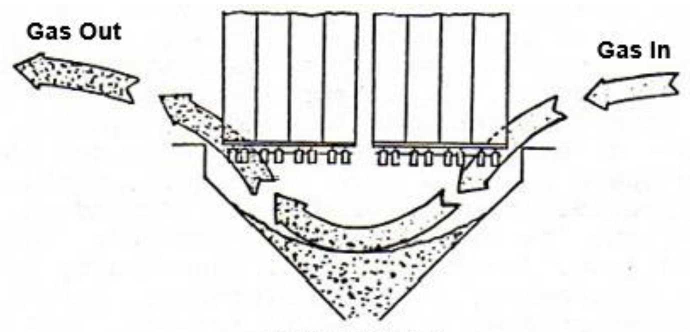
Fluidizing with hot dry air also is reported to help. Fluidizing is carried out by a porous membrane (usually a fluidizing stone) which allows pressurized air to flow through it and uniformly distribute it to the ash above it. However, the air should be preheated above the dew point temperature; otherwise, more harm than good will result. Aerators are usually operated when the hopper is being evacuated. Unlike vibrators, their continuous use will not compact the ash.

In the sizing of hoppers, consideration should be given to the fact that about 80 percent of the collected dust is removed in the first field. A conservatively designed dust removal system will keep pluggage to a minimum. The trend is toward large sized hoppers so that operators can respond to hopper plugging before electrical grounding or physical damage is done to the electrodes.

Dust level detectors in the hoppers can help alert ESP operators that hoppers are nearly full. It is recommended to locate/install the dust level detectors between one-half and two-thirds of the way up the side of the hopper. As long as hoppers are not used for storage, this should provide an adequate safety margin. It should be remembered that it takes much longer to fill the upper 2 feet of a pyramid hopper than the lower 2 feet.

Two types of level indicators are commonly in use (although others are available). The older of the two is the capacitance probe, which is inserted into the hopper. As dust builds up around the probe, a change in the capacitance occurs and triggers an alarm. Although these systems are generally reliable, they can be subject to dust buildup and false alarms in some situations. This causes the operators to mistrust the alarm and, in time, to ignore it. A newer system is the nuclear or radioactive detector. These systems utilize a shielded Cesium radioisotope to generate a radioactive beam that is received by a detector on the opposite side of the hopper. Two of the advantages of this system are: they do not include a probe that is subject to dust buildup and more than one hopper can be monitored by one radioactive source. The major drawback is that the plant personnel would be dealing with a low-level radioactive source and adequate safety precautions must be taken.

Other indirect methods are available for determining whether the hopper is emptying properly. On vacuum discharge/conveying systems, experienced operators can usually tell where the hopper is plugged or if a "rat hole" is formed by checking the time and vacuum drawn on each hopper as dust is removed. On systems that use a screw conveying system, the current drawn by the conveyor motor can serve as an indicator of dust removal. Another simple method for determining hopper pluggage is through a thermometer located approximately two-thirds of the way up on the hopper. If dust covers the probe because of hopper buildup, the temperature will begin to drop, which signals the need for plant personnel to take corrective action.



Hopper Sneakage

Hopper aspect ratio (height to width) is another important design consideration. The correct ratio will minimize gas sneakage (bypassing of the electrically energized zone of the ESP area by the flue gas) to the hoppers and possible reentrainment.

Low aspect ratio hoppers can be corrected by a center vertical division plate termed as anti-sneakage hopper baffle. However, the baffle should not extend too far into the hopper (which can increase plugging).

It may be noted that hopper sneakage is the worst form of bypassing because the flue gas not only escapes ESP treatment over a given area, but also re-entrains ash which has already been collected.

Severe collection plate warpage can result in distorted gas distribution within a precipitator. Warped plates can act as flow diverters, and may even direct flue gas into hoppers resulting in gas sneakage.

Poor gas distribution can also cause gas sneakage through hoppers. Expansion plenums or top-entry cause gas vectors to be directed toward the hopper; if multiple perforated distribution plates do not fit well in the lower portion of the plenum or if the lower portion has been cut away because of dust buildup, gas is channeled into the hoppers.

Shell

The shell structure encloses the electrodes and supports the precipitator components in a rigid frame to maintain proper electrode alignment. The support structure is especially critical for hot side precipitators because precipitator components can expand and contract when the temperature differences between the ESP (400°C or 752°F) and the ambient atmosphere (20°C or 68°F) are large. Excessive temperature stresses can tear the shell and hopper joints and welds apart. The outer sheet or casing wall is usually made of low carbon or mild grade steel that is 0.5 to 0.6 cm (3/16 to 1/4 in.) thick.

Collection plates and discharge electrodes are normally attached to the frame at the top so that the elements hang vertically due to gravity. This allows the elements to expand or contract with temperature changes without binding or distorting.

Anti-sneakage baffles are provided to the side walls of the precipitator to prevent untreated gas from passing along the side walls of the precipitator, where it is impossible to mount discharge electrodes.

Most precipitator loads are calculated with the hoppers filled with fly ash to the bottom of the emitting system. However, continued boiler operation with a shorted precipitator can result in ash settlement until the precipitator is filled almost to the roof. No precipitators are designed for such a load and, if the hoppers do not split open, the structural steel will surely fail.

Shells, hoppers, and connecting ducts should be covered with thermal insulation to conserve heat, and to prevent corrosion resulting from water vapor and acid condensation on internal components of the precipitator. Unless contained within a weather enclosure, the insulation should be protected by weatherproof lagging/cladding. The outer lagging should have a weatherproof finish. All outdoor lagging should be capable of withstanding wind load, applicable live loads, and snow load, and should be sloped for proper drainage. If the ESP is installed on a coal fired boiler, the flue gas temperature should be kept above 120°C (250°F) at all times to prevent any acid mists in the flue gas from condensing on ESP internal components. Ash hoppers should be insulated and heated because cold fly ash has a tendency to cake, making it extremely difficult to remove. Insulation material is usually 10 to 15 cm (4 to 6 in.) thick.

Heat sinks require a great deal of attention in design, if they are to be avoided. A particularly bad practice is the attachment of stairway or walkway supports directly to the precipitator casing. Such members are excellent radiators of heat, and the area of casing plate to which they are attached will invariably corrode to such an extent that the entire structure may fail within a short time. A separately supported stair and platform tower should always be used. Lighting stanchions/supports, bus duct supports, blower supports, test ports, rappers, roof walkways, and access doors all present the designer with the opportunity of inadvertently creating a heating sink. Whenever it is absolutely necessary to fasten something to the shell which will protrude through the thermal insulation, the connection should be designed with care. A large pad that can subsequently be well insulated should be welded to the casing, and the device to be welded to the pad should have no more cross section through which heat will be conducted, than absolutely necessary. Such an attachment minimizes, but may not eliminate the corrosion damage caused by the heat sink.

ESP Design

Manufacturers use mathematical equations to estimate collection efficiency or collection area. They also consider a variety of design parameters that affect collection efficiency. In addition, they may build a pilot-plant to determine the parameters necessary to build the full-scale ESP. They may also use a mathematical model or computer program to test the design parameters. In view of this, brief information about mathematical equations used to estimate collection efficiency and design parameters that affect collection efficiency is given in this chapter. This information will be useful in troubleshooting.

Collection efficiency (mass of particulate matter collected divided by the mass of such material entering the ESP over a period of time) is the primary consideration of an ESP design. The collection efficiency and/or the collection area of an ESP can be estimated using several equations. These equations give a theoretical estimate of the overall collection efficiency of the unit operating under ideal conditions.

Particle Migration Velocity

The particle migration velocity (or drift velocity) is the speed at which a particle, once charged, migrates toward the grounded collection electrode. Variables affecting particle migration velocity are particle size, the strength of the electric field and the viscosity of the gas. Following is one of the equation used to express the particle migration velocity.

$$w = \frac{d_p E_o E_p}{4 \pi \mu}$$

Where:
w = particle migration velocity
d_p = diameter of the particle, µm
E_o = strength of field in which particles are charged
(represented by peak voltage), V/m (V/ft)
E_p = strength of field in which particles are collected
(normally the field close to the collecting plates), V/m (V/ft)
µ = gas viscosity, Pa·s (cp)
π = 3.14

As shown in above equation, particle migration velocity depends on the voltage strength of both the charging and collection fields. Therefore, the precipitator must be designed using the maximum electric field voltage for maximum collection efficiency. The particle migration velocity also depends on particle size; larger particles are collected more easily than smaller ones.

However, most ESPs are designed using a particle migration velocity based on field experience rather than theory. Typical particle migration velocity rates, such as those listed in the following table have been published by various ESP vendors.

Application	Typical Effective Particle Migration Velocity	
	(ft/sec)	(cm/s)
Utility fly ash	0.13-0.67	4.0-20.4
Pulverized coal fly ash	0.33-0.44	10.1-13.4
Pulp and paper mills	0.21-0.31	6.4-9.5
Sulfuric acid mist	0.19-0.25	5.8-7.62
Cement (wet process)	0.33-0.37	10.1-11.3
Cement (dry process)	0.19-0.23	6.4-7.0

Gypsum	0.52-0.64	15.8-19.5
Open-hearth furnace	0.16-0.19	4.9-5.8
Blast furnace	0.20-0.46	6.1-14.0
Hot phosphorous	0.09	2.7

Deutsch-Anderson Equation

Deutsch-Anderson equation is used to determine the collection efficiency of the precipitator under ideal conditions. The simplest form of the equation is given below.

$$\eta = 1 - e^{-w(A/Q)} \quad \text{or} \quad A = -(Q / w) \times [\ln(1 - \eta)]$$

Where:
η = collection efficiency of the precipitator
e = base of natural logarithm = 2.718
w = particle migration velocity, cm/s (ft/sec)
A = the effective collecting plate area of the precipitator, m^2 (ft^2)
Q = gas flow through the precipitator, m^3/s (ft^3/sec)

This equation has been used extensively for many years to calculate theoretical collection efficiencies (or plate area for required efficiency). However, while the equation is scientifically valid, a number of operating parameters can cause the results to be in error by a factor of 2 or more because the equation neglects three significant process variables.

First, it completely ignores the fact that dust reentrainment may occur during the rapping process. Second, it assumes that the particle size and, consequently, the migration velocity are uniform for all particles in the gas stream. As stated previously, this is not true; larger particles generally have higher migration velocity rates than smaller particles do. Third, it assumes that the gas flow rate is uniform everywhere across the precipitator and that particle sneakage (particles escaping their capture) through the hopper section does not occur. Particle sneakage can occur when the flue gas flows down through the hopper section instead of through the ESP chambers, thus preventing particles from being subjected to the electric field.

More accurate estimates of collection efficiency can be obtained by modifying the Deutsch-Anderson equation. This is accomplished either by substituting the effective precipitation rate, w_e in place of the migration velocity, w, [The effective precipitation rate (w_e) refers to the average speed at which all particles in the entire dust mass move toward the collection electrode. The variable, w_e, is calculated from field experience rather than from theory.] or by decreasing the calculation of collection efficiency by a factor of k, which is constant (in Matts-Ohnfeldt equation).

The Matts-Ohnfeldt equation is:

$$\eta = 1 - e^{-w_k (A/Q)^k}$$

Where:
η = collection efficiency of the precipitator
e = base of natural logarithm = 2.718
w_k = average migration velocity, cm/s (ft/sec)
k = a constant, usually 0.4 to 0.6
A = collection area, m^2 (ft^2)
Q = gas flow rate, m^3/s (ft^3/sec)

Most people who have used Matts-Ohnfeldt equation report that a value of k equal to 0.5 gives satisfactory results.

Resistivity

Resistivity, a characteristic of particles in an electric field, is a measure of a particle's resistance to transferring charge (both accepting and giving up charges). Resistivity is a function of a particle's chemical composition as well as flue gas operating conditions such as temperature and moisture. Particles can have high, moderate (normal), or low resistivity.

Resistivity is an important factor that significantly affects collection efficiency. While resistivity is an important phenomenon in the inter electrode region where most particle charging takes place, it has a particularly important effect on the dust layer at the collection electrode where discharging occurs. Particles that exhibit high resistivity are difficult to charge. But once charged, they do not readily give up their acquired charge on arrival at the collection electrode. On the other hand, particles with low resistivity easily become charged and readily release their charge to the grounded collection plate. Both extremes in resistivity impede the efficient functioning of ESPs. ESPs work best under normal resistivity conditions.

Resistivity is the electrical resistance of a dust sample 1.0 cm^2 in cross-sectional area, 1.0 cm thick, and is recorded in units of ohm-cm.

Following table gives value ranges for low, normal, and high resistivity.

Resistivity	Range of measurement
Low	Between 10^4 and 10^7 ohm-cm
Normal	Between 10^7 and 10^{10} ohm-cm
High	Above 10^{10} ohm-cm (usually between 10^{10} and 10^{14} ohm-cm)

Dust Layer Resistivity

A potential electric field (voltage drop) is formed across the dust layer as negatively charged particles arrive at the dust layer surface and leak their electrical charges to the collection plate. At the metal surface of the electrically grounded collection plate, the voltage is zero. Whereas at the outer surface of the dust layer, where new particles and ions are arriving, the electrostatic voltage caused by the gas ions can be quite high. The strength of this electric field depends on the resistivity and thickness of the dust layer.

In high resistivity dust layers, the dust is not sufficiently conductive, so electrical charges have difficulty moving through the dust layer. Consequently, electrical charges accumulate on and beneath the dust layer surface, creating a strong electric field. Voltages can be greater than 10,000 volts. Dust particles with high resistivities are held too strongly to the plate, making them difficult to remove and cause problems in rapping.

In low resistivity dust layers, the corona current is readily passed to the grounded collection electrode. Therefore, a relatively weak electric field, of several thousand volts, is maintained across the dust layer. Collected dust particles with low resistivity do not adhere strongly enough to the collection plate. They are easily dislodged and become re-entrained in the gas stream.

The following discussion of normal, high, and low resistivity applies to ESPs operated in a dry state; resistivity is not a problem in the operation of wet ESPs because of the moisture concentration in the ESP.

Normal Resistivity

ESPs work best under normal resistivity conditions. Particles with normal resistivity do not rapidly lose their charge on arrival at the collection electrode. These particles slowly leak their charge to grounded plates and are retained on the collection plates by intermolecular adhesive and cohesive forces. This allows a particulate layer to be built up and then dislodged from the plates by rapping. Within the range of normal dust resistivity (between 10^7 and 10^{10} ohm-cm), fly ash is collected more easily than dust having either low or high resistivity.

High Resistivity

Due to high resistivity, the high voltage drop (across the dust layer) reduces the voltage difference between the discharge electrode and collection electrode, and thereby reduces the electrostatic field strength used to drive the gas ion - charged particles over to the collected dust layer. As the dust layer builds up, and the electrical charges accumulate on the surface of the dust layer, the voltage difference between the discharge and collection electrodes decreases. The migration velocities of small particles are especially affected by the reduced electric field strength.

Another problem that occurs with high resistivity dust layers is called **back corona**. This occurs when the potential drop across the dust layer is so great that corona discharges begin to appear in the gas that is trapped within the dust layer. The dust layer breaks down electrically, producing small holes or craters from which back corona discharges occur. Positive gas ions are generated within the dust layer and are accelerated toward the "negatively charged" discharge electrode. The positive ions reduce some of the negative charges on the dust layer and neutralize some of the negative ions on the "charged particles" heading toward the collection electrode. The disruptions of the normal corona process greatly reduce the ESP's collection efficiency.

The third, and generally most common problem with high resistivity dust is increased electrical sparking. When the sparking rate exceeds the "set spark rate limit," the automatic controllers limit the operating voltage of the field. This causes reduced particle charging and reduced migration velocities toward the collection electrode.

High resistivity can generally be reduced by doing the following:

- Adjusting the temperature
- Increasing moisture content
- Adding conditioning agents to the gas stream

A simple rule of thumb involving the electrical resistivity of collected fly ash is that above a certain temperature, about 400°F (225°C), resistivity decreases with increasing temperature, and below some temperature, about 350°F (140°C), resistivity decreases with decreasing temperature.

The moisture content of the flue gas stream also affects particle resistivity. Increasing the moisture content of the gas stream by spraying water or injecting steam into the duct work preceding the ESP lowers the resistivity. However, in moisture conditioning, one must maintain gas conditions above the dew point to prevent corrosion problems in the ESP or downstream equipment.

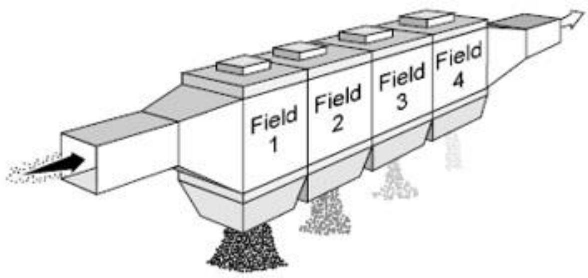
The presence of SO_3 in the gas stream has been shown to favor the electrostatic precipitation process when problems with high resistivity occur. Most of the sulfur content in the coal burned for combustion sources converts to SO_2. However, approximately 1% of the sulfur converts to SO_3. The amount of SO_3 in the flue gas normally increases with increasing sulfur content of the coal. The resistivity of the particles decreases as the sulfur content of the coal increases. Hence SO_3 can be injected into the duct work preceding the precipitator to reduce the resistivity. Conversely, change to low sulfur coal will increase ash resistivity. Other conditioning agents, such as sulfuric acid, ammonia, sodium chloride, and soda ash, have also been used to reduce particle resistivity.

Low Resistivity

Particles that have low resistivity are difficult to collect because they are easily charged (very conductive) and rapidly lose their charge on arrival at the collection electrode. The particles take on the charge of the collection electrode, bounce off the plates, and become re-entrained in the gas stream. Thus, attractive and repulsive electrical forces that are normally at work at higher resistivities are lacking, and the binding forces to the plate are considerably lessened. Examples of low-resistivity dusts are unburned carbon in fly ash and carbon black.

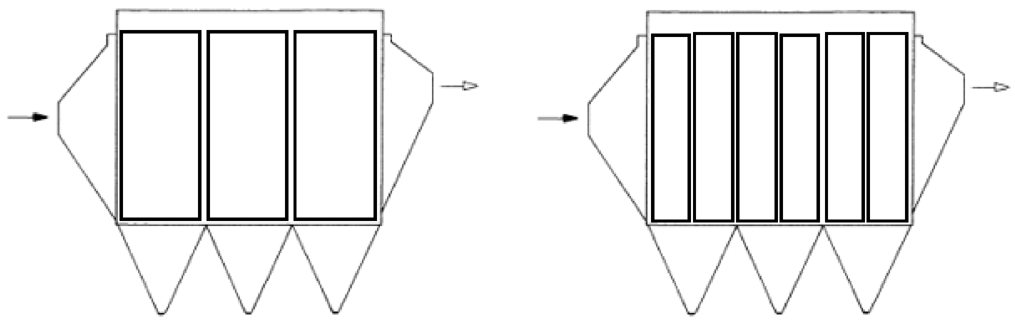
The injection of NH_3 has improved the resistivity of fly ash from coal-fired boilers with low flue gas temperatures.

Electrical Sectionalization



Field Sectionalization

In **field sectionalization**, an ESP is divided into a series of independently energized bus sections or fields (also called stages) in the direction of the gas flow. Each field has individual T-R sets, voltage-stabilization controls, and high-voltage conductors that energize the discharge electrodes within the field. This design feature, called field electrical sectionalization, allows greater flexibility for energizing individual fields to accommodate different conditions within the precipitator. Above figure shows an ESP consisting of four fields, each of which acts as an independent precipitator.



3 Field ESP 6 Field ESP

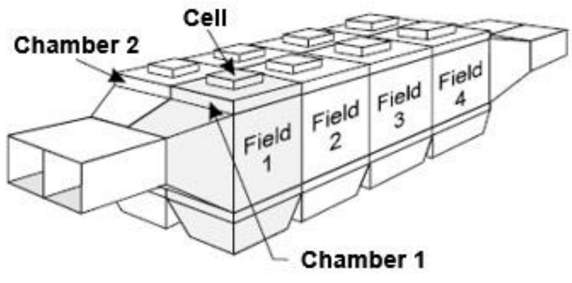
3 and 6 Field Sectionalization

It may be noted that field sectionalization does not depend on number of hoppers but on number of independently energized bus sections or fields. As shown in above figure, there may be more than one field in a hopper.

Most ESP vendors recommend that there be at least three or more fields in the precipitator. However, to attain a collection efficiency of more than 99%, some ESPs have been designed with as many as seven or more fields.

The need for separate fields arises mainly because power input requirements differ at various locations within a precipitator. The maximum voltage at which a given field can be maintained depends on the properties of the gas and dust being collected. The particulate matter concentration is generally high at the inlet fields of the precipitator. High dust concentrations tend to suppress corona current, requiring a great deal of power to generate corona discharge for optimum particle charging. In the downstream fields of a precipitator, the dust loading is usually lighter, because most of the dust is collected in the inlet fields. Consequently, corona current flows more freely in downstream fields. Particle charging will more likely be limited by excessive sparking in the downstream than in the inlet fields. If the precipitator had only one power set, the excessive sparking would limit the power input to the entire precipitator, thus reducing the overall collection efficiency. The rating of each power set in the ESP will vary depending on the specific design of the ESP.

Besides allowing for independent voltage control, another major reason for having a number of fields in an ESP is that electrical failure may occur in one or more fields. Electrical failure may occur as a result of a number of events, such as over-filling hoppers, discharge-wire breakage, or power supply failure. ESPs having a greater number of fields are less dependent on the operation of all fields to achieve a high collection efficiency.



Parallel Sectionalization

In **parallel sectionalization**, the series of fields is electrically divided into two or more sections so that each field has parallel components. Such divisions are referred to as chambers (or streams) and each individual unit is called a cell. A precipitator such as the one shown in above figure has two parallel sections (chambers), four fields, and eight cells. Each cell can be independently energized by a bus line from its own separate transformer-rectifier set.

One important reason for providing sectionalization across the width of the ESP is to provide a means of handling varying levels of flue gas temperature, dust concentration, and problems with gas flow distribution. When treating flue gas from a boiler, an ESP may experience gas temperatures that vary from one side of the ESP to the other, especially if a rotary air preheater is used in the system. Since fly ash resistivity is a function of the flue gas temperature, this temperature gradient may cause variations in the electrical characteristics of the dust from one side of the ESP to the other.

It is recommended to provide approximately one T-R set for every 930 to 2970 m^2 (10,000 to 30,000 ft^2) of collection-plate area.

Specific Collection Area

The specific collection area (SCA) is defined as the ratio of collection surface area to the gas flow rate into the collector. This ratio represents the A/Q relationship in the Deutsch-Anderson equation and consequently is an important determinant of collection efficiency.

Increases in the SCA of a precipitator design will, in most cases, increase the collection efficiency of the precipitator. Most conservative designs call for an SCA of 20 to 25 m^2 per 1000 m^3/hr (350 to 400 ft^2 per 1000 actual cubic feet per minute, acfm) to achieve collection efficiency of more than 99.5%. The general range of SCA is between 11 and 45 m^2 per 1000 m^3/hr (200 and 800 ft^2 per 1000 acfm), depending on precipitator design conditions and desired collection efficiency.

Aspect Ratio

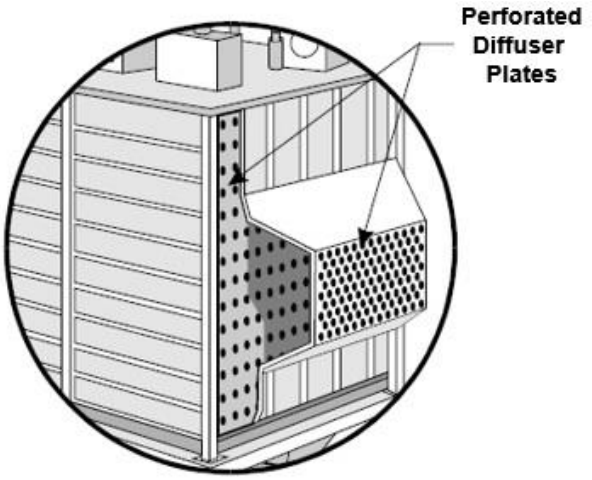
The aspect ratio is the ratio of the effective length to the effective height of the collector surface.

The effective length of the collection surface is the sum of the plate lengths in each consecutive field and the effective height is the height of the plates. For example, if an ESP has four fields, each containing plates that are 10 feet long, the effective length is 40 feet. If the height of each plate is 30 feet, the aspect ratio is 1.33.

The aspect ratio, which relates the length of an ESP to its height, is an important factor in reducing rapping loss (dust reentrainment). When particles are rapped from the electrodes, the gas flow carries the collected dust forward through the ESP until the dust reaches the hopper. Although the amount of time it takes for rapped particles to settle in the hoppers is short (a matter of seconds), a large amount of "collected dust" can be reentrained in the gas flow and carried out of the ESP if the total effective length of the plates in the ESP is small compared to their effective height.

Aspect ratios for ESPs range from 0.5 to 2.0. However, for high-efficiency ESPs (those having collection efficiencies of > 99%), the aspect ratio should be greater than 1.0 (usually 1.0 to 1.5) and in some installations may approach 2.0.

Gas Flow Distribution



Gas Inlet with Perforated Diffuser Plates

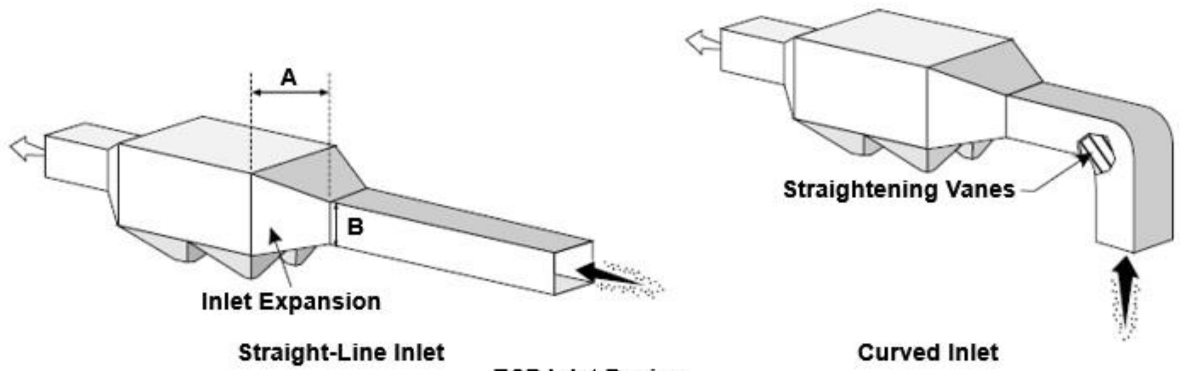
Gas flow through the ESP chamber should be slow and evenly distributed through the unit. As shown in above figure, gas velocity is reduced by the expansion, or diverging, section of the inlet plenum. The gas velocities in the duct leading into the ESP are generally between 12 and 24 m/s (40 and 80 ft/sec). The gas velocity into the ESP must be reduced to 0.6-2.4 m/s (2-8 ft/sec) for adequate particle collection. The slower the velocity of the particle, the more readily the particle will be collected, as the residence time in the precipitator will be increased. With aspect ratios of 1.5, the optimum gas velocity is generally between 1.5 and 1.8 m/s (5 and 6 ft/sec).

It may be noted that an ESP will operate best with the optimum gas velocity only because above optimum gas velocity, potential losses through rapping and reentrainment tend to increase rapidly because of the aerodynamic forces on the particles whereas if velocity is allowed to drop quite below optimum gas velocity, performance problems can occur as a result of misdistribution of gas flow and dropout of dust in the ducts leading to the ESP. Dropout of dust in the ducts may increase pressure drop resulting in increased power consumption.

In order to use all of the discharge and collection electrodes across the entire width of the ESP, the flue gas must be evenly distributed. The inlet plenum contains perforated openings, called diffuser plates (distribution baffles) to evenly distribute the gas flow into the chambers formed by the plates in the precipitator. Sometimes diffuser plates are provided in the outlet plenum also.

The gas distribution plates should be kept free of excessive particulate buildup (because change in size of the design openings due to particulate buildup can cause severe mal-distribution of gas within the ESP, lowering its performance) and may require rapping with a cycle time in the range of 10 to 20 minutes depending on the inlet particulate loading of the precipitator and the nature of the particulate. Gas distribution plates in the outlet of the precipitator may be rapped less often (every 30 to 60 minutes).

Frequent operation at low gas velocities may cause dust to settle to the bottom of the inlet duct. This deposit may not be swept away at higher velocities, resulting in an increasing depth of deposit with time of operation. If the deposit covers a significant portion of the gas distribution plates, mal-distribution of flue gas in the ESP will result. Redesign of the inlet duct, possibly including the addition of a hopper in the bottom, is the cure for this condition.



ESP Inlet Design

As shown in above figure, in case of ESPs with straight-line inlets, the distance of A should be at least as long as the distance of B in the inlet. In situations where a straight-line inlet is not possible and a curved inlet must be used, straightening vanes should be installed to keep the flue gas from becoming stratified.

Particle Size Distribution

The relative size and number of particles in a sample is referred to as the particle size distribution. For example, in case of a coal fired boiler, fly ash sample is made up of a variety of particle sizes and shapes.

ESPs have a somewhat lower collection efficiency for fine particulate (typically 95% for particles less than 2.5 microns versus 99% for particles greater than 2.5 microns). Therefore, decreasing the average inlet particle size will decrease the overall collection efficiency of precipitator.

Hence, major process changes such as coal blending or switching, particularly from bituminous to subbituminous coals, which tend to produce finer ash, could be a problem for some smaller ESPs if they are not designed to take care for such changes.

Corona Power

A strong electric field is needed for achieving high collection efficiency of dust particles. The strength of the field is based on the rating of the T-R set. The corona power is the power that energizes the discharge electrodes and thus creates the strong electric field. The corona power used for precipitation is calculated by multiplying the secondary current by the secondary voltage and is expressed in units of watts. In ESP design specifications, the corona power is usually given in units of watts per 1000 m^3/hr (watts per 1000 acfm). Corona power expressed in units of watts/1000 acfm is also called the **specific corona power**.

Corona power increases as the voltage and/or current increases. The total corona power of the ESP is the sum of the corona power for all of the individual T-R sets.

For high collection efficiency, corona power is usually between 59 and 295 watts per 1000 m^3/hr (100 and 500 watts per 1000 acfm). Recent ESP installations have been designed to use as much as 470 to 530 watts per 1000 m^3/h (800 to 900 watts per 1000 acfm).

Corona current for the collecting plate area is usually 107-860 microamps/m^2 (10-80 microamps/ft^2).

It may be noted that hard, crusty, almost uniform deposits are often found on emitting electrodes following incidents of condensation. These increase the effective radius of the emitting electrode, causing a decrease in corona current, resulting in a reduction in ESP performance.

ESP for Cement Plants

In cement plants, a special problem arises during kiln startup due to the fact that the temperature of the kiln must be raised slowly to prevent damage to the heat-resistant (refractory) lining in the kiln. While kilns (especially coal-fired ones) are warming up and temperatures are below those for steady-state operating conditions, complete combustion of the fuels cannot occur, giving rise to combustible gases in the exhaust stream leading into the ESP. Electrostatic precipitators cannot be activated in the presence of combustibles, because the internal arcing of the precipitator could cause a fire or explosion. In view of this, periods of excessive emissions during startup, malfunction, or shutdown are specifically exempted from the federal (USA) New Source Performance Standards for cement kilns. Use of a cyclone preceding the precipitator helps to minimize the excessive emissions during startup.

ESP Erection and Commissioning

For trouble free operation and maintenance, care should be taken during ESP erection. In view of this, information on some key considerations during erection and commissioning of an ESP is given in this chapter.

As much as half the total cost of a complete ESP can consist of the erection costs. Erection by the ESP supplier has certain advantages. It avoids disputes between erection contractor and supplier (with the purchaser caught in the middle) over such things as erection and fabrication tolerances and responsibility for damage in shipping and handling, Furthermore, since the supplier is more familiar with his own equipment, his handling of erection sequence is apt to be better. And lastly, since the supplier is ultimately responsible for the performance of the unit, he cannot blame lack of performance on poor erection, if he does it himself. Thus, the finished job may be of higher quality if it is erected by the supplier.

However, ESPs are usually erected by skilled craftsmen of an erection contractor who do not work for the ESP vendor, and, therefore, may not be informed of specific installation instructions. Since all design tolerances are critical (especially those affecting discharge and collection electrode alignment), it is imperative that information about the proper installation procedures be transferred from designers to the erector.

The quality of construction required by an ESP cannot be obtained merely by inspecting and correcting the completed job. A complete quality assurance program covering the design, procurement, fabrication, and erection phases will, if properly carried out, result in a satisfactory installation. In view of this, the erection contractor's QA program should be closely monitored by the purchaser throughout the erection.

Following are some key considerations.

Emitting Electrodes and Collecting Plates Alignment

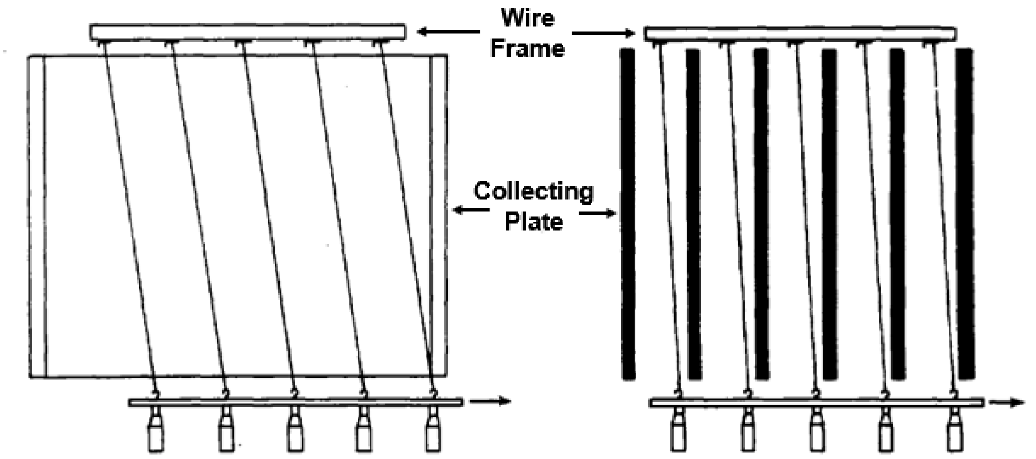
Nothing in a precipitator is so vital to performance as uniform spacing of the emitting and collecting systems. It is obvious that the maximum voltage that can be carried on any bus section is a function of the closest electrical clearance within that section. Most suppliers furnish a drawing or sketch of critical electrical clearances between the emitting system and grounded members, with stated tolerances on the various dimensions. If these tolerances are not carefully observed throughout the entire precipitator, maximum performance will not be attained.

In view of above, insure proper installation of discharge electrodes and collection plates. Collection electrodes are usually installed first, and the discharge wires or rigid frames are positioned relative to them. Check each section of electrodes to ensure that the electrodes are plumb, level, and properly aligned.

Following figure shows misalignment between discharge and collection electrodes. In general, most ESPs are not affected by a misalignment of less than about ± 5 mm (3/16 inches).

Misalignment Between Discharge and Collection Electrodes

Movement of either the lower or upper wire frame in the direction of gas flow (longitudinal movement) may cause close clearances to occur as shown at (A) in the following figure and movement of either the upper or lower wire frame perpendicular to gas flow (lateral movement) may cause close clearances to occur as shown at (B) in the following figure.

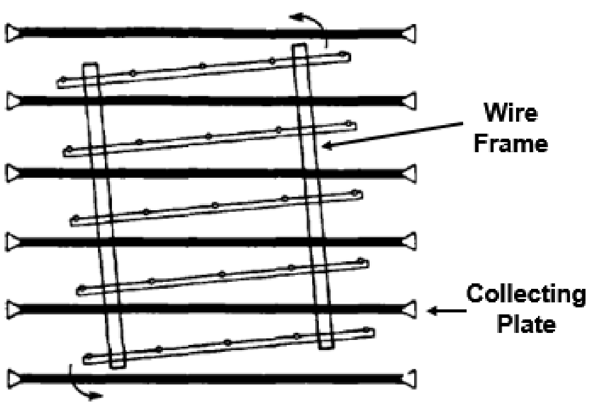


(A) Longitudinal Movement of Wire Frame (Side View)

(B) Lateral Movement of Wire Frame (Elevation)

Close Clearances Due to Longitudinal and Lateral Movement of Wire Frame

Rotation of upper or lower wire frame can cause close clearances to occur as shown in the following figure.



Close Clearances Due to Rotation of Wire Frame (Plan View)

In above figures, it can be seen that amount of misalignment (variation of clearance between discharge electrode and collecting plate/electrode) varies at different elevation. Hence alignment readings should be taken at different elevations to cover the full height of electrodes.

Seal Welding

The precipitator chamber must be gas-tight whether it is to be operated under positive or negative pressure. Under negative pressure, air inleakage at incomplete seal welds, flanges or collector access points adds additional airflow to be processed. The inleakage of cold air creates cold spots which can lead to moisture or acid condensation and possible corrosion. If severe, it can cause the entire process gas temperature to fall below the gas dew point, causing moisture or acid to condense on the hopper walls, the discharge electrode, or collection plates. In addition, air inleakage and moisture condensation can cause caking of fly ash in the hopper, making normal dust removal by the discharge device very difficult. Under positive pressure, the outleakage from the same locations will cause process gas and particulate matter to leak into the thermal insulation and lagging, eventually destroying it. The outleakage of process gas and particulate matter will also pollute the environment. The best way to check for leaks is an inspection of the walls from inside the system during daylight. Light penetration from outside helps to identify the problem areas.

Rappers Installation

Collection plate rappers and discharge electrode rappers should be installed and aligned according to vendor specifications. Check hammer and anvil rappers to see if the hammers strike the anvils squarely.

Thermal Insulation

Most ESPs use some type of thermal insulation to keep the flue gas temperature high. This prevents any moisture or acids present in the flue gas from condensing on the hoppers, electrodes, or duct surfaces. In addition, it also protects personnel and equipment adjacent to the precipitator from radiant heat. Because most ESPs are installed in the field, check that all surfaces and areas of potential heat loss are adequately covered.

Occasionally overlooked is the necessity for access to test ports located on the inlet and outlet ducts. If the ports are located on the top of the ducts and no access walkways are provided, the foot traffic generated in just one test can often ruin the insulation on the top of the ducts. Access walkways and platforms for such test ports should always be installed.

Thermal Expansion

ESPs for power plants are large boxes having numerous points of support. They are generally fixed to the support steel at one location (most commonly at the center) and, at operating temperature, they expand as much as several inches in all directions from the fixed point. Designers allow for this expansion by including sliding connections of various types at all support points except the fixed point. In addition, inlet and outlet ducts have expansion joints which compress when the system is heated.

During construction, the precipitator supports will be temporarily fixed in their "cold" position on the support steel. Upon completion of steel erection, and before applying thermal insulation, all such temporary tack welds and stops must be removed so that sliding supports can move in the designed manner. This is vitally important because the structural steel can be torn apart by expansion forces if sliding supports are inadvertently restrained.

Location of Electrical Equipment

Present day practice is to locate the transformer rectifier cabinet on the top of the precipitator. Although these cabinets are invariably weather-proof (NEMA-IV construction), they are frequently mounted within a weather enclosure.

T-R cabinets are designed for a specified ambient temperature, usually 40°C, 50°C or 55°C. The weather enclosure must be adequately ventilated to keep the maximum ambient temperature in the enclosure at or below that specified for the particular T-R cabinets being used. Failure to do so may reduce the life of the transformer, particularly those being operated at or near full load rating.

The T-R cabinet should be mounted on a platform, or heat shield, above the thermal insulation of the roof. Failure to allow a space for ambient air to circulate beneath the T-R cabinet will cause excessive oil temperatures and premature transformer failure.

Control cabinets are most commonly located in a room especially built to accommodate them and ancillary electrical gear such as main breakers, heater and rapper controls, etc. To minimize lengths of low voltage cable, the room is often located close to the precipitator and the distribution transformer.

The room should be clean and well ventilated. Control cabinets are usually constructed to NEMA I or NEMA XII standards (General Purpose or Industrial Dust-Tight). Even NEMA XII cabinets, however, will, in time, ingest a substantial quantity of dust if the control room is not reasonable clean. Dust in the cabinets will eventually insulate electronic components from cooling air and cause them to fail due to excessive temperature.

Poor locations for precipitator control rooms are those, such as under the precipitator, which become extremely dirty when servicing the ash handling equipment. In an attempt to keep a control room clean, filters are often used on the ventilating air intake. In a very dirty environment, such filters rapidly become clogged, restricting the flow of ventilating air, and adding ambient temperature problems to that of dust covering the electronic equipment.

In addition to the items listed above, each ESP erection should have its own checklist reflecting the unique construction features of that unit.

ESP Commissioning (for coal fired boilers)

Information on commissioning of an ESP for coal fired boilers (for power generation) is given in this section (instead of an ESP in general) because ESPs are most widely used to limit fly ash emissions from coal fired boilers.

In general, there are fewer problems in the start-up of a retrofit ESP than are encountered in the simultaneous startup of a new boiler plant and a new ESP. This is because everything that might affect boiler operation also, in turn, affects the ESP. When the boiler has been stabilized, it is usually possible to minimize low load operation which often results in condensation in the precipitator with resulting ash handling problems. New boilers may have repeated startups and prolonged low-load operation which, in turn, creates problems in the precipitator.

Broiler Operation and Hazards

During startup, the ignition of coal fired boilers is obtained by the use of gas, light oil, or heavy oil burners. While the ignition burners are heating up the boiler, comparatively cool flue gases pass through the precipitator. If gas ignition is used, there will usually be some moisture condensation in the precipitator until it, too, is warmed up. If the precipitator is clean, as in an initial startup, this condensation will eventually evaporate without causing any problems.

If the precipitator is dirty, as during subsequent startups, the condensation may cause some of the more pozzolanic fly ashes to hydrate, resulting in crusty deposits. Such deposits do not usually cause any problems unless they accumulate over a number of such instances to a thickness of 3 mm (1/8") or more. It is important, during this period, for condensation on the support insulators to be prevented by the use of heaters or purge air. When the boiler ignition burners use light oil for startup, the moisture condensation is similar to that obtained with gas ignition, except that there may be some soot also deposited in the precipitator from initial poor combustion of the ignition burners. From a precipitator viewpoint, the worst type of ignition is heavy, high sulfur oil because it increases the amount of condensation (the acid dew point is much higher than the water dew point). Acid bonded pozzolanic fly ash also often creates stronger and more adhesive deposits then does water hydrated fly ash. As more soot is created by the heavy oil burners, air purging of the support insulators is highly desired to keep them free of soot if boiler ignition is obtained with heavy oil burners.

The precipitator should not be operated while the ignition burners are on before at least one coal mill is in operation, and coal combustion has been assured.

One reason for this is to minimize the collection of condensation droplets and soot. However, the other and most important reason is safety.

An ignition failure in the boiler will result in a combustible mixture of fuel and air entering the precipitator. A spark in the precipitator might ignite this mixture with explosive results. Even if an explosion is avoided, the precipitation of combustible, carbonaceous material on the collection plates creates ideal conditions for a flash fire in the presence of oxygen (boiler excess air and/or air inleakage). Such fires, rather than explosions, have been the cause of most precipitator damage attributable to ignition failure and premature precipitator energization.

Common Startup Problems

The most common precipitator problem traceable to premature precipitator energization is over filling of ash hoppers. The process usually proceeds as follows:

The precipitator is energized when gas temperatures are below the acid dew point. Fly ash and condensate are deposited simultaneously on the collecting plates, forming a more or less damp layer. Some of this material is rapped off the plates, falling into the cooler area of the hoppers, in which even more condensation is taking place. The condensation runs down into the damp ash at the bottom of the hopper, creating a muddy mass which bridges the hopper outlet, preventing the ash from falling into the ash conveying system. Thus, fly ash continues to rise, and, as it approaches the bottom of the emitting system, the high voltage parts arc to the top of the ash level. The ash continues to rise, the precipitator controls decrease the voltage, and the arcing continues. By the time that solid contact is made between the ash level and the emitting system, and the controls recognize the dead short and shut off the power to that bus section, the electrical power flowing through the ash has provided enough energy to fuse parts of the ash into clinkers, some a foot or more in diameter. Even though the bus section above a hopper is de-energized, ash continues to be collected by settlement often reaching a level ten or more feet above the bottom of the collecting plates.

When the operators eventually get around to the hopper problem, the initial, condensate formed ash plug is removed by rodding through the poke hole, and ash flows freely out of the hopper until one of the clinkers reaches the bottom of the hopper, when the whole problem begins again. In the meantime, however, ash pressure has bent some of the collecting plates, reducing electrical clearances and permanently (until repaired) lowering the performance of that bus section.

In addition, another problem may be that the damp ash deposit on the collecting plates described above may, when dry, be firmly cemented to the plate and not removable by normal rapping.

There may also be problems with support, anti-sway and rapping insulators if operation of the precipitator is attempted when they are covered with acid condensation or acid smuts. Although heating and air purging help a great deal, a severe condensation problem may still overwhelm the system. Anti-sway insulators are particularly vulnerable as they cannot ordinarily be purged or heated. Their only defense is a sufficiently long tracking length (24" or more) to enable them to function even when coated with damp fly ash. Tracking across any insulator will short the bus section and eventually destroy the insulator,

In spite of these problems, local air pollution authorities frequently demand a smokeless boiler startup and want the precipitator energized prior to boiler light-off. They must be made aware of the dangers and consequences of such a requirement.

Air Loading

After completion of precipitator construction and a thorough mechanical and electrical inspection, but before placing the precipitator in operation, there are a number of measurements that should be taken with the fans drawing ambient air through the boiler and precipitator. The I.D. fans should be operated at full horsepower for maximum flow which will produce less than the rated volume of flue gas because of the increased density of the air. If the unit is a pressurized boiler, the F.D. fans should be operated at full horsepower.

Velocity Profiles

During this period of air load operation, the air distribution within each chamber should be measured. Since velocities will be in the vicinity of 3 feet per second, instrumentation accurate in this range should be used. Pitot tubes are unsatisfactory. Hot wire or vane anemometers are satisfactory. The hot wire anemometer is preferable, in spite of its fragility.

As a minimum a complete velocity traverse at the inlet and outlet of each chamber should be made. Ideally, a traverse should also be run in each passageway between fields.

Gas distribution measurements in any one chamber are usually more qualitative than quantitative, and determine relative rather than absolute individual velocities, especially when more than one instrument is used. Thus, the average velocity in one chamber cannot be used to compare with that in another chamber to determine if the gas distribution among chambers is uniform. A better method is to locate ports for a pitot tube traverse in the various chamber inlet or outlet ducts, and run pitot tube traverses during gas load conditions to ascertain that equal gas volumes are being handled by each chamber. Since correction of inequalities can often be accomplished externally (by I.D. fan biasing or damper control) it is usually not necessary to perform these measurements prior to unit start up.

Sneakage Determination

Special attention should be given to the qualitative determination of air sneakby above the plates, through the hoppers, or between the casing walls and adjacent rows of collecting plates. Smoke bombs and wands are useful for this work. Sneakage problems, if detected at this stage, can often be corrected before unit startup.

Voltage - Current Measurements

Other work that must be accomplished under air load conditions involves the energization of all bus sections to make sure that none are grounded by construction debris and close clearances which could cause premature sparking do not exist. This work must be done with air flowing through the precipitator. Otherwise, the accumulation of ionized gases and heat (from hopper heaters, for example) will result in atypical readings. At the same time, all auxiliaries such as rappers, heaters, and ventilation blowers should be run to make sure that they operate properly and do not affect the precipitator energization. However, clear all personnel and equipment from the precipitator and lock the access doors before energization of bus sections.

The relationship between precipitator voltage (V) and precipitator current (I) is one of the most important tools available for diagnosing conditions in the precipitator and the state of operation at a given time. There is only one opportunity to make this determination under clean plate conditions, and that is during the initial air load. Other work may be deferred until after boiler boil-out, but this cannot. By then, the plates will be dirty.

With insulator heaters and purge blowers on, and both collecting plate and emitting system rappers on (to check for plate or wire flutter during rapping), the following procedures can be used to develop an air load curve.

1. Energize a de-energized bus section (T-R set) on manual control (but with zero voltage and current), and increase the power to the T-R set manually.

2. At corona initiation the meters should suddenly jump and the voltage and near zero current levels should be recorded. It is sometimes difficult to identify this point precisely, so the lowest practical value should be recorded.

3. After corona initiation is achieved, increase the power at predetermined increments [for example, every 50 or 100 milliamps of secondary current or every 10 volts of A.C. primary voltage (the increment is discretionary)], and record the values for voltage and current.

4. Continue this procedure until one of the following occurs:
   - Sparking
   - Current limit is achieved
   - Voltage limit is achieved

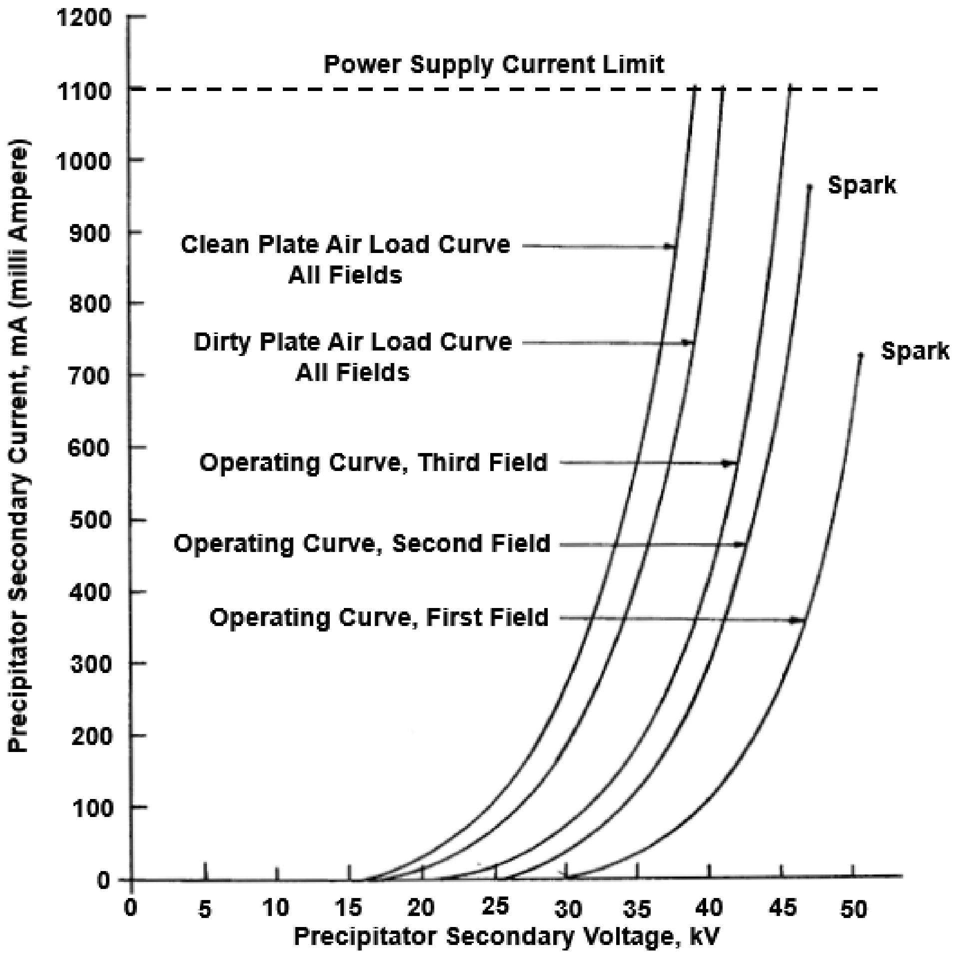
5. Repeat this procedure for each bus section (T-R set).

When plotted on rectangular coordinates, the curves for all identically sized bus sections should be the same, within the accuracy of the meters, and none should reach sparking before current limit, unless the power supplies are grossly oversized. These curves should become part of the permanent record of the ESP.

If one or more bus sections spark at less than full power, it is an indication of a close electrical clearance. Those bus sections should be inspected again. Sometimes such locations are difficult to find, and it may be necessary to station an observer at a safe location, upstream of the inlet duct gas distribution plate, to spot the location of the arc and close clearance. Under no conditions should the precipitator itself be entered without all power supplies being locked out and all bus sections grounded.

Flue Gas Introduction

After the boiler has been started and flue gas has been introduced to the ESP, it is energized, when safe to do so (after boiler light-off). When the boiler load has stabilized, a set of "gas load" current and voltage readings should be recorded, in the same manner as those obtained under air load conditions. A plot of precipitator voltage (V) as a function of precipitator current (I) can be a useful diagnostic toot. An idealized set of such V-I curves for a three field precipitator is shown in the following figure.



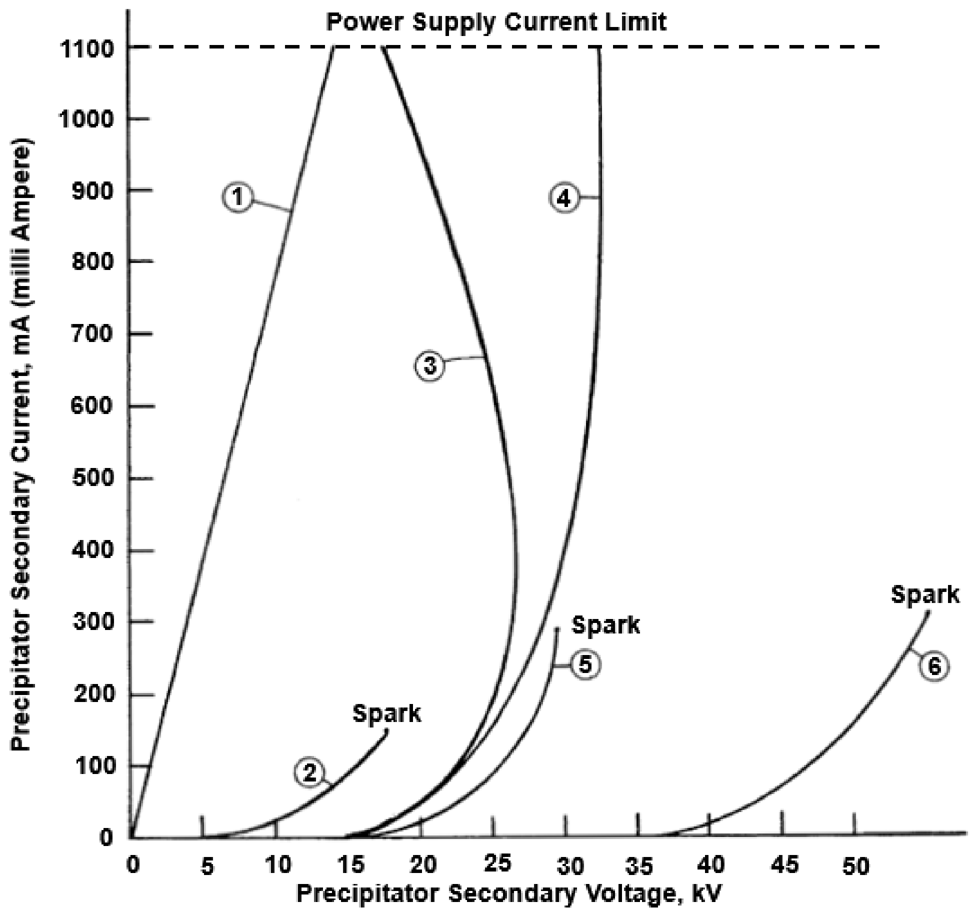
Normal Precipitator Voltage Current Curves

First, notice the difference between the clean plate and dirty plate air load curves. The higher voltage, at all currents, of the dirty plate curve is caused by the additional voltage drop of the dust layer on the collecting plates. All dirty plate curves do not necessarily have to be the same, because neither the resistivity nor the thickness of the residual layer in all fields and cells is necessarily identical. On occasion, the dirty plate curve will reach spark-over before current limit. This indicates that the resistivity of the dust layer in ambient dry air is high. In these idealized curves it is assumed that the dust layer does not have a high resistivity under either air load or operating (flue gas) conditions.

Now note that the three operating curves are shifted to the right of the dirty plate air load curve. In part, this is due to the higher resistivity of the fly ash layer at operating temperature. In addition, the space charge created by the cloud of charged dust particles in the inter-electrode space decreases corona emission (current) at any given voltage. This effect is most pronounced in the first field, where dust concentration is the highest. It decreases as the dust concentration decreases toward the rear of the precipitator.

As illustrated, the third field is able to be operated at current limit without sparking. Hence, this field is able to absorb more power than the maximum available from its power supply. A larger power supply on this field would result in an increase in precipitator performance. Whether or not the increase will be sufficient to justify the added cost depends upon individual circumstances.

Following figure illustrates abnormal voltage current (V-I) curves which are indicative of various precipitator problems.



Abnormal Precipitator Voltage Current Curves

Curve (1) illustrates a resistance path to ground. It might represent a dirty / cracked insulator or a high hopper ash level. With significant ash buildup on the support insulators, current flows through the ash deposit on the insulator before the operating voltage is high enough to cause corona onset. The slope of the line reflects the thickness of the ash deposit on the insulator - the thicker the ash deposit, the greater the slope. In case of high hopper ash level, clinkers are being formed whenever the set is operated.

Curve (2) illustrates severe misalignment between emitting electrodes and collecting plates. The curve is characterized by a low voltage corona onset and spark-over at a low voltage. The wires are too close to the plates.

Curve (3) illustrates high resistivity and severe back corona. A backward curve, with decreasing voltage at increasing current is a certain indication of this condition. Sparking may, or may not occur below current limit.

Curve (4) illustrates high resistivity and moderate back corona, as indicated by the vertical portion of the curve. As in the previous case, sparking may or may not occur before the current limit is reached.

Curve (5) indicates high resistivity with near normal operation. Spark-over at low voltage and current levels is caused by the breakdown of the collection plate dust layers at a critical current density determined by the resistivity of the layer.

Curve (6) illustrates the effect of heavy dust deposits on the emitting electrodes The corona starting voltage is abnormally high due to the increase in effective radius of the emitting electrodes. The curve has a normal shape, until breakdown voltage is reached at some weak point in the system. In particularly severe cases, the breakdown voltage may be lower than the corona start voltage, and no curve can be obtained.

Thus air load and gas load curves can be used to evaluate ESP performance by comparing the graphs from inlet field to outlet field and over periods in time. Deviation from the normal or previous results can indicate that a problem exists.

Whenever a precipitator problem is suspected, a set of voltage current (V-I) curves should be made and compared with those obtained after initial unit start-up.

ESP Operation

As with any system, an ESP must be operated and maintained according to the manufacturer's recommendations. Information on ESP operation, performance monitoring and recommended rapper cycle times is given in this chapter.

ESP Startup and Shutdown Procedure for Coal-fired Boiler

ESP Startup

Startup of an electrostatic precipitator is generally a routine operation. It involves heating a number of components such as support insulators and hoppers. If possible, the ESP should not be turned on until the process reaches steady state conditions. There are two startup procedures: classical and aggressive.

The typical classical ESP startup procedure is as follows:

1. Start the unit ignitors and/or warm-up guns and raise boiler temperatures at the recommended rate. During a unit startup sequence, the ignitor (gas or oil) flames are added in a slow sequence to allow the boiler to warm and stretch slowly. During this period, the boiler and combustion air are cold and the ignitor is firing into a cold black body environment.

2. Inspect the ignitors and/or warm-up guns periodically and make necessary adjustments to insure that proper combustion is maintained and smoke is minimized. Under startup conditions, the ignitor flame in the boiler can become quickly quenched, producing smoke and soot. In fact, until the boiler and combustion air warm up, even raw fuel can escape the active flame front.

3. When the ESP outlet temperature reaches 200-230°F, energize the second field with respect to flow at low power (50-100 ma) to minimize sparking. Any sparking in the ESP is very undesirable when oil is being fired without coal.

4. Add additional fields at low power as necessary to minimize opacity. Add fields downstream of the second field as needed with the inlet field energized last.

5. As the unit begins to fire coal and load is raised, begin the transfer of ESP voltage controls to automatic operation. It may be necessary to reduce the current limit or leave some controls on manual to minimize sparking during initial coal operation.

Startup Risks

Early energization of the ESP can be very effective in reducing reentrained ash and oil igniter smoke; however, this practice has risks. The most common problem is the collection of raw oil mist and soot, which can coat insulators, plates and wires inside the ESP and cause poor ESP performance following startup. Given the low gas flow and characteristics of raw oil mist and soot, an energized ESP will collect essentially 100% of this material during startup. In the worse case, internal ESP flash fires can be initiated if considerable raw oil is collected and a spark in the ESP occurs under the right conditions (oxygen - air inleakage and/or boiler excess air). Such fires, rather than explosions, have been the cause of most precipitator damage attributable to ignition failure and premature precipitator energization. Since these flash fires only last a short time, there is almost no real-time evidence. They are usually only discovered when the field shorts soon after startup and a subsequent off-line inspection reveals severely warped ESP plates and other internal ESP damage where none existed before. In order to minimize these risks and the collection of condensation droplets and soot, the precipitator should not be operated while the ignition burners are on before at least one coal mill is in operation, and coal combustion has been assured.

Some plants may be forced to initiate ESP operation during unit startup due to a permit requirement. In these cases, an aggressive startup procedure is required. It should be noted that the procedures discussed below are only an attempt to share information about practices used by some utilities.

Aggressive ESP Startup procedure is as follows.

The most aggressive ESP startup approach is to energize a field or two of the ESP at low power before the unit ID and FD fans are started. This approach prevents the initial opacity excursions caused by loose ash in the boiler and ductwork when the fans start. The ESP is then allowed to remain in service throughout the startup period and subsequent operation. This is referred to as an aggressive approach because, as discussed above, it has considerable risk of causing an internal ESP flash fire.

A less aggressive ESP startup approach, but one that still carries some risk is outlined below.

1. Energize two fields of the ESP at low power (50-100 mA) prior to the fans being started. Ensure that the ESP plate and wire rappers are operating. After the fans are stabilized at startup airflow, continue operation of the ESP for approximately 10 minutes. Then slowly reduce the ESP power to zero. (Note that many utilities omit this step.)

2. Start the unit ignitors and/or warm-up guns and begin raising boiler temperatures at the recommended rate.

3. Immediately inspect the ignitors and/or warm-up guns and make necessary adjustments to insure that proper combustion is maintained and smoke is minimized.

4. As soon as a clean ignitor flame is achieved, energize the inlet ESP fields at low power (50-100 ma) to minimize sparking. Any sparking in the ESP is very undesirable when oil is being fired without coal.

5. Continue ignitor and/or warm-up gun inspection as the startup proceeds and additional ignitors are added or oil pressure is increased. Make adjustments as necessary to insure minimum smoke and soot.

6. Add additional fields at low power as necessary to minimize opacity.

7. As the unit begins to fire coal and load is raised, begin the transfer of ESP voltage controls to automatic operation. It may be necessary to reduce the current limit or leave some controls on manual to minimize sparking during initial coal operation.

This approach is designed to energize the ESP as soon as practical. It does require some operating experience regarding when the ignitors are burning clean enough to put the ESP in service. This judgment usually takes 30 minutes to an hour. In addition to the flash fire risk, early ESP energization may also serve to degrade ESP performance for a period of days following startup. Experience with this procedure has shown that the ESP initially operates at reduced power and that the power slowly increases over a period of several days.

Shutdown Procedures

The shutdown of the ESP is usually done by reversing the order of the startup steps. Begin with de-energizing the ESP fields starting with the inlet field to maintain appropriate opacity levels from the stack. The rappers should be run for a short time after the ESP is de-energized so that accumulated dust from the collection plates and discharge wires can be removed. All hoppers should be emptied completely before bringing the unit back on line.

A general ESP shutdown approach is outlined as follows:

1. As unit load is dropped, inspect the ESP to detect excessive sparking. The further load is reduced, the more likely excessive sparking and arcing will be to occur.

2. As load approaches zero, put the ESP controls in manual at low power (50-100ma) to minimize sparking.

3. Continue ESP operation at low power until the unit ID and FD fans are shutdown. Ensure that ESP plate and wire rappers also remain in operation.

During shutdown, considerable ash is being shed from inside the furnace and ductwork due to the "thermal shock/rapid cooling" conditions that exist. At the same time, the temperature of the ESP is dropping into a very unfavorable range for ESP operation. While there is little risk of ESP damage during a shutdown, good ESP performance should not be expected. The ESP does collect a considerable amount of the ash during shutdown; however, opacity excursions are usually inevitable.

Note:

When an industrial process is shut down temporarily, the ESP system should be de-energized to save energy.

Performance Monitoring

As with the operation of any piece of equipment, performance monitoring and recordkeeping are essential to establishing a good operation and maintenance program. The key to any monitoring program is establishing an adequate baseline of acceptable ranges that is used as a reference point. Then, by monitoring and recording key operating parameters, the operator can identify performance problems, need for maintenance, and operating trends.

Typical parameters that can be monitored include:

- Voltage/current
- Opacity
- Gas temperature
- Gas flow rate and distribution
- Gas composition and moisture

Voltage and Current

Voltage and current values for each T-R set should be recorded; they indicate ESP performance more than any other parameter. Most modern ESPs are equipped with primary voltage and current meters on the low-voltage (a.c.) side of the transformer and secondary voltage and current meters on the high-voltage rectified (d.c.) side of the transformer. When both voltage and current meters are available on the T-R control cabinet, these values can be multiplied to estimate the power input to the ESP. (Note that the primary current reading is multiplied by the primary voltage reading and the secondary current reading is multiplied by the secondary voltage reading). These values (current times voltage) represent the number of watts being drawn by the ESP and is referred to as the corona power input. In addition, whenever a short term spark occurs in a field it can be detected and counted by a spark rate meter. ESPs generally have spark rate meters to aid in the performance evaluation.

The power input on the primary versus the secondary side of the T-R set will differ because of the circuitry and metering of these values. The secondary power outlet (in watts) is always less than the primary power input to the T-R. The ratio of the secondary power to the primary power will range from 0.5 to 0.9 and average from 0.70 to 0.75.

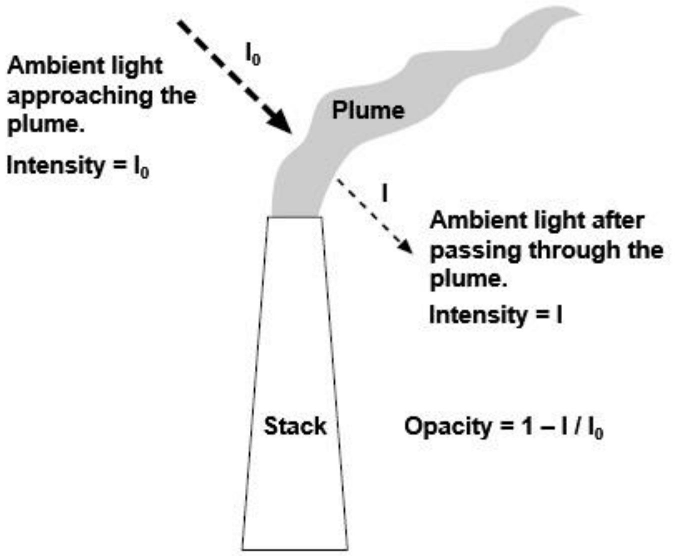
Voltage and current values for each individual T-R set are useful because they inform the operators how effectively each field is operating. However, the trends noted within the entire ESP are more important. T-R set readings for current, voltage, and sparking rates should follow certain patterns from the inlet to the outlet fields. For example, corona power density should increase from inlet to outlet fields as the particulate matter is removed from the gas stream.

Opacity

Opacity is a measure of the extent to which the particulate matter emissions reduce the ambient light passing through the plume as indicated in the following figure.

Opacity is a convenient indirect indicator of particulate matter emissions and can be determined by a trained visible emissions observer without the need for special instruments.

Initially, opacity regulations were used primarily as general indicators of particulate matter problems. As the regulations evolved, however, opacity has become a separately enforceable emission characteristic.



Opacity of a Plume

Particles entrained in a gas stream scatter visible light. The extent to which the intensity of the light beam is reduced is described by the Beer-Lambert law shown as following equation, which indicates that the extent of light reduction is exponentially related to the particle concentration.

Equation for Beer-Lambert law:

$$T = \frac{I}{I_0} = e^{-\alpha c l}$$

Where,

T = Light transmittance
I = Intensity of the light energy leaving the gas
I_0 = Intensity of the light energy entering the gas
α = Attenuation coefficient
c = Concentration of the pollutant
l = Distance the light beam travels through the gas

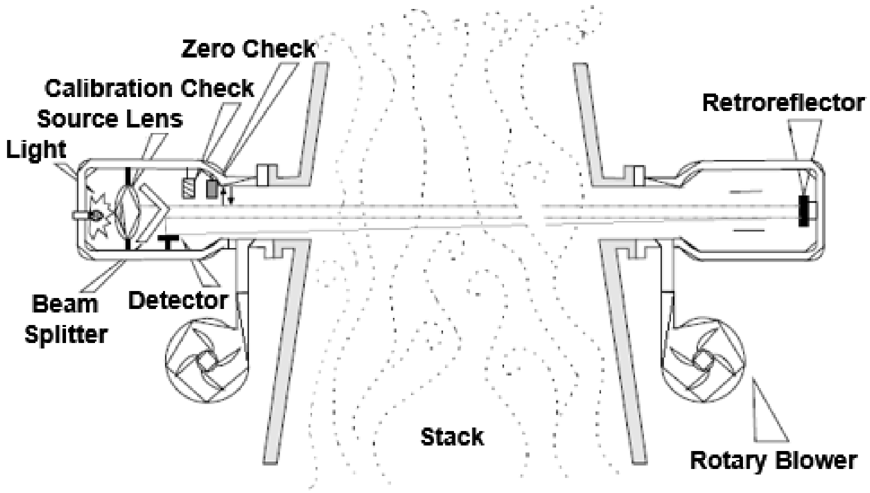
The most convenient way to express the reduction in light intensity is the opacity. This term is defined in the following equation.

Opacity = 100 - Transmittance (%)

If there is no reduction in light intensity, the transmittance is 100% and the opacity is zero. If all the light is scattered, the transmittance is zero and the opacity is 100%. High opacity is generally associated with high particulate matter concentrations. Accordingly, opacity is used as an indirect indicator of particulate emissions.

In many situations, ESP operation is evaluated in terms of the opacity monitored by a transmissometer (opacity monitor, sometimes called smoke meter) on a real-time basis. Under optimum conditions the ESP should be able to operate at some base-level opacity with a minimum of opacity spiking from rapper reentrainment. A facility can have one or more monitors that indicate opacity from various ESP outlet ducts and from the stack.

An opacity monitor compares the amount of light generated and transmitted by the instrument on one side of the gas stream with the quantity measured by the receiver on the other side of the gas stream. The difference, which is caused by absorption, reflection, refraction, and light scattering by the particles in the gas stream, is the opacity of the gas stream. Opacity is expressed as a percent from 0 to 100% and is a function of particle size, concentration, and path length.

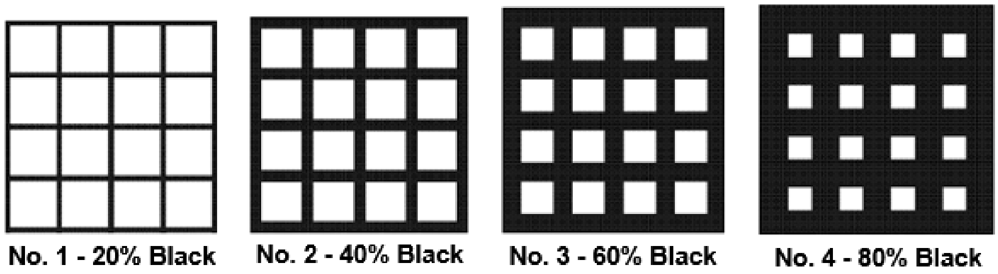


Double-pass Opacity Monitor

Most of the opacity monitors being installed today are double-pass monitors; that is, the light beam is passed through the gas stream and reflected back across to a detector.

A simplified schematic of a continuous opacity monitor is shown in above figure. Visible light from a specially designed lamp passes through a beam splitter. Part of the light beam goes directly to the detector as an indication of the initial light intensity. The remainder of the light beam passes across the stack (or ESP outlet duct), is reflected over the retroreflector, passes across the stack a second time, and strikes the detector. The difference between the two light beam intensities is used as a measure of the light transmittance. Blowers and filters are used to keep optical windows on both the source and retroreflector clean.

One of the early tools for the quantification of stack opacity was the Ringelmann chart. The chart consisted of calibrated black grids on a white background. The grids ranged from approximately 20 percent ink coverage for a Ringelmann No. 1 through 100 percent ink coverage, or solid black for a Ringelmann No. 5 as shown in the following figure.



Ringelmann Chart

An observer compared the appearance of a stack plume with the Ringelmann chart, and noted the number that most closely agreed with the stack opacity. Observers typically recorded observations to the nearest half-Ringelmann number. Observations were to be made successively from positions to the North, East, South, and West of the stack, and the four readings averaged to produce a composite Ringelmann number for that stack at that time.

Untrained observers obtained excellent agreements when evaluating the opacity of black smoke against a bright sky. However, the Ringelmann chart is more difficult to interpret when viewing a light colored smoke against a dark background (such as a green, tree covered mountain, for example).

EPA (Environmental Protection Agency, United States) relies upon trained observers to determine opacity without reference to any external aids. Each observer is trained at a school where they make observations of various opacities produced with smoke of different colors. Upon graduation, they are qualified to make visual observations of stacks for conformance with EPA regulations.

However, the impracticalities of continuous human stack observation have led to the development of opacity monitoring equipment.

Gas Temperature

Monitoring the temperature of the gas stream can provide useful information concerning ESP performance.

Changes in gas temperature can have profound effects on ESP performance. The temperature variation can be very small (in some cases as little as 15°F) and yet cause a significant change in ESP power levels and opacity because the particle resistivity depends on its temperature.

Temperature measurement can also be a useful tool in finding excessive inleakage or unequal gas flow through the ESP. Both of these conditions can affect localized gas velocity patterns without noticeably affecting the average velocity within the ESP. Yet, localized changes in gas velocities can reduce ESP performance even though the average gas velocity seems adequate.

Gas Flow Rate and Distribution

Gas flow rate determines most of the key design and operating parameters such as specific collection area (ft^2/1000 acfm), gas velocity (ft/sec) and treatment time within the ESP, and specific corona power (watts/1000 acfm). The operator should calculate the flue gas flow rate if the ESP is not operating efficiently.

Another important parameter is gas flow distribution through the ESP. Ideally, the gas flow should be uniformly distributed throughout the ESP (top to bottom, side to side).

Gas Composition and Moisture

The chemical composition of both the particulate matter and flue gas can affect ESP performance. In many applications, key indicators of gas composition are often obtained by using continuous emission monitors. However, particle concentration and composition are determined by using intermittent grab sampling.

Reducing Reentrainment Losses

Reentrainment occurs when the ash on the plates is not collected in the hopper but re-enters the gas stream. Several things can contribute to reentrainment such as:

- Ash projected away from the plates by rapping.
- Ash swept from the ash hoppers back into the gas stream.
- Particulate sheared by the action of the flue gas flowing by the collected ash layer.
- Ash dislodged by excessive sparking.

As a general rule, rapping reentrainment is excessive if the opacity is 1.4 times higher with the rappers on for a cold side ESP, or 1.5 times higher with the rappers on for a hot side ESP. Instantaneous opacity spikes are also a good indicator of reentrainment resulting from rapping problems. In rapping optimization, the chief focus is on reducing reentrainment from the outlet collection plates, as this is the major contributor to outlet emissions from the ESP. Fly ash removed from the collecting plates (and to some degree from the discharge electrodes) will tend to break up when the rappers are activated. Most of the ash will fall into the hoppers, while the remainder will be reentrained into the flue gas with the uncollected fly ash. The reentrained ash will not usually contain any sub-micron particles, as it comprises mostly agglomerates of the previously collected material. The reentrained material from all but the last field will usually be recollected in the remaining downstream fields. Because there is no downstream section to recollect this reentrained material, proper adjustment of the rapping parameters for the outlet field is especially important to obtain optimum ESP performance.

Optimal rapping frequency and intensity are achieved by trial and error - making an adjustment, then checking the opacity trace to see if it had the desired effect. The process usually requires more than a week to establish the correct parameters. The goal is to minimize rapping puffs.

Insofar as possible, for both discharge and collection rapping systems, optimize rapping intensity before adjusting the frequency interval.

To determine the appropriate intensity for the collecting system by trial and error, the objective should be to find the minimum shear force necessary to dislodge the dust cake (collected ash layer) at the extremities of the system, while avoiding over-rapping some portion of the collecting electrode. For some top-rapped systems with very tall collecting plates, the required rapping energy can be quite high. In these cases, a compromise must often be reached between over-cleaning the upper portions of the system (which would create unnecessary reentrainment) while providing adequate cleaning at the bottom.

Intensity requirements usually decrease in the direction of gas flow. Along with shear forces (linear to the plate), some normal forces (perpendicular to the plate) are developed. Normal forces tend to disperse the dust cake, a condition that should be minimized in the outlet sections to limit reentrainment. Sometimes it is necessary to vary intensity across gas flow, especially when gas velocities are unbalanced or the resistivity of the ash changes across the face because of temperature differences.

When the appropriate intensity has been determined, further improvement is gained through optimizing the frequency.

Recommended Rapper Cycle Times

Rapper timing is very important because most of the ash emitted from an ESP is caused by rapping reentrainment from a modern, large SCA, low velocity, highly sectionalized ESP. When the inlet section of the ESP is rapped, a considerable amount of the collected ash is reentrained in the gas stream and then rapidly collected again. This cycle of collection and reentrainment is repeated numerous times as the ash moves through the ESP so that most of the ash makes its way to the ash hoppers and only a small quantity of ash makes it to the exit of the ESP.

Optimal Rapper Timing

The purpose of optimizing rapping cycles is to optimize the thickness of the collected ash layer. Successful rapping shears a compacted layer of ash off the plate so that the sheet of ash falls directly into the ash hopper, minimizing ash reentrainment. Rapping timing is a delicate balance between ESP electrical performance and ash reentrainment. Infrequent rapping cycles lead to excessive ash buildup and interferes with ESP electrical operations. Rapping less frequently typically results in a deterioration of the electrical power input by adding an additional resistance into the power circuit. However, rapping intervals that are too rapid can also be detrimental. If a compacted sheet of ash is not allowed to form on the plate, then the loose ash collected will just fluff off the plate when rapped, resulting in higher reentrainment losses.

General Rapper Timing Procedure

It should first be noted that if an ESP is performing satisfactorily and well in compliance with the emission limits, there is no reason to adjust rapper timing. If it is determined that rapper timing adjustments will be advantageous, always write down the existing timings so that you can return to the starting point, just in case the changes result in poorer performance.

It is important to note that an ESP has a tremendous amount of inertia when rapper settings are changed. It takes a long time for a rapper timing change to be reflected throughout the entire ESP because the residual dust cake on the plates has to stabilize at the new setting and this can require a number of rapping cycles. Obviously, the larger the ESP, the longer it takes to stabilize. At least 24 hours are required for most ESPs to stabilize after a change is made. All evaluations should be made at a consistent unit load (preferably full load) and ESP temperature.

Most of the ash that enters an ESP is captured very rapidly. Some estimate that 50% of the ash is collected within the first three to six feet of the ESP given a reasonable power level. Therefore, the basic rapper scheme is to rap the first field on a frequent basis and then to lengthen the rapping interval as the last field is approached. This method takes some experimentation especially with the last and next to the last fields.

Initial Rapper Settings

A general rule-of-thumb for initial rapper timing settings is to set the inlet field timing interval at about 10 minutes and then to double the time for each field in sequence. For example, for a 5 field (in the direction of gas flow) ESP, the base timings would be 10, 20, 40, 80 and 160 minutes. Often, large ESPs are over rapped in the outlet fields.

Other two general rules-of-thumb are:

1. Ensuring that no two rappers on a straight pass in the direction of gas flow are rapping at the same time.

2. Ensuring that no two outlet fields are rapping at the same time.

Secondary voltage and current readings should be taken on all ESP sections for comparison purposes before and after making a rapping change. In addition, unit load, ESP temperature and opacity reading should also be recorded. The ESP should operate for at least 24 hours after making the initial adjustment.

<u>Evaluate Outlet Field Rapping</u>

After 24 hours have elapsed, and the ESP temperature and unit load are in the range where the previous power and opacity readings were taken, another set of secondary voltage and current readings should be taken on all ESP sections. It should be noted whether there was a significant change in voltage or current on a field wide basis. Unless the previous rapping intervals were excessively fast or slow, there should not have been much change in the voltage or current readings. Changes that might be observed include higher voltage and reduced current. This indicates a thicker ash layer has formed. A lower voltage and higher current indicate a thinner ash layer. As long as the voltage or current or stack opacity change is not significant, there will usually be no problem.

Next, the impact of rapping the outlet field on opacity must be determined. Ideally, outlet rapping should cause only a slight ‘blip’ in the opacity. The magnitude of the blip is relative to the ESP design - primarily the internal velocity and number of fields in the direction of gas flow. The fewer the number of fields and the higher the internal velocity, the more pronounced the opacity ‘blip’ during outlet rapping.

If the opacity blip is small (2-4%), then no additional timing adjustments are necessary. If the opacity blip is large (10%), it may be caused by too thick or too thin an ash layer on the plates in the outlet field. In order to determine which is the case, the rapping interval on the outlet rappers should be doubled and checked again after 24 hours. If the opacity blip decreased, stayed the same, or only increased slightly, no additional adjustments are necessary. However, if the opacity blip increased significantly, the outlet rapping interval should be reduced to half the initial setting and the test repeated. It is important to note that the amount of ash leaving the ESP is dependent on the setting of the last field's rapper timing. As a general rule, the faster the last field is rapped, the more ash will escape as rapping losses. Therefore, it is best to keep the outlet field rapping to the longest possible interval.

Adjust Remaining Outlet Rapping Intervals

Once the outlet field rapping interval is properly set, timing intervals between the outlet fields should be compared, beginning with the next-to-last field. In general, this field should be rapped twice as fast as the outlet field. If the outlet field timing was adjusted, the interval may need to be adjusted on this field as well. Similar action can be taken with the second-to-last field if there are five or more fields in the ESP. However, increasing the rapping interval on the first two fields of the ESP is not recommended, since these two fields collect most of the ash and need to be kept clean.

Reduced Power / Power-Off Rapping

For difficult to remove ashes, a reduced power or power-off rapping approach can be used. The technique of power-off rapping is to de-energize an electrical section before rapping the collecting plates. This approach significantly enhances plate cleaning because the electrical holding force is removed during the rapping sequence. For obvious reasons, power-off rapping can succeed only with a precipitator which has a high degree of electrical sectionalization. Alternatively, power can be reduced to minimum levels during rapping. This approach is preferred when existing precipitator electrical sectionalization is marginal for power-off rapping. The voltage set point used during rapping should be approached incrementally since ash reentrainment can overwhelm potential improvement. At low load, more aggressive set points may be implemented. The effects of this are temporary, lasting several hours, when full load operation is resumed and set points are returned to normal.

Discharge Electrode Rapping

Discharge electrode rapping is appropriately set for near-maximum cleaning levels, because, unlike collection plate rapping, there is little or no significant reentrainment penalty associated with the discharge electrode system. However, excessive rapping of the discharge electrode system wastes energy and may lead to premature mechanical failure of the discharge electrodes, as well as the rappers themselves. The appropriate rapping level produces sufficient cleaning while limiting wear and tear on the discharge electrode system.

As with the collecting plates, adjust the rapping frequency field by field. The same time intervals suggested for collecting plate rapping - or perhaps more frequent intervals - are good starting points.

Acceptable cleanliness can be determined by evaluating voltage current (V-I) curves taken under both dirty and clean air load conditions. As ash buildup increases, corona start voltage increases and the V-I curve shifts toward a secondary voltage noticeably higher than clean air load condition.

Rapping changes and upgrades on discharge electrode systems can produce significant performance improvement. This is especially true on installations using electromagnetic vibrators because plant operators or maintenance personnel inspecting vibrators tend to simply listen for vibrator operation, which does not ensure that adequate energy is being transmitted to the electrode. The internal strike plate clearance must be checked and vibration should be verified internally using a vibration monitor or accelerometer at the discharge electrode support frame. Vibrators should be set to an "on" time duration of not less than 30 seconds. Due to minimal surface area of discharge electrodes, no opacity responses should be observed.

Safety

Safety First

If high levels of carbon are known to exist on the collecting plates or in the hoppers, do not open the precipitator access doors until the precipitator has cooled below 52°C (125°F). Spontaneous combustion of hot dust may be caused by an inrush of air.

Gases inside a precipitator are toxic and can cause severe injury or death. The precipitator must be purged completely before personnel are allowed to enter. Adequate ventilation must be maintained because collected fly ash may give off toxic fumes.

Extreme caution is required when conducting an internal inspection of an ESP and the associated ductwork. The first precaution is to make sure that the electrical power supplies are off and tagged out. Short each individual discharge electrode structure to ground with an appropriate clamp-type shorting shunt. It is recommended that the Safety Key Interlock System be implemented when entering the precipitator. The system ensures that a correct sequential procedure is followed for switching-off and earthing of the precipitator. Install adequate lighting when entering the ESP. Exercise care when moving through the unit, especially on ladders and walkways. Ash falling from plates and structures presents a hazard. Wear hard hat (helmet), safety glasses, lung protection and gloves as appropriate. Make sure there is always someone in talking distance, either directly or by radio. If you are new at inspections, work with an experienced partner.

Dealing with Fly Ash Hopper

Since fly ash may be hot, fatal accident can occur if care is not taken. While dealing with a fly ash hopper, always follow the guidelines given below.

If it is necessary to rod a hopper, either through a hand hole in the ash intake or through a poke hole in the hopper, to clear a plug, the operator must use protection for the body, hands, feet and face against any possible outflow of ash. Never rod hoppers with uninsulated metal.

Never open a hopper filled with ash (except in an emergency).

Hot/Flammable Dust

- **Latch Safety Chain**
- **Open Door Slowly**
- **Knock Overhead Dust**

Warning for Opening Hopper Door

Never use a ladder for gaining access to a hopper that must be opened.

Never place yourself, or any other person, in the path of an ash flow. If a hopper must be opened, the person opening it must be safely away from the path of any possible ash flow.

As shown in above figure, before opening a hopper door, latch safety chain and open the door slowly. Knock overhead dust before entering in the hopper.

No one should enter a hopper for inspection unless the hopper is cool and ventilated. Another person, who is prepared and equipped to help in case of an emergency must be stationed outside the hopper.

ESP Maintenance

Routine maintenance of an ESP is very simple. The only maintenance requirement is the periodic lubrication of external equipment on an ESP, as set forth in the maintenance manual, are drive elements of collecting and emitting rapping systems. These may be motors, gear reducers, vibrators, air valves and cylinders, chain drives or similar mechanical equipment. Hence, most so-called maintenance work is really the thorough inspection of components to ascertain that they are functioning properly.

Inspection and Maintenance of External Components

The thorough inspection of components is very important for successful operation of an ESP. The external components should be inspected on a regular basis as per vendors' recommendations. In absence of any recommendation by vendor, once a week inspection is suggested.

Rapping system problems are diagnosed by observing trends in the stack opacity. In order to evaluate the severity of rapping losses, opacity is compared with the rappers on to the opacity with the rappers off. If the average opacity with the rappers on is more than 1.4 times the average opacity with the rappers off for cold-side units (or more than 1.5 times for hot-side units), then reentrainment is likely excessive. Opacity trends can also be analyzed to determine insufficient rapping, excessive rapping, and localized reentrainment problems.

Collection plate rapping can cause significant reentrainment losses if improperly timed. Significant power reduction, if collection plate rapping is absent, will be experienced due to thick layers of ash buildup on collection plates that are not rapped.

The rapping of discharge electrodes is generally more critical to performance. Ash buildup on discharge electrodes interferes with corona formation by reducing the desired steep electrical field gradient close to the electrode. This forces the power supply to operate at higher voltage levels for any given current flow needed to collect particulate. Discharge electrode buildup may be diagnosed online by plotting the observed operating point against the clean V-I curve. If, for a given primary or secondary current flow, the voltage is more than 15% above that of the clean curve, rapping problems are probable.

All motor driven rapping shafts should be checked to see that they are actually rotating. Do not rely on the on/off indicating lights in the control room. Vibrators and impact rappers should also be checked to see that they are in operation.

Ten Penny Nail

Vibrators sometimes stick, or lose their effectiveness as internal stops and spacers wear. A simple check to ascertain that all roof mounted vibrators are functioning, at least to some extent, is to stand a common ten penny nail (a ten penny nail is a nail 3 inches long) on its head atop each vibrator. At the end of one rapping cycle, all nails should have fallen over.

One of the most common ESP operating incidents is T-R-set trip out. T-R set failure can be caused by a number of ground-related issues, including overfilled hoppers, carbon fouling or tracking of high voltage insulators internal to the precipitator box, electrically shorted insulators, discharge electrode failure, low-voltage relay failure, or other internal grounding problems.

T-R sets should be inspected to see that all selector switches are in the correct position and that temperature indicators are normal. Listen for sounds of electrical arcing in the T-R set, or in the high voltage bus duct. Arcing in the T-R set may be a sign of deteriorating dielectric strength of the transformer oil, and prompt attention may prevent complete breakdown with resulting destruction of the transformer. Arcing in the bus duct may be the result of condensation on insulators or an off-center bus. In either case, it should be corrected before further damage ensues.

Most T-R set failures begin with contamination of the transformer oil. Daily fluctuations in oil temperatures (due extreme environment or sets installed on cycling boilers) cause the tank to breathe. Such breathing results in water condensation and a loss of dielectric strength of the transformer oil. In time, this leads to internal arcing, oil carbonization, further loss of dielectric strength and eventually unit failure.

Voltage controller panel meters can be used to diagnose and troubleshoot T-R set grounding problems. The telltale signs of a grounded field are high current readings and low or zero voltage readings.

This first step in troubleshooting a DC-side ground is to check the ash level in the hopper below the grounded field. If the hopper is overfilled, the T-R set should be de-energized as soon as possible to prevent clinker formation. Overfilled hoppers can result in ash levels that are high enough to form a conductive bridge between the bottom of the discharge electrode frame and the collecting plate. In some cases, the ash may be electrically heated by the current passing to the grounded plate, forming a solid mass referred to as a “clinker”. Clinkers are difficult to remove and may further aggravate ash removal.

If the hopper is not plugged, the ground could be elsewhere in the precipitator or in the T-R set itself. To make this determination, the high voltage bushing in the grounded section should be disconnected from the precipitator (observing necessary safety procedures). If the meter readings show no current flow, then the grounding problem is within the precipitator. In this case, the cause may be a broken wire/defective electrode, or a grounded or defective insulator. If the meter readings show current flow after disconnecting the high voltage bushing, the grounding problem is within the T-R set or the bushing itself is defective.

Much less common are short circuits that occur within the T-R set itself. A common cause of T-R set problems is failure of the internal diode network. Diodes may fail due to excessive electrical stress (prolonged operation in overcurrent or overvoltage conditions) or overheating. Diodes should be checked for shorts. If the diodes are working properly, the problem may be a defective transformer. This can be checked by engaging the T-R set without the diodes. If the primary current level is still high, then the transformer may need replacement. Most T-R set failures begin with contamination of the transformer oil, which serves both as a cooling and dielectric medium to handle voltage stress on the T-R set.

To insure continued performance of T-R sets, it is recommended that regular preventative maintenance checks of T-R set oil should be carried out to prevent future failures. This would include annual oil quality tests and particulate filtering, as needed.

The best way to prevent insulator failure is through effective preventative maintenance on the insulators themselves and the seal air system for the insulator.

All support insulators should be checked at least annually for chips or cracks and evidence of electrical tracking and replaced, as necessary. Tracking can cause insulator failure by concentrating excessively high temperatures on the surface. Alignment and anti-sway insulators should be checked for integrity and for dust buildup or other evidence of conduction paths to ground.

There should be no significant buildup of dust on any of the insulators. Dust buildup, particularly high concentrations of carbon, may cause increased sparking and/or grounding. If there is any evidence of significant ash buildup, the seal air system for the insulators should be inspected for proper operation.

Insulators should be brushed down during the inspection to facilitate inspection. Technicians should use a heavy bristle brush, as opposed to a wire brush, to complete this task in order to minimize the risk of damaging the insulator. For tenacious residues, a solvent may be used for the final wipe down. Abrasive cleaners should not be used, since they may damage the surface glaze.

Check condition of the thermal insulation. In particular, be alert to damaged cladding (protective sheeting). Damaged cladding might admit rainwater and ruin the under lying insulation material.

Listen for sounds of air in leakage, particularly at access doors. Door gasket may need to be replaced

When inspecting the hopper area, check that all level alarms are in working order. Most such alarms have a "test" switch or button on their control panel. Use it.

Observe the operation of the ash handling system valves, and listen for air leaks through worn valves or seats.

Finally, when inspecting the precipitator control room, check to see that the ambient temperature is in range, and that the cabinets are clean, both inside and outside.

Problem Evaluation

During operation, the condition of internal parts of the precipitator can be inferred from the electrical meter readings. Hence electrical meter readings should be recorded in every shift and they should be evaluated at the end of the shift for maintenance needs.

A comparison between design records and operating records indicate whether operating parameters have changed significantly from the design conditions.

Analog meters are typically more useful than digital meters in troubleshooting various ESP problems. For this reason, it is recommended that analog meters also be installed on newer systems that have only digital meters. As a key troubleshooting tool, it is also important that panel meters be calibrated regularly.

The EPA (1985) categorized the major performance problems associated with electrostatic precipitators into seven areas: resistivity, dust buildup, wire breakage, hopper pluggage, misalignment of ESP components, changes in particle size distribution, and air inleakage. These problems are related to design limitations, operational changes, and/or maintenance procedures.

Problems Related to Resistivity

The resistivity of the collected dust on the collection plate affects the acceptable current density through the dust layer, dust removal from the plates, and indirectly, the corona charging process. The optimum resistivity range for ESP operation is relatively narrow; both high and low resistivity cause problems. Expensive retrofitting or modifications may be required if the dust resistivity is vastly different than the design range.

High Resistivity

High dust resistivity is a more common problem than low dust resistivity. Particles having high resistivity are unable to release or transfer electrical charge. Hence, at the collection plate, the particles neither give up very much of their acquired charge nor easily pass the corona current to the grounded collection plates. High dust resistivity conditions are indicated by low primary and secondary voltages, suppressed secondary currents and high spark rates in all fields. This condition makes it difficult for the T-R controller to function adequately.

The most significant effect of high resistivity ash is the potential for back corona formation and/or sparking. High resistivity ash particles do not readily lose their charge after depositing on the collecting plate. As a result, as the ash layer begins to build, a voltage drop forms across the layer and a surplus of positive ions is created on the surface of the dust. Depending on the resistivity of the ash and the thickness of the ash layer, an electrical field strong enough to breakdown the ash layer electrically may form. When electrical breakdowns occur, either a spark will be generated or back corona will occur. In the latter case, positive ions will be formed and these positive ions will cross the inter-electrode space and collide with the negative ions and charged particles that are undergoing the normal charging process. This phenomenon is also called "reverse ionization" or back corona. It effectively neutralizes the normal charging process and significantly reduces ESP performance.

Back corona may be diagnosed by observing the analog panel meters as the secondary current limit is gradually increased from its minimum value. Under back corona conditions, as the current increases, the secondary kV meter (and primary) will initially show a corresponding, gradual increase but suddenly begin dropping.

Severe sparking can cause excessive charging off-time, spark "blasting" of particulate on the plate, broken wires due to electrical erosion, and reduced average current levels. The reduced current levels generally lead to deteriorated performance. Because the current level is indicative of the charging process, the low current and voltage levels that occur inside an ESP operating with high resistivity dust generally reflect slower charging rates and lower particle migration velocities to the plate. Particle collection is reduced; consequently, the ESP operates as though it were "undersized." The operating conditions can be modified (for example, increasing temperature) or conditioning agents (for example, sulfur) can be used to accommodate/solve this problem and thereby improve performance.

High resistivity also tends to promote rapping problems, as the electrical properties of the dust tend to make it very tenacious. High voltage drop through the dust layer and the retention of electrical charge by the particles make the dust difficult to remove because of its strong attraction to the plate. The greater rapping forces usually required to dislodge the dust may also aggravate or cause a rapping reentrainment problem. Important items to remember are (1) difficulty in removing the high-resistivity dust is related to the electrical characteristics, not to the sticky or cohesive nature of the dust; and (2) the ESP must be able to withstand the necessary increased rapping forces without sustaining damage to insulators or plate support systems.

Low Resistivity

Low dust resistivity, although not as common, can be just as detrimental to the performance of an ESP as high resistivity. When particles with low resistivity reach the collection plate, they release much of their acquired charge and pass the corona current quite easily to the grounded collection plate. Without the attractive and repulsive electrical forces that are normally present at normal dust resistivities, the binding forces between the dust and the plate are considerably weakened. Therefore, particle reentrainment is a substantial problem at low resistivity.

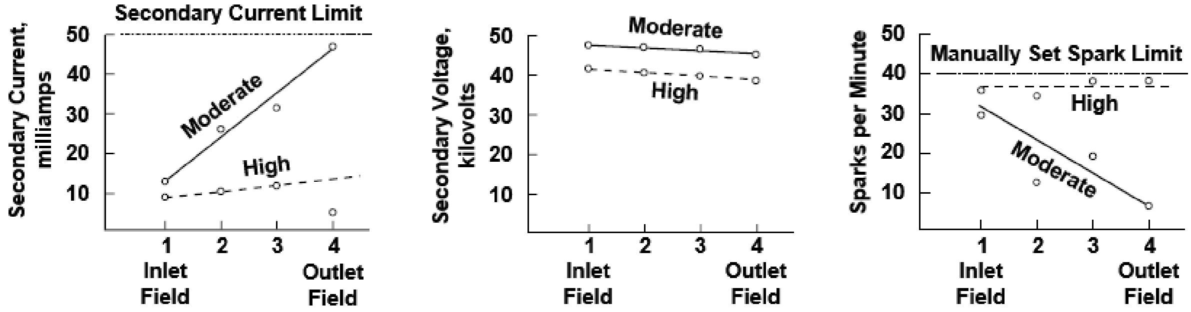
Since there is lower resistance to current flow for particles with low resistivity (compared to normal or high), lower operating voltages are required to obtain substantial current flow. Operating voltages and currents are typically close to clean plate conditions, even when there is some dust accumulation on the plate. Low resistivity conditions, are typically characterized by low operating voltages, high current flow, and low spark rates.

Despite the large flow of current under low resistivity conditions, the corresponding low voltages yield lower particle migration velocities to the plate. Thus, particles of a given size take longer to reach the plate than would be expected. When combined with substantial dust reentrainment, the result is poor ESP performance. In this case, the large flow of power to the ESP represents a waste of power.

Low-resistivity problems typically result from the chemical characteristics of the particulate and not from flue gas temperature. The particulate may be enriched with compounds that are inherently low in resistivity, either due to poor operation of the process or to the inherent nature of the process. Examples of such enrichment include excessive carbon levels in fly ash (due to poor combustion – large modern pulverized coal fired boilers typically contains from 2% to 10% carbon), the presence of naturally occurring alkalis in wood ash, iron oxide in steel-making operations, or the presence of other low-resistivity materials in the dust.

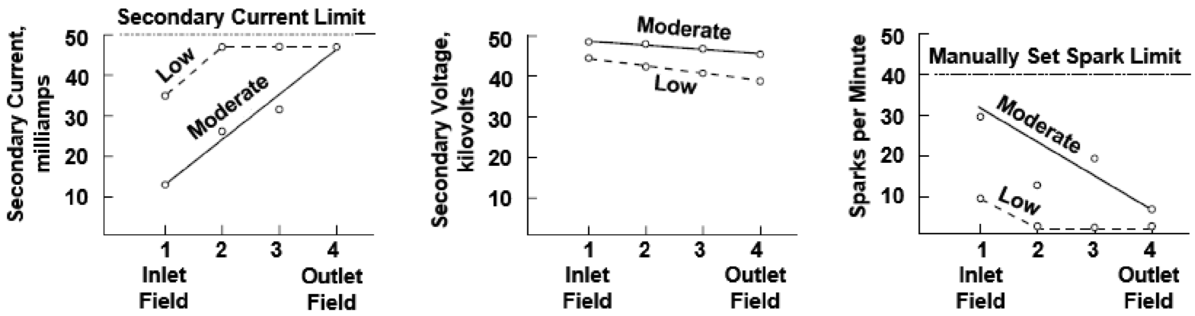
Typical High, Normal and Low Resistivity Curves

Evaluating the current and spark rate trends from the inlet to the outlet fields provides a means of evaluating the general resistivity conditions. Moderate dust resistivity conditions, under which ESPs work very well, are indicated by low secondary currents in the inlet field and progressively higher values going toward the outlet. Spark rates under moderate resistivity are moderate in the inlet fields and decrease to essentially zero in the outlet field. High resistivity conditions are indicated by low secondary currents in all of the fields coupled with very high spark rates. Conversely, low resistivity has very high currents and low spark rates in all the fields.



Typical T-R Set Plots - High Resistivity Versus Moderate (Normal) Resistivity

Above figure shows the typical trend lines for moderate (normal) and high resistivity dusts in a four field ESP. As the resistivity goes from moderate to high, the currents decrease dramatically in all of the fields. This is due to the suppressing effect caused by the strong electrostatic field created on the dust layer, and to increased electrical sparking. The decrease in currents is most noticeable in the outlet fields which previously had relatively high currents. Spark rates increase dramatically during high resistivity. Often most of the fields will hit the spark rate limits programmed in by the plant operators. Once the spark rate limit is sensed by the automatic voltage controllers, it no longer attempts to drive up the voltage. This causes a reduction in the operating voltages of these fields. The overall impact on the opacity is substantially increased emissions. In some cases, puffing again occurs during rapping. This is due to reduced capability of the precipitator fields to collect the slight quantities of particles released during rapping of high resistivity dust.



Typical T-R Set Plots - Low Resistivity Versus Moderate (Normal) Resistivity

Above figure shows the typical trend lines for moderate (normal) and low resistivity dusts in a four field ESP. The moderate resistivity dust shows a steady increase of current from the first field to the fourth field, while the secondary current increases rapidly for all fields when the dust exhibits low resistivity. This effect is especially noticeable in the inlet fields which previously had the lowest currents. This increase in current is due simply to the fact that the dust layer's electrostatic field is too weak to significantly impede the charging field created by the discharged electrodes. At low resistivity, the spark rates are generally very low or zero. The voltages in all of the fields are a little lower than normal since the automatic voltage controllers sense that the power supply is at its current limit; therefore, the controller does not attempt to drive the voltage up any further. While the low resistivity conditions persist, there can be frequent and severe puffs (opacity increase) which occur after each collection plate rapper activates.

Using the current, voltage, and spark rate plots is a very good way to use readily available information to evaluate the impossible-to-directly monitor but nevertheless important resistivity conditions. It is possible to differentiate between problems caused by mechanical faults in a single field (such as insulator leakage) and resistivity conditions which inherently affect all of the fields in varying degrees. However, these trend lines are not a perfect analysis tool for evaluating resistivity. A few precipitators never display typical electrical trend lines since they have undersized T-R sets, undersized fields, improperly set automatic voltage controllers, or severe mechanical problems affecting most of the fields.

Dust Accumulation

There are three primary causes of dust accumulation on electrodes:

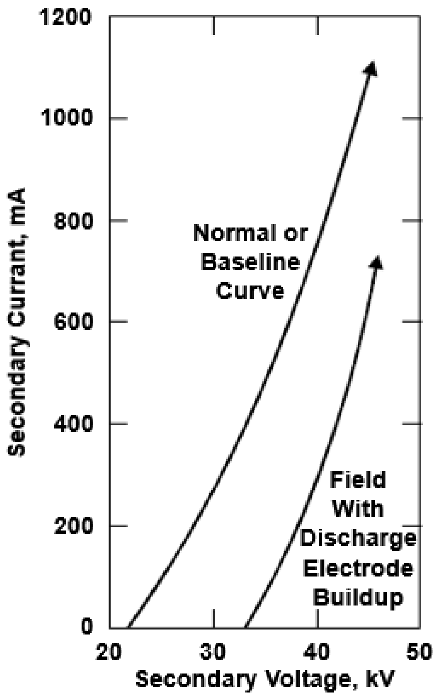
- Inadequate rapping system
- Sticky dust
- Operation at temperatures below the dew point level

The usual cause for buildup of dust on the collection plates or discharge wires is failure of the rapping system or an inadequate rapping system. The rapping system must provide sufficient force to dislodge the dust without damaging the ESP or causing excessive reentrainment.

Rapper operation may be difficult to check on some ESPs because the time periods between rapper activation can range from 1 to 8 hours on the outlet field. One method of checking rapper operation involves installing a maintenance-check cycle that allows a check of all rappers in 2 to 5 minutes by following a simple rapping pattern.

Excessive dust buildup also may result from sticky dusts or operation at gas dew point conditions. In some cases, the dusts may be removed by increasing the temperature, but in many cases the ESP must be entered and washed out. If sticky particulates are expected (such as tars and asphalts), a wet wall ESP is usually used because problems can occur when large quantities of sticky particles enter a dry ESP.

Sticky particulates can also become a problem when the flue gas temperature falls below the dew point level. Although acid dew point is usually of greater concern in most applications, moisture dew point is important, too. When moisture dew point conditions are reached, liquid droplets tend to form that can bind the particulate to the plate and wire. These conditions also accelerate corrosion. Carryover of water droplets or excessive moisture can also cause this problem (e.g., improper atomization of water in spray cooling of the gas or failure of a waterwall or economizer tube in a boiler). In some instances the dust layer that has built up can be removed by increasing the intensity and frequency of the rapping while raising the temperature to "dry out" the dust layer. In most cases, however, it is necessary to shutdown the unit and wash out or "chisel out" the buildup to clean the plates. Localized problems can occur where inleakage causes localized decreases in gas temperature.



V-I Curve for a Field with Excessive Wire Buildup

In an operating ESP, differences in the V-I curves can be used to evaluate if a dust buildup problem exists. Buildup of material on the discharge electrodes often means an increase in voltage to maintain a given operating current. The effect of dust buildup on discharge electrodes is usually equivalent to increasing the effective wire diameter. Since the corona starting voltage is strongly a function of wire diameter, the corona starting voltage tends to increase and the whole V-I curve tends to shift to the right as shown in above figure. Sparking tends to occur at about the same voltage as it does without dust buildup, unless resistivity is high. This effect on corona starting voltage is usually more pronounced when straight wires are uniformly coated with a heavy dust, and less pronounced on barbed wires and rigid electrodes or when the dust layer is not uniform. Barbed wires and rigid electrodes tend to keep the "points" relatively clean and to maintain a small effective wire diameter and, therefore, a low corona starting voltage. Nevertheless, a higher voltage would still be required to spread the corona discharge over the wire when dust buildup occurs. Thus, buildup on the discharge electrodes would still be characterized by a higher voltage to maintain a given current level.

Wire Breakage

Wires usually fail in one of three areas: at the top of the wire, at the bottom of the wire, and wherever misalignment or slack wires reduce the clearance between the wire and collecting plate. Wire failure may be due to electrical erosion, mechanical erosion, corrosion, or some combination of these. When wire failures occur, they usually short-out the field where they are located. Thus, the failure of one wire can cause the loss of particle collection in an entire field or bus section. One of the advantages of rigid frame and rigid electrode ESPs is their use of shorter wires or no wires at all. Hence rigid frame or rigid electrode are used in all new ESP or engineered upgrades.

Electrical erosion is caused by excessive sparking. Sparking usually occurs at points where there is close clearance within a field due to a warped plate, misaligned guidance frames, or bowed wires. The maximum operating voltage is usually limited by these close tolerance areas because the spark over voltage depends on the distance between the wire and the plate. The smaller the distance between the wire and plate, the lower the spark over voltage. Under normal circumstances random sparking does little damage to the ESP. During sparking, most of the power supplied to energize the field is directed to the location of the spark, and the voltage field around the remaining wires collapses. The considerable quantity of energy available during the spark is usually sufficient to vaporize a small quantity of metal. When sparking continues to occur at the same location, the wire usually "necks down" because of electrical erosion until it is unable to withstand the tension and breaks. Misalignment of the discharge electrodes relative to the plates increases the potential for broken wires, decreases the operating voltage and current because of sparking, and decreases the performance potential of that field in the ESP.

Although the breakage of wires at the top and bottom where the wire passes through the field can be aggravated by misalignment, the distortion of the electrical field at the edges of the plate tends to be the cause of breakage. This distortion of the field, which occurs where the wire passes the end of the plate, tends to promote sparking and gradual electrical erosion of the wires.

Design faults and the failure to maintain alignment generally contribute to mechanical erosion (or wear) of the wire.

Corrosion of the wires can also lead to wire failures. Corrosion, an electrochemical reaction, can occur for several reasons, the most common being acid dew point. When the rate of corrosion is high because of long periods of operating the ESP below the acid dew point, failures are frequent. In these cases the corrosion problem is more likely to be a localized one (e.g., in places where cooling of the gas stream occurs, such as inleakage points and the walls of the ESP). Corrosion-related wire failures can also be aggravated by startup-shutdown procedures that allow the gas streams to pass through the dew point many times.

Wire crimping is another cause of wire failure because a crimp creates a residual stress. Crimps usually occur at the top and bottom of the wires where they attach to the upper wire frame or bottle weight; however, a crimp may occur at any point along the wire.

Although ESP performance will generally not suffer with up to approximately 10% of the wires removed, records should be maintained to help avoid a condition in which entire gas lanes may be de-energized.

Hopper Pluggage

Perhaps no other problem (except fire or explosion) has the potential for degrading ESP performance as much as hopper pluggage. Hopper pluggage can permanently damage an ESP and severely affect both short-term and long-term performance. Hopper pluggage is difficult to diagnose because its effect is not immediately apparent on the T-R set panel meters. In many cases, the effect of pluggage does not show up on the electrical readings until the hopper is nearly full.

The electrical reaction to most plugged hoppers is the same as that for internal misalignment, a loose wire in the ESP, or excessive dust buildup on the plates. Typical symptoms include heavy or "bursty" sparking in the field(s) over the plugged hopper and reduced voltage and current in response to the reduced clearance and higher spark rate. In weighted wire designs, high dust levels in the hopper may raise the weight and cause slack wires and increased arcing within the ESP. In many cases, this will trip the T-R set off-line because of overcurrent or undervoltage protection circuits. In some situations, the sparking continues even as the dust level exceeds hopper capacity and builds up between the plate and the wire; whereas in others, the voltage continues to decrease as the current increases and little or no sparking occurs. This drain of power away from corona generation renders the field performance virtually useless. Over filled hoppers can result in ash levels that are high enough to form a conductive bridge between the bottom of the discharge electrode frame and the collecting plate. In some cases, the ash may be electrically heated by the current passing to the grounded plate, forming a solid mass referred to as a “clinker”.

The buildup of dust under and into the collection area can cause the plate or discharge electrode guide frames to shift. The buildup can also place these frames under enough pressure to distort them or to cause permanent warping of the collection plate(s). If this happens, performance of the affected field remains diminished by misalignment, even after the hopper is cleared.

Hopper pluggage can be caused by the following:

- Obstructions due to fallen wires and/or bottle weights
- Inadequately sized solids-removal equipment
- Use of hoppers for dust storage
- Inadequate insulation and hopper heating
- Air inleakage through access doors

Most dusts flow best when they are hot, therefore, cooling the dusts can promote a hopper pluggage problem.

Misalignment

Since the maximum operating voltage/current levels depend on the path of least resistance in a field, electrode misalignment (between discharge electrode and collector plates) reduces the operating voltage and current required for sparking. The V-I curve would indicate a somewhat lower voltage to achieve a low current level with the sparking voltage and current greatly reduced.

Changes in Particle Size

Unusually fine particles present a problem under the following two circumstances:

1. When the ESP is not designed to handle them

2. When a process change or modification shifts the particle size distribution into the range where ESP performance is poorest.

A shift in particle size distribution tends to alter electrical characteristics and increase the number of particles emitted in the light-scattering size ranges (opacity).

There are two principal charging mechanisms: field charging and diffusion charging. Although field charging tends to dominate in the ESP and acts on particles greater than 1 micrometer in diameter, it cannot charge and capture smaller particles. Diffusion charging, on the other hand works well for particles smaller than 0.1 micrometer in diameter. ESP performance diminishes for particulates in the range of 0.2 - 0.9 micrometer because neither charging mechanism is very effective for particles in this range. These particles are more difficult to charge and once charged, they are easily bumped around by the gas stream, making them difficult to collect. Depending upon the type of source being controlled, the collection efficiency of an ESP can drop from as high as 99.9% on particles sized above 1.0 micrometer or below 0.1 micrometer, to only 85 to 90% on particles in the 0.2 - 0.9 micrometer diameter range.

When heavy loadings of fine particles enter the ESP, two significant electrical effects can occur: space charge and corona quenching. At moderate resistivities, the space-charge effects normally occur in the inlet or perhaps the second field of ESPs. Because it takes a longer time to charge fine particles and to force them to migrate to the plate, a cloud of negatively charged particles forms in the gas stream. This cloud of charged particles is called a space charge. It interferes with the corona generation process and impedes the flow of negatively charged gas ions from the wire to the collection plate. The interference of the space charge with corona generation is called corona quenching.When this occurs, the T-R controller responds by increasing the operating voltage to maintain current flow and corona generation. The increase in voltage usually causes increased spark rates, which may in turn signal the controller to reduce the voltage and current in an attempt to maintain a reasonable spark rate. Under moderate resistivity conditions, the fine dust particles are usually collected by the time they reach the third field of the ESP which explains the disappearance of the space charge in these later fields. The T-R controller responds to the cleaner gas in these later fields by decreasing the voltage level, but the current levels will increase markedly. When quantities of fine particles being processed by the ESP increase, the space charging effect may progress further into the ESP.

Air Inleakage

In some instances, air inleakage can be beneficial to ESP performance, but in most cases its effect is detrimental. Inleakage may occur within the process itself (for example, in case of a boiler due to bypassing of the air preheater) or in the ESP and is caused by leaking access doors, leaking ductwork, and even open sample ports.

Inleakage usually cools the gas stream, and can also introduce additional moisture. Air inleakage often causes localized corrosion of the ESP shell, plates, and wires. The temperature differential also can cause electrical disturbances (sparking) in the field. Finally, the introduction of ambient air can affect the gas distribution near the point of entry.

Inleakage is also accompanied by an increase in gas volume. In some processes, a certain amount of inleakage is expected. Excessive gas volume due to air inleakage, however, can cause an increase in emissions due to higher velocities through the ESP and greater reentrainment of particulate matter.

Internal Inspection

Internal inspection of the full precipitator can only be performed during a boiler outage. Every such outage, whether scheduled or not, should be considered as an opportunity to inspect the inside of the precipitator.

Note:
When shutting down the ESP, be sure to turn off the rapper system before turning off power to the transformer rectifier sets (T-R sets) so that the ash layer will remain on the collecting plates and discharge electrodes. This is essential for the dirty air load test and inspection.

When a boiler outage occurs, inspect those bus sections known to be grounded, or displaying unusual electrical performance.

During a scheduled outage of an ESP, first empty all hoppers. Then visual inspections of the ESP should be conducted just after the unit/stream has gone offline when the ESP is still loaded with ash ("dirty") and again after the ESP has been cleaned through water washing or grit/sand blasting. Dirty ESP inspection assist in diagnosing problems with ash buildup, gas flow distribution, rapping, and electrical tracking. Clean ESP inspection assist in diagnosing problems with misalignment, corrosion, leaks, and other mechanical damage.

Water washing either involves the use of multiple high-volume, high-pressure water hoses or the installation of a permanent wash header. Use plenty of water to avoid ash caking. Once washing has started, there should be no interruptions in the cleaning, especially in the presence of high-calcium ashes. The pozzolanic activity in high-calcium ashes can cause the formation of cement-like substances that are very difficult to remove. Use of high water volume should minimize this problem because large quantities of water will dilute the mixture sufficiently to avoid pozzolanic activity.

The advantages of water washing are as follows:

- A more thorough cleaning is possible, because reach is not limited to throw distance.
- It can be done quickly by few personnel. Because reach is not limited to throw distance, most units can be completely washed from the top elevation.
- There is less airborne ash, and thus less likelihood of a cleaning-induced visibility/opacity problem.

However, in case of water washing, a sluicing system is necessary for drainage and disposal.

Contrary to popularly held beliefs, water washing does not promote corrosion of ESP internals. If fact, this process can actually prevent surface corrosion (due to acid condensation) in high-sulfur coal situations compared to that can occur in an unwashed precipitator left offline for several weeks.

During internal inspection, check and take corrective action for the following Items.

- The access doors for cracked or broken gasket material.
- Gas distribution plates and flow straighteners in the inlet nozzle for buildup or pluggage.
- Collecting plates should be checked for structural integrity and areas of corrosion or erosion should be identified. Bowed or warped plates should be straightened. It is customary to find a thin layer of material on all surfaces. Both the corona and collecting surfaces may have as much as 1/8 in. of material uniformly distributed on their surfaces. In some instances, the collection electrodes may have a patchy appearance with some regions covered by a very thin layer while others may be 1/8 to 1/4 in. thick. this is usually not detrimental to performance. However, Excessive dust buildup (greater than 1/4 in.) should be removed manually. The location of unusual dust deposits should be recorded, and the rapping system serving that section should be carefully checked. Check the plate alignment (alignment between discharge electrode and collector plate). In practice, variations of ± 1/4 in. is acceptable. For plate heights greater than 40 feet, with plate spacing of 12 in. the tolerance may be increase to ± 1/2 in.
- The discharge electrodes should be checked for proper tension, excessive dust buildup (greater than 1/8 in.), and signs of arcing. Also check them for loose or broken wires, wire guides, and pipe frames.
- Check rapping shafts for wear of couplings, bearings and hammers. Check the rapper hammer alignment, and check for freedom of movement.
- Check the hoppers for clinkers or dust buildup.
- Inspect all internal structural members for signs of deterioration, corrosion, or distortion.

When the ground or close clearance has been found and corrected, a set of air load V-I readings should be recorded to be sure that all such defects have been located and repaired.

Collector Plates Straightening

One of' the typical reasons for degradation of precipitator performance and reliability is poor electrode clearances, often caused by collector plate distortion.

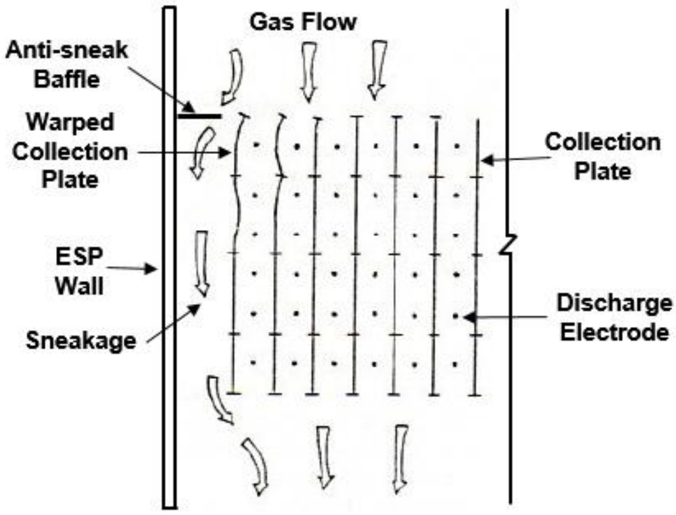
Collector plate distortion is most typically caused by improperly designed or installed plate spacer hardware at the top, bottom or sides of the plate. The bottom side spacer retaining bar usually interfaces with the precipitator structure in some manner to maintain the plate section in a particular position in space. If this hardware is designed in a manner which binds the plate section to the structure, the plates adjacent to that structure can be expected to bow. High level of ash in hoppers can also stress the plates during operation, resulting in permanent warpage and buckling.

The minimum clearance between the electrodes and plates is often referred to as the “spark gap". To realize design performance, the spark gap must remain within the design tolerance. Should the spark gap become shorter, for instance, due to a warped collector plate, a spark will occur at a lower voltage than otherwise thus causing the entire field to function at a lower voltage. In addition, this will typically result in a higher spark rate and less "on tine" for that electrical field. The effect is the same as if the precipitator were reduced in size.

Should electrode clearances become excessively close, performance will drop off' sharply, and reliability will be reduced as well. This condition is normally anticipated with a spark gap of 75% of optimum or less (3 3/8 in. for 9 in. plate spacing) but will vary depending on numerous factors.

In view of this, as a temporary measure, the decision is often made to remove large quantities of wires in order to increase the minimum spark gap to a more acceptable level. The precipitator is effectively reduced in size, but the reliability is restored. Many rigid frame designs offer no opportunity for this compromise, as close clearances cannot be eliminated by simple wire removal. Sometimes the discharge electrode frame or mast is also subject to distortion in the same manner as the collector plate.

Besides causing poor electrode clearances, collector plate distortion can reduce precipitator performance due to sneakage. Warped plates can act as flow diverters and may even direct flue gas into hoppers resulting in sneakage through hopper.



Sneakage along ESP Wall

As shown in above figure, collector plate warpage adjacent to precipitator walls can result in large openings at leading edge of anti-sneak baffles. Under this condition, flue gas is allowed to bypass the treatment area by travelling along the wall.

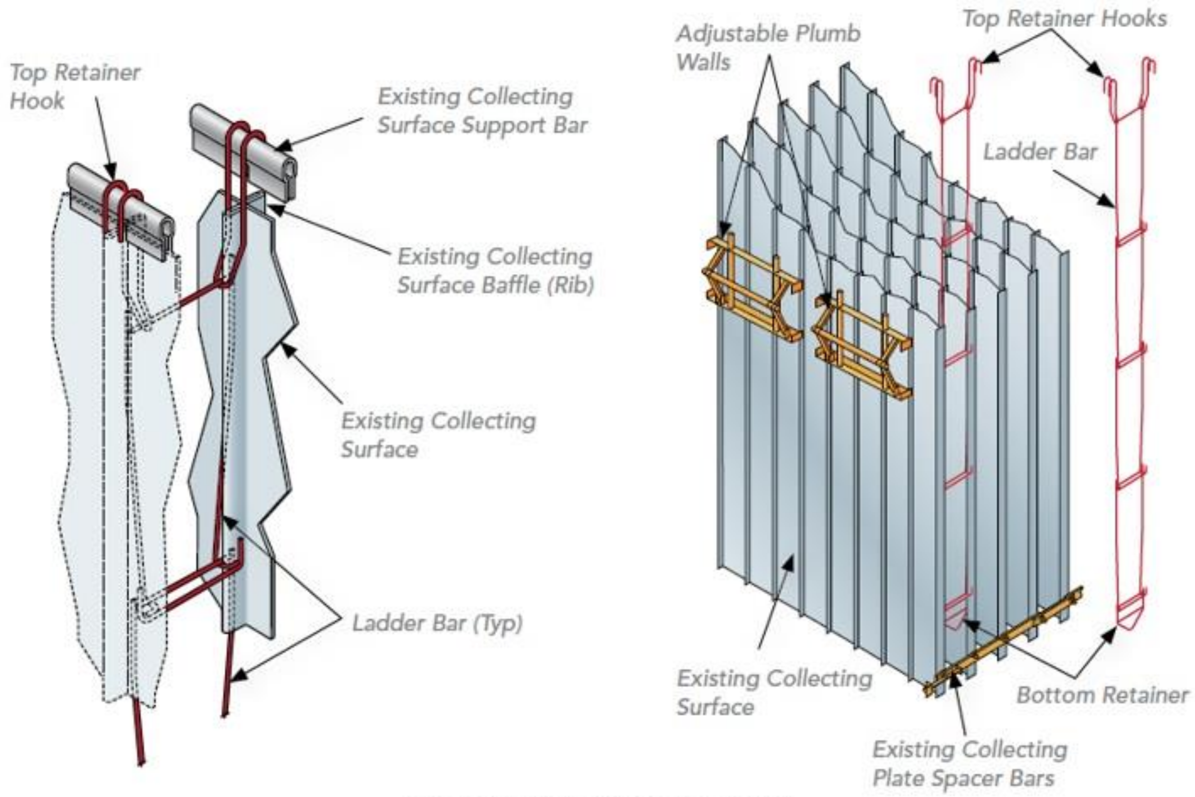
Another area of concern is the detrimental effect on collector plate rapping. A severely warped collector plate can dampen transmission of acceleration to its far corners. Even greater effect is due to the re-entrainment of the rapped material. To visualize, picture two collector plates: one in its original straight condition, one with a large simple bow along its entire length. Ideally, the straight collector plate is properly rapped, separating the ash layer from the surface cleanly under the shearing effect. Due to gravitational force, the ash then slides along the plate surface, within the dead air space created by the stiffener baffle of' the collector plate. The ash is thus protected from re-entrainment into the gas stream until reaching the hopper. The stiffener baffle looses its effect in the case of the bowed collector plate. On the prominent side of the bow, the ash moves along the plate surface until reaching the lower elevations. At this point, the slope of the collector plate cross section is reversed. The ash can then fall directly into the gas stream and be re-entrained into the system.

In view of above, several methods of repair have been devised which impose a localized stress upon the collector plate in an attempt to return the plate to a straight condition without their removal from the precipitator. One method which has been widely applied is known in the industry as “crimping". In this technique, a simple tool is used to form a small bend on the stiffener baffle on one side of the collector plate. Thus crimped, one side of the baffle is effectively shorter than in the uncrimped condition. Therefore, by crimping the collector plate at chosen locations, the plate is brought into alignment.

However, once crimped, a collector plate looses much of its structural rigidity. The plate is then more conducive to distortion than prior to repair. Collector plates repaired in this manner tend to further distort, and it has proven necessary, in a number of precipitators, to perform widespread crimping as a routine outage item. In addition, plates have been observed to return to the previous bowed condition almost immediately after straightening by this method.

Another method of collector plate repair, generally employed throughout the industry, is known as "heat straightening". A torch is used to heat the surface of the plate at chosen locations to change the shape of the plate in an attempt to bring the plate into satisfactory alignment. The plate is, in effect, intentionally warped and buckled in a way intended to counteract the existing warpage. However, such heating of the collector plates destroys the original cold rolled condition of the steel and imposes local stresses of an unknown nature within the plate. Once repaired in this manner, a collector plate will often distort more dramatically than the condition before repair. Like mechanical crimping, heat straightened plates have also been observed to return to a bowed condition almost immediately after repair.

To overcome above problems, many companies are now offering state of the art systems employing spacers or ladders to permanently repair the warped plates.



Ladder Bars by Babcock & Wilcox

Above figure shows a ladder bar system offered by Babcock & Wilcox (www.babcock.com).

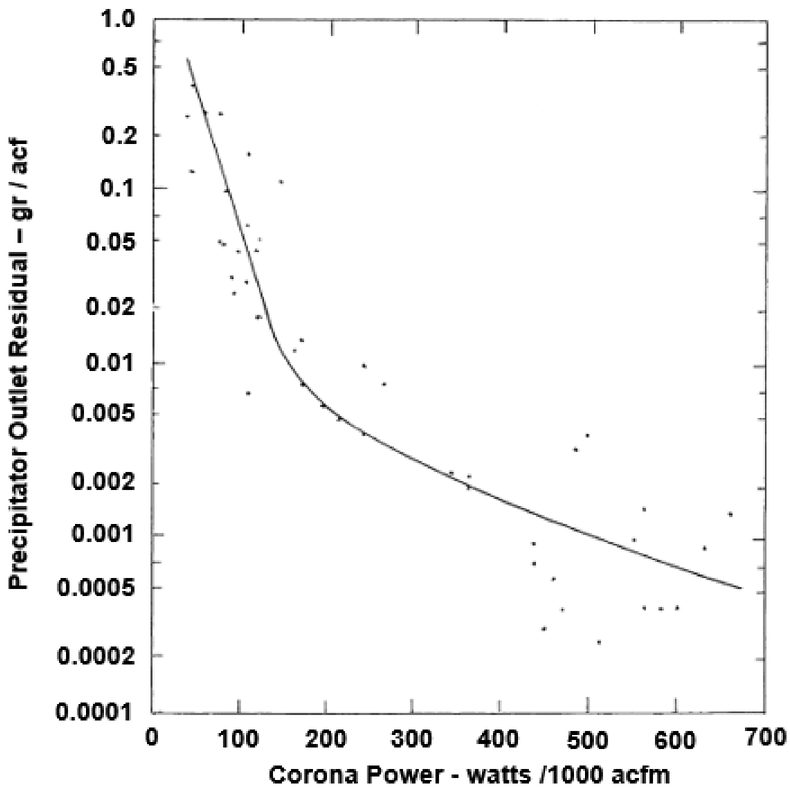
As shown in the figure, to restore ESP performance, ladder bars can be installed in the gas pass between the stiffeners of bowed collector plates. B&W offers customized ladder bars to fit most major ESP designs. Even severely bowed collector plates can be restored using their patented ladder bar system.

Ladder bars install quickly and easily to create a permanent repair that not only removes bowing, but prevents it from occurring. Hooks at the top of the ladder bar assembly hold it in position, with no welding, bolting or riveting required. ESP performance can be restored during a short outage at a fraction of the cost of plate replacement.

The ladder bar system is complemented by other products that improve the effectiveness of the straighteners. Beta bars are adjustable jacks used between the first collector plates and the wall to provide a stable foundation for the ladder bar system.

Dirty Stack Improvement Procedures

Precipitator trouble is, to the plant operator, any occurrence which results in an unacceptable opacity of the stack plume. As long as the stack is clean, he believes that he has no precipitator trouble (when in fact he may), and when the stack gets dirty, he believes that he has precipitator problems, although the cause of the dirty stack may lie elsewhere. Thus, it might be more accurate to call the so called precipitator trouble as "dirty stack improvement procedures."



Precipitator Outlet Fly Ash Concentration vs. Specific Corona Power

A dirty stack is almost invariably associated with a decrease in corona power. Therefore, the first step must be to obtain a set of control panel meter readings and compute the specific corona power. Above figure indicates the stack loading which should reasonably be expected for any level of specific corona power. If the stack appearance is much worse than should be expected from the indicated exit loading and particularly, if the opacity had deteriorated without a corresponding decrease in specific corona power, it would be a very unusual situation. Hypotheses which should be investigated are:

1. Loss of a sneakby baffle in the precipitator, permitting untreated gas to bypass the effective zones.
2. Bad gas distribution caused by breaking or plugging of gas distribution baffles.
3. Poor boiler operation, resulting in incomplete combustion and the production of smoke.
4. The venting of another boiler or smoke producing device into the same stack.
5. Problems with the opacity meter or the observer's eyesight.

Most commonly, however, the increased stack opacity will be found to correspond to a decrease in specific corona power.

If the specific corona power is indeed too low for the unit to attain its design performances, the problem becomes one of finding out why this is so. Electrical readings and V-I curves of parallel bus sections should be similar. If they are not, close clearances in the low powered sections should be suspected. Variations in operating power level of parallel sections may also be caused by temperature stratification of the flue gases entering the precipitator. Fields toward the rear of the precipitator should normally spark at a higher current level than those preceding fields in the same cell. If this is not so, there may be a close electrical clearance, a rapping failure, or cold air infiltration in the offending bus section.

If, as is often the case, the power levels of all of the power supplies are uniformly low, and the relationship between power levels of different sets is reasonable, the problem is most likely one of high ash resistivity, and originates in the boiler, not the precipitator.

Recordkeeping

The ability to learn from experience is especially important when dealing with electrostatic precipitator systems. In consideration of the rapid personnel turnover that typically occurs at utility plants, the need for accurate record keeping may be appreciated. Without accurate records, consulting engineers or service representatives may be denied information that could be vital to the proper diagnosis of a problem.

Depending upon the specifics of a particular utility installation, accurate records must be kept for the following:

- Precipitator electrical readings.
- Opacity readings.
- Electrical grounds.
- Discharge electrode failures.
- Ash accumulations on discharge and collecting electrodes.
- Ash accumulation on gas distribution devices.
- Hopper pluggage.
- Insulator cleanliness and failures.
- Misalignment.
- Rapping system problems.
- Corrosion problems.
- Component failures.
- Time and cost of repairs.
- Performance test data.

Emission Standards

Brief History of the U.S. Clean Air Act and information on current U.S. and Indian emission standards is given in this chapter.

Brief History of the Clean Air Act

In October 1948, a thick cloud of air pollution (smog) formed above the industrial town of Donora, Pennsylvania. The cloud which lingered for five days, killed 20 people and caused sickness in 6,000 of the town’s 14,000 people. In 1952, over 3,000 people died in what became known as London’s "Killer Fog." The smog was so thick that buses could not run without guides walking ahead of them carrying lanterns.

Events like these alerted Americans to the dangers that air pollution poses to public health and several federal and state laws were passed, including the original Clean Air Act of 1963, which established funding for the study and the cleanup of air pollution. But there was no comprehensive federal response to address air pollution until Congress passed a much stronger Clean Air Act in 1970. That same year Congress created the Environmental Protection Agency (EPA) and gave it the primary role in carrying out the law. Since 1970, EPA has been responsible for a variety of Clean Air Act programs to reduce air pollution nationwide.

Under the Clean Air Act, EPA sets limits on certain air pollutants, including setting limits on how much can be in the air anywhere in the United States. This helps to ensure basic health and environmental protection from air pollution for all Americans. The Clean Air Act also gives EPA the authority to limit emissions of air pollutants coming from sources like chemical plants, utilities, and steel mills. Individual states or tribes may have stronger air pollution laws, but they may not have weaker pollution limits than those set by EPA.

The Clean Air Act, which was last amended in 1990, requires EPA to set National Ambient Air Quality Standards (NAAQS) for pollutants considered harmful to public health and the environment. The Clean Air Act identifies two types of national ambient air quality standards. **Primary standards** provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. **Secondary standards** provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

The EPA has set National Ambient Air Quality Standards for six principal pollutants, which are called "criteria" air pollutants. They are particle pollution (often referred to as particulate matter), ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. Of the six pollutants, particle pollution and ground-level ozone are the most widespread health threats. Periodically, the standards are reviewed and may be revised.

Particle Pollution

Particle pollution, also known as particulate matter (PM), includes the very fine dust, soot, smoke, and droplets that are formed from chemical reactions, and produced when fuels such as coal, wood, or oil are burned. For example, sulfur dioxide and nitrogen oxide gases from motor vehicles, electric power generation, and industrial facilities react with sunlight and water vapor to form particles. Particles may also come from fireplaces, wood stoves, unpaved roads, crushing and grinding operations, and may be blown into the air by the wind.

Particulate matter regulations adopted over the years have gradually shifted from regulating the coarse particles that comprised total suspended particulate matter (TSP) to regulating the very small particles in the PM_{10} and $PM_{2.5}$ size ranges. This shift has occurred primarily because health effects research data indicated that small particles are most closely related to adverse health effects.

Total Suspended Particulate Matter (TSP)

Due to increasing concerns about the possible health and welfare effects of ambient particulate matter, U. S. regulatory agencies in the late 1960s began to measure the ambient concentrations of total suspended particulate matter (TSP) using High-Volume (Hi-Vol) ambient samplers that provided a single concentration value for a 24-hour sampling period. Particulate matter that was sufficiently small to remain suspended in the atmosphere and captured in the sampling systems of the Hi-Vol samplers was defined as TSP. Particles smaller than approximately 45 micrometers (45μm) - approximately the diameter of a human hair - are considered to be TSP.

PM_{10} and $PM_{2.5}$

The U.S. EPA defines PM_{10} as particulate matter with a diameter of 10 micrometers collected with 50% efficiency by a sampling collection device. However, for convenience purposes, PM_{10} is considered to include particles having an aerodynamic diameter of less than or equal to 10 micrometers. $PM_{2.5}$ will include particles having an aerodynamic diameter of 2.5 micrometers or less.

The term aerodynamic diameter is useful for all particles including the fibers and particle clusters. The aerodynamic diameter provides a simple means of categorizing the sizes of particles with a single dimension and in a way that relates to how particles move in a fluid.

In 1987, the U.S. EPA revised the NAAQS for particulate matter to include only particles equal to or smaller than 10 micrometers (μm). This change was made to focus regulatory attention on those particles that are sufficiently small to penetrate into the respiratory system and, therefore, contribute to adverse health effects. Particles larger than 10 μm are effectively filtered out by the nose and upper respiratory tract. Therefore, only particles equal to or smaller than 10 μm were measured in evaluating ambient air quality levels with respect to the NAAQS. These particulate matters are collectively designated as PM_{10} to differentiate them from TSP.

In 1997, the U.S. EPA added a new NAAQS applicable to particulate matter equal to or less than 2.5 μm and termed $PM_{2.5}$. The U.S. EPA concluded that the $PM_{2.5}$ NAAQS were needed in response to health effects research indicating that particulate matter in this size category was most closely associated with adverse health effects.

Health effects attributed to $PM_{2.5}$ are believed to result from both their small size and their composition. Small size increases the probability that the particles will penetrate deeply into the respiratory tract and be retained. There are also data indicating that materials present in $PM_{2.5}$ particles are considerably more toxic than those present in the larger particles.

Primary and Secondary Particulate Matter

Particulate matter can be divided into the following two categories: primary particulate matter and secondary particulate matter.

Primary particulate matter is material emitted directly in to the atmosphere. These emissions have been the focus of all particulate matter control programs prior to 1997. Primary particulate matter can consist of particles less than 0.1 micrometer to more than 100 micrometers; however, most of the primary particulate matter is in the coarse mode.

With the promulgation of the $PM_{2.5}$ standard aimed at fine and ultrafine particles, there is increasing attention concerning “secondary” particulate matter. This is particulate matter that forms in the atmosphere due to reactions of gaseous precursors. Secondary formation processes can result in the formation of new particles or the addition of particulate material to pre-existing particles. The gases most commonly associated with secondary particulate matter formation include sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds. Most of these gaseous precursors are emitted from anthropogenic sources; however, biogenic sources also contribute some nitrogen oxides, ammonia, and volatile organic compounds.

Current U. S. Standards

The current U. S. National Ambient Air Quality Standards are as per the following table. Units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air (µg/m^3).

Pollutant		Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)		primary	8 hours	9 ppm	Not to be exceeded more than once per year
			1 hours	35 ppm	
Lead (Pb)		primary and secondary	Rolling 3 month average	0.15 µg/m^3 (1)	Not to be exceeded
Nitrogen Dioxide (NO_2)		primary	1 hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		primary and secondary	1 year	53 ppb (2)	Annual Mean
Ozone (O_3)		primary and secondary	8 hours	0.070 ppm (3)	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	12.0 µg/m^3	annual mean, averaged over 3 years
		secondary	1 year	15.0 µg/m^3	annual mean, averaged over 3 years
		primary and secondary	24 hours	35 µg/m^3	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24 hours	150 µg/m^3	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		primary	1 hours	75 ppb (4)	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

(1) In areas designated nonattainment for the Pb standards prior to the promulgation of the current (2008) standards, and for which implementation plans to attain or maintain the current (2008) standards have not been submitted and approved, the previous standards (1.5 µg/m3 as a calendar quarter average) also remain in effect.

[(2)] The level of the annual NO_2 standard is 0.053 ppm. It is shown here in terms of ppb for the purposes of clearer comparison to the 1-hour standard level.

[(3)] Final rule signed October 1, 2015, and effective December 28, 2015. The previous (2008) O_3 standards additionally remain in effect in some areas. Revocation of the previous (2008) O_3 standards and transitioning to the current (2015) standards will be addressed in the implementation rule for the current standards.

[(4)] The previous SO_2 standards (0.14 ppm 24-hour and 0.03 ppm annual) will additionally remain in effect in certain areas: (1) any area for which it is not yet 1 year since the effective date of designation under the current (2010) standards, and (2) any area for which implementation plans providing for attainment of the current (2010) standard have not been submitted and approved and which is designated nonattainment under the previous SO_2 standards or is not meeting the requirements of a SIP call under the previous SO_2 standards (40 CFR 50.4(3)), A SIP call is an EPA action requiring a state to resubmit all or part of its State Implementation Plan to demonstrate attainment of the require NAAQS.

Emission Standard for Thermal Power Plant in India

The Central Pollution Control Board (CPCB) of India has developed National Standards for Effluents and Emission under the statutory powers of the Water (Prevention and Control of Pollution) Act, 1974 and the Air (Prevention and Control of Pollution) Act, 1981. These standards have been approved and notified by the Government of India, Ministry of Environment & Forests, under Section 25 of the Environmental (Protection) Act, 1986. Till now, Effluent standards for 37 categories of industries and Emission Standards for 31 categories of industries have been evolved and notified besides standards for ambient air quality, ambient noise, automobile and fuels quality specifications for petrol and diesel. Guidelines have also been developed separately for hospital waste management.

The emission standard for thermal power plant in India is as under.

Generation Capacity	Pollutant	Emission Limit
Generation capacity 210 MW or more	Particulate matter	150 mg/Nm^3
Generation capacity less than 210 MW	Particulate matter	350 mg/Nm^3

However, depending upon the requirement of local situation, such as protected area, the State Pollution Control Boards and other implementing agencies under the Environment (Protection) Act, 1986, may prescribe a limit of 150 mg/Nm^3, irrespective of generation capacity of the plant.

Glossary of Electrostatic Precipitator Terminology

For quick reference, information on some common terms related with ESP is given in this chapter.

Acid Dew Point

The temperature at which combustion gases are saturated with sulfuric acid.

Aerodynamic Diameter

It is the diameter of a sphere of density 1000 kg/m^3 with the same settling velocity as the particle of interest. Thus the aerodynamic diameter standardizes for: Shape (sphere) and Density (the density of a water droplet) of a particle.

Anti-sneakage Baffles

Internal baffle elements within the precipitator to prevent the gas flow from passing through the precipitator without being influenced by the active field.

Arc

A discharge of substantial magnitude from the high voltage system to the grounded system, of relatively long duration and not tending to be immediately self-extinguishing.

Back Corona

A condition which results from the electrical breakdown of a very high resistivity dust layer on the collecting plates at very low current densities. Also referred to as reverse ionization, this condition is extremely detrimental to precipitator performance.

Collection Efficiency

The weight of dust collected per unit time divided by the weight of dust entering the precipitator during the same unit time, expressed in percentage.

Corona

A gaseous discharge found near an ESP discharge electrode resulting in a faint glow caused by ionization of gas molecules due to the electric field.

Corona Power

The product of ESP voltage and current expressed in watts.

Current Density

A measure of corona current in an ESP expressed in nanoamps/crn^2 or microamps/foot^2. Current density is governed by electrode geometry, the mobility of the charge carrier, and the electrical resistivity of the dust.

Dust or Mist Concentration

The weight of dust or mist contained in a unit of gas (the temperature and pressure of the gas must be specified if given as volume).

Effective Length

Total length of collecting surface measured in the direction of gas flow.

Effective Height

Total height of collecting surface, as measured from top to bottom.

Effective Width

Total number of gas passages multiplied by the center to center spacing of the collecting surfaces.

Effective Cross Sectional Area

Effective width times effective height.

Fly Ash

Particulate matter entrained in the flue gas leaving a fossil-fuel-fired boiler. It consists of both ash and combustible material.

Fog

The condensation of water vapor in air.

Gas Velocity

A figure obtained by dividing the volume rate of flow through the precipitator by the effective cross sectional area of the precipitator.

Gas Distribution Devices

Internal elements in the duct to produce the desired downstream velocity contour; example: adjustable baffles or perforated plate.

Gas Passage

Passage/lane formed by two adjacent rows of collecting plates/surfaces.

Gas Sneakage

Bypassing of dust-laden gas around ESP electrified regions, such as through hoppers and above the collecting plates.

Grain

A dust weight unit commonly used in air pollution control. Equal to one seven thousandth of a pound. One grain = 1/7000 lb.

Inlet Dust Loading

A measure of the particulate matter entering an ESP expressed in grains of particulate matter per actual cubic foot of flue gas.

Opacity

Percent reduction of light intensity. Opacity = $(I_0 - I)\ 100/I_0$. Where, I = the intensity of light reaching the observer and I_0 = the original intensity of the light.

Particle Resistivity

The electrical resistance (inverse of conductivity) of a 1 cm cube of material expressed in units of ohm-cm.

Particle Size

The diameter in microns (micrometers) of a particular piece of particulate matter. This is often a function of the measurement technique.

Particulate Matter

Any solid or liquid particle material in the atmosphere.

Penthouse

A weatherproof gas-tight enclosure over the precipitator to contain the high voltage insulators.

Precipitator Current

The rectified or unidirectional average current to the precipitator bus section under consideration measured by a milliammeter in the ground return leg of the rectifier.

Precipitator Voltage

The average DC voltage between the high voltage system (bus section under consideration) and grounded side of the precipitator.

Reentrainment

Reintroduction of fly ash into the gas stream after it has been collected.

Safety Grounding Device

A device for physically grounding the high voltage system prior to personnel entering the precipitator. (The most common type consists of a conductor, one end of which is grounded to the casing, the other end attached to the high voltage system by an insulated operating lever.)

Smog

The irritating haze resulting from the sun's effect on certain pollutants in the air, notably those from automobile exhaust. Also a mixture of smoke and fog.

Smoke

Carbon or soot particles, less than 0.1 micrometers in size which result from the incomplete combustion of carbonaceous materials such as coal, oil, tar and tobacco.

Soot

Very finely divided carbon particles clustered together in long chains.

Spark

A discharge from the high voltage system to the grounded system, self-extinguishing and of short duration.

Specific Collecting Area

The quotient of the total collecting plate area divides by the total gas volume handled by the precipitator multiplied by 1000. Units are expressed as ft^2/1000 acfm.

Specific Corona Power

The quotient of the total corona power of all precipitator bus sections divided by the total gas volume handled by the precipitator, multiplied by 1000. Units are expressed as watts/1000 acfm.

Treatment Time

A figure, in seconds, obtained by dividing the effective length of a precipitator by the precipitator gas velocity.

Weather Enclosure

A non-gas tight enclosure on the roof of the precipitator to shelter equipment and/or maintenance personnel.

ESP Manufacturers and Part Suppliers

Following is the list of ESP manufacturers and part suppliers (Source: Particulate Control Handbook for Coal-Fired Plants, IEA Coal Research, 1997).

ABB Flakt Industri AB
Vaxjo, S-35187, Sweden
Telephone: +46 470 365 50

Apparatebau Rothemuhle, Brandt and Kritzler
PO Box 5140, Wildenburger Strasse 1
Wenden-Rothemuhle, D-57479, Germany
Telephone: +49 2762 611 0

Austrian Energy and Environment
Siemenstrasse 89
Vienna, A-1211, Austria
Telephone: +43 222 25 0 45

Babcock and Wilcox – Utility and Environmental Power Division
20 South Van Buren Avenue
PO Box 351
Barberton, OH 44203-0351, USA
Telephone: (330) 753 4511

Belco Technologies Corporation
7 Entin Road
Parsippany, NJ 07054, USA
Telephone: (201) 884 4700

Bharat Heavy Electricals, Ltd.
Integrated Office Complex
Lodhi Road
New Delhi, IN- 110 003, India
Telephone: +91 11 4636411

China National Building Material Industrial Construction Company
Nanhuan Road
Pingdingshan City, Henan Provice, 467001, China
Telephone: +86 375 493 7548

CR Clean Air Technologies
P.O. Box 2325
Westfield, NJ 07091, USA
Telephone: (908) 389 1220

Deutsche Babcock Anlagen AG
46041 Oberhausen
Duisburger Strasse 375
Oberhausen, D46049, Germany
Telephone: +49 208 833 0

Enviroenergy Solutions, Incorporated
35 Seacoast Terrance, Suite 11
Brooklyn, New York 11235, USA
Telephone: (347) 312-7606

Clyde Bergemann EEC (formerly Environmental Elements Corporation)
7380 Coca-Cola Drive, Suite 126
Hanover, Maryland 21076
Telephone: (800) 333-4331

Fisher-Klosterman, Inc.
PO Box 11190
Louisville, KY 40251-0190, USA
Telephone: (502) 776 1505

General Electric Environmental Systems, Inc.
200 North Seventh Street
Lebanon, PA 17046-5006, USA
Telephone: (717) 274 7000

Company: Hamon Cifa Progetti Spa
Viale Rimembranze
3-20026 Novate Milanese
Milan, 20026, Italy
Telephone: +39 2 3525 1

Korea Cottrell Company, Ltd.
160-1 Donggyo-Dong
Mapo-Ku
Seoul, 121-200, Republic of Korea
Telephone: +82 2 3206 114

LAB S.A.
Tour Credit Lyonnais
Lyon Cedex 03, F-69431, France
Telephone: +33 478 63 70 90

Lentjes Bischoff
Bonsiepen 13
Essen, D-45136, Germany
Telephone: +49 201 8112 270

Lodge Sturtevant, Ltd. (Division of Korea Cottrell)
21 George Street
Birmingham, B3 1QQ, United Kingdom
Telephone: +44 121 214 1300

Mitsubishi Heavy Industries, Lt.
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www.neundorfer.com/knowledgebase/