

Lesson 1

Electrostatic Precipitator Operation

Goal

To familiarize you with the operation of electrostatic precipitators (ESPs).

Objectives

At the end of this lesson, you will be able to do the following:

1. Describe the theory of precipitation
2. Describe how an ESP operates to collect particulate matter
3. Describe the two ESP designs for particle charging and collection: high voltage single-stage and low voltage two-stage
4. Distinguish between cold-side and hot-side ESPs
5. Briefly describe wet ESP operation

Introduction

As you may know, particulate matter (particles) is one of the industrial air pollution problems that must be controlled. It's not a problem isolated to a few industries, but pervasive across a wide variety of industries. That's why the U.S. Environmental Protection Agency (EPA) has regulated particulate emissions and why industry has responded with various control devices. Of the major particulate collection devices used today, **electrostatic precipitators** (ESPs) are one of the more frequently used. They can handle large gas volumes with a wide range of inlet temperatures, pressures, dust volumes, and acid gas conditions. They can collect a wide range of particle sizes, and they can collect particles in dry and wet states. For many industries, the collection efficiency can go as high as 99%. ESPs aren't always the appropriate collection device, but they work because of **electrostatic attraction** (like charges repel; unlike charges attract). Let's see how this law of physics works in an ESP.

Theory of Precipitation

Every particle either has or can be given a charge—positive or negative. Let's suppose we impart a negative **charge** to all the particles in a gas stream. Then suppose we set up a grounded plate having a positive charge. What would happen? The negatively charged particle would migrate to the grounded collection plate and be captured. The particles would quickly **collect** on the plate, creating a dust layer. The dust layer would accumulate until we **removed**

it, which we could do by rapping the plate or by spraying it with a liquid. *Charging, collecting, and removing*—that's the basic idea of an ESP, but it gets more complicated. Let's look at a typical scenario using a common ESP construction.

Particle Charging

Our typical ESP as shown in Figure 1-1 has thin wires called **discharge electrodes**, which are evenly spaced between large plates called **collection electrodes**, which are grounded. Think of an electrode as 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. You can mentally divide this field into three regions (Figure 1-2). The field is strongest right next to 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 region around the discharge electrode is where the particle charging process begins.

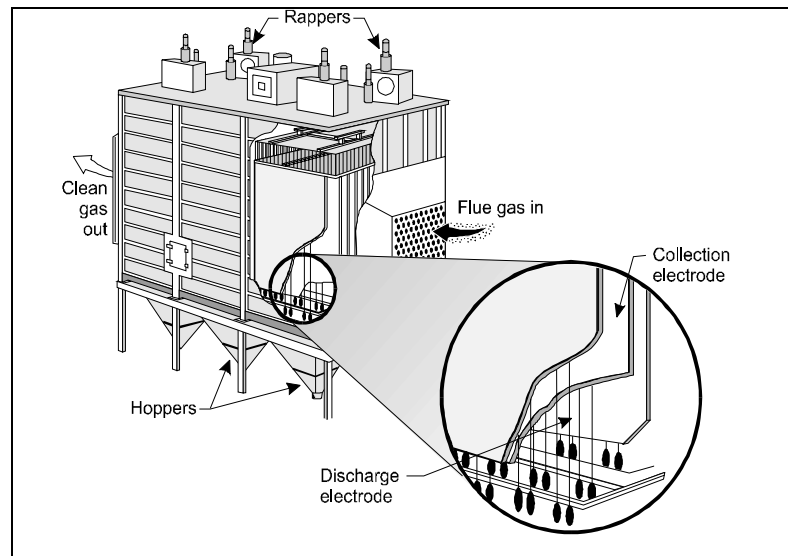


Figure 1-1. Typical dry electrostatic precipitator

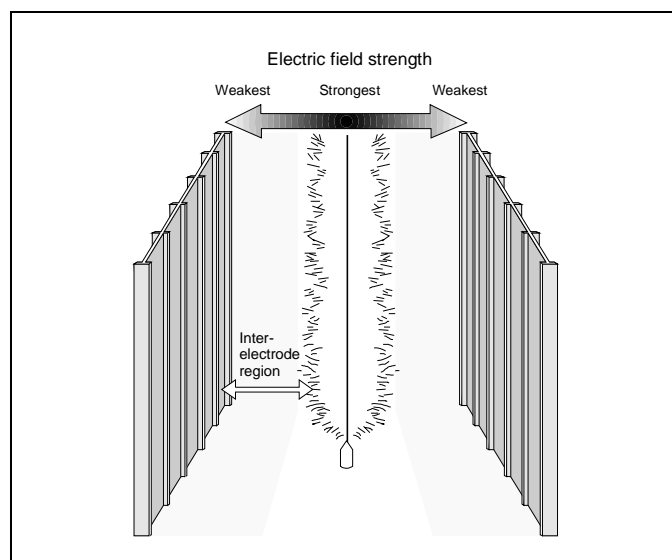


Figure 1-2. ESP electric field

Corona Discharge: 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**, which can be seen as a luminous blue glow around the discharge electrode. The free electrons created by the corona are rapidly fleeing the negative electric field, which 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 in the molecules. As a result of losing an electron (which is negative), the gas molecules become positively charged, that is, they become positive ions (Figure 1-3). So, this is the first thing that happens—gas molecules are ionized, and electrons are liberated. All this activity occurs very close to the discharge electrode. This process continues, creating more and more free electrons and more positive ions. The name for all this electron generation activity is **avalanche multiplication** (Figure 1-4).

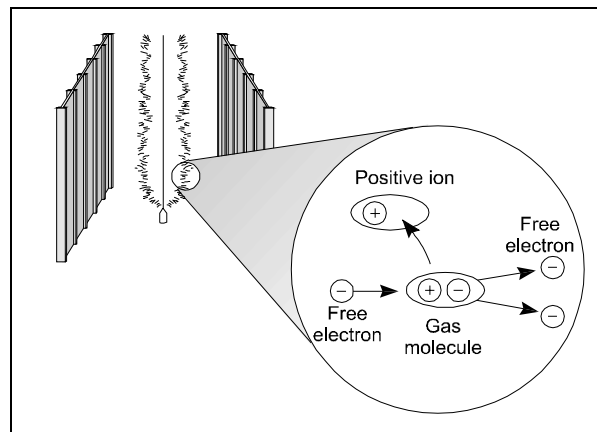


Figure 1-3. Corona generation

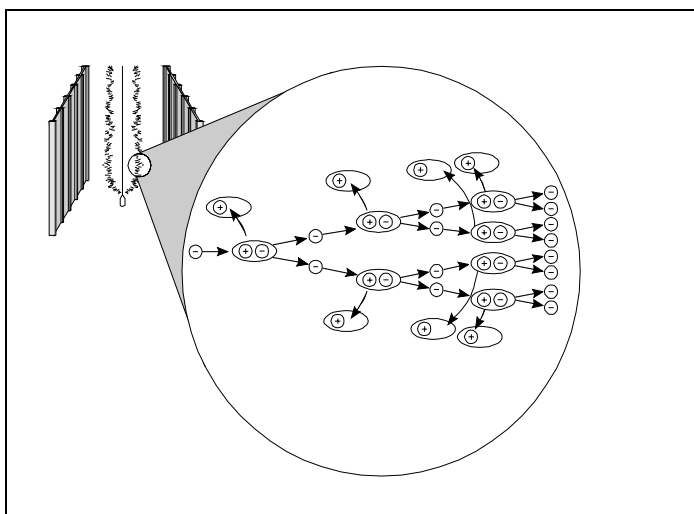


Figure 1-4. Avalanche multiplication of gas molecules

The electrons bump into gas molecules and create additional ionized molecules. The positive ions, on the other hand, are drawn back toward the negative discharge electrode. The molecules are hundreds of times bigger than the tiny electrons and move

slowly, but they do pick up speed. In fact, 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**. So, this is the second thing that happens. We still have positive ions and a large amount of free electrons.

Ionization of Gas Molecules

As the electrons leave the strong electrical field area around the discharge electrode, they start slowing down. Now they're in the inter-electrode area where they are still repulsed by the discharge electrode but to a lesser extent. There are also gas molecules in the inter-electrode region, but instead of violently colliding with them, the electrons kind of bump up to them and are captured (Figure 1-5). This imparts a negative charge to the gas molecules, creating negative gas ions. This time, because the ions are negative, they too want to move in the direction opposite the strong negative field. Now we have ionization of gas molecules happening near the discharge electrode and in the inter-electrode area, but with a big difference. The ions near the discharge electrode are positive and remain in that area. The ions in the middle area are negative and move away, along the path of invisible electric field lines, toward the collection electrode.

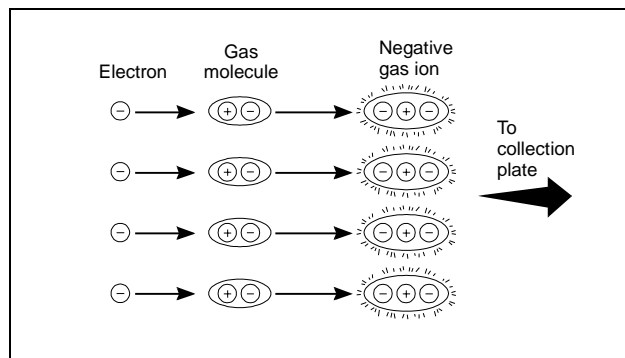


Figure 1-5. Negative gas ions formed in the inter-electrode region

Charging of Particles

These negative gas ions play a key role in capturing dust particles. Before the dust particles can be captured, they must first acquire a negative charge. This is when and where it happens. The particles are traveling along in the gas stream and encounter negative ions moving across their path. Actually, what really happens is that the particles get in the way of the negatively charged gas ions. 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 (Turner et al. 1992). 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**. 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 are pulled more strongly to the collection plate. In other words, they move faster than smaller particles. Regardless of

size, the particles encounter the plate and stick, because of adhesive and cohesive forces.

Let's stop here and survey the picture. Gas molecules around the discharge electrode are positively ionized. Free electrons are racing as fast as they can away from the strong negative field area around the discharge electrode. The electrons are captured by gas molecules in the inter-electrode area and impart a negative charge to them. Negative gas ions meet particles and are captured (Figure 1-6). And all this happens in the blink of an eye. The net result is negatively charged particles that are repulsed by the negative electric field around the discharge electrode and are strongly attracted to the collection plate. They travel toward the grounded collection plate, bump into it, and stay there.

More and more particles accumulate, creating a dust layer. This dust layer builds until it is somehow removed. Charging, collecting, and removing—isn't that what we said it's all about?

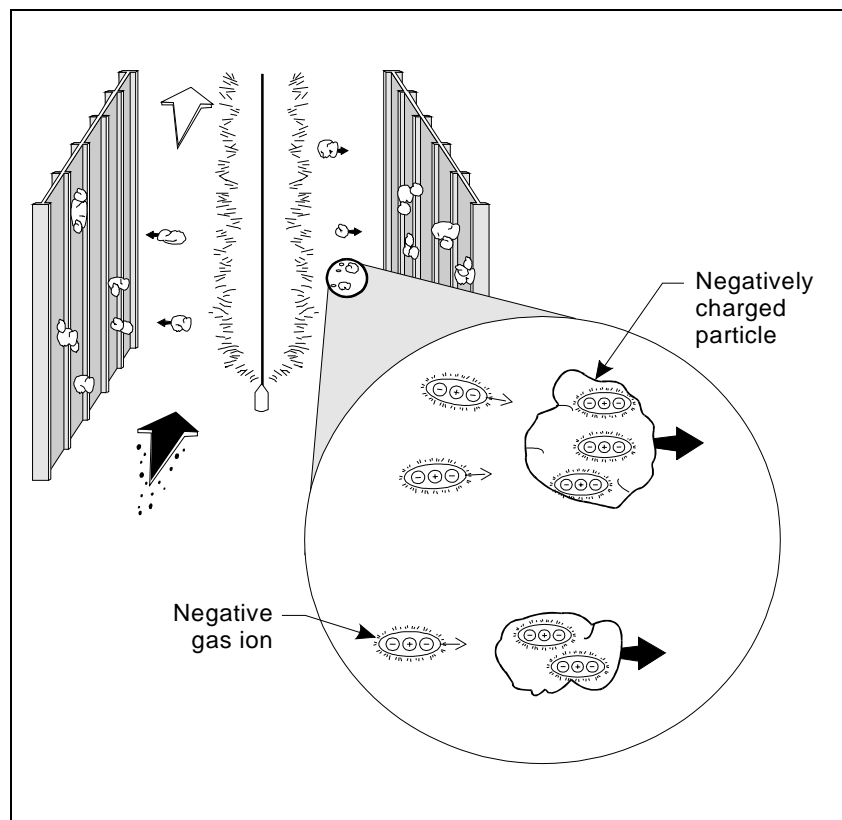


Figure 1-6. Particle charging

Particle Charging Mechanisms

Particles are charged by negative gas ions moving toward the collection plate by one of these 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.

In **field charging** (Figure 1-7), as particles enter the electric field, they cause a local dislocation of the field. Negative gas ions traveling along the electric field lines collide with the suspended particles and impart a charge to them. The ions will continue to bombard a particle until the charge on that particle is sufficient to divert the electric lines away from it. 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. Saturated charged particles then migrate to the collection electrode and are collected.

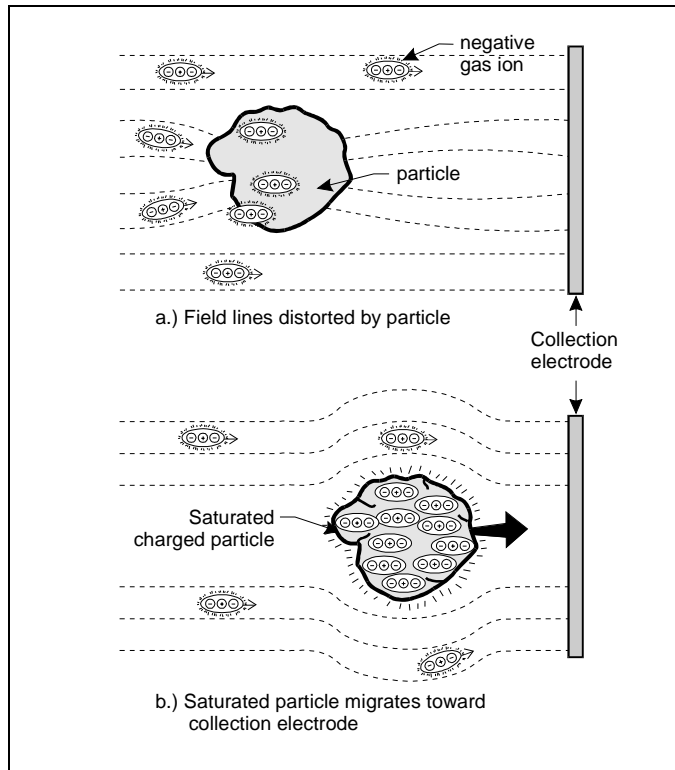


Figure 1-7. Field charging

Diffusion charging is associated with the random Brownian motion of the negative gas ions. The random motion is related to the velocity of the gas ions due to thermal effects: the higher the temperature, the more movement. Negative gas ions collide with the particles because of their random thermal motion and impart a charge on the particles. Because the particles are very small (submicrometer), they do not cause the electric field to be dislocated, as in field charging. Thus, diffusion charging is the only mechanism by which these very small particles become charged. The charged particles then migrate to the collection electrode.

Each of these two charging mechanisms occurs to some extent, with one dominating depending on particle size. Field charging dominates for particles with a diameter >1.0 micrometer because particles must be large enough to capture gas ions. Diffusion charging 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

In the inter-electrode region, negative gas ions migrate toward the grounded collection electrode. A **space charge**, which is a stable concentration of negative gas ions, forms in the inter-electrode region because of the high electric field applied to the ESP. Increasing the applied voltage to the discharge electrode will increase the field strength and ion formation until **sparkover** occurs. Sparkover 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 (Figure 1-8.)

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 average sparkover 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 collapse of the electric field.

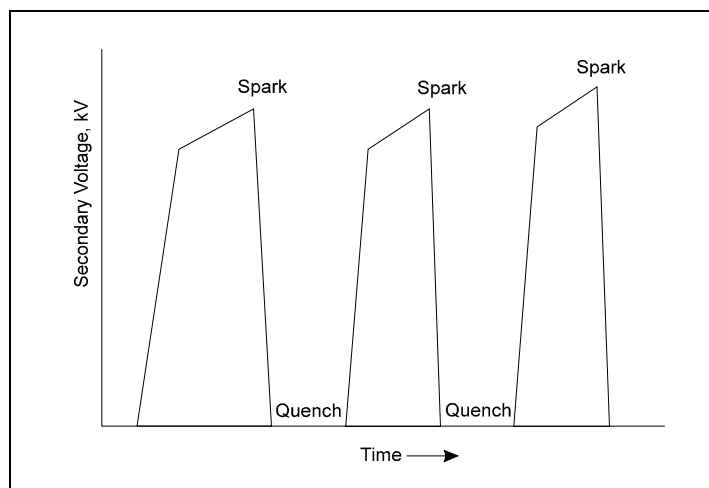


Figure 1-8. Spark generation profile

Particle Collection

When a charged particle reaches the grounded collection electrode, the charge on the particle is only partially discharged. 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 (Figure 1-9). 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.

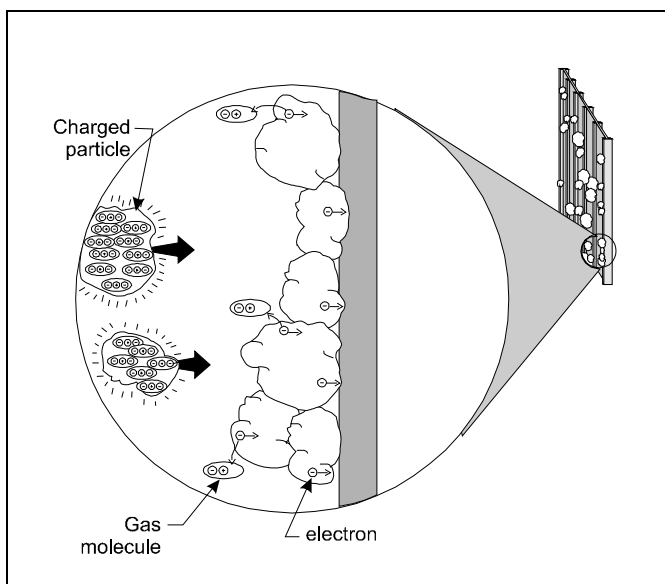


Figure 1-9. Particle collection at collection electrode

Particle Removal

Dust that has accumulated to a certain thickness on the collection electrode is removed by one of two processes, depending on the type of collection electrode. As described in greater detail in the next section, collection electrodes in precipitators can be either plates or tubes, with plates being more common. Tubes are usually cleaned by water sprays, while plates 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 and helps eliminate dust reentrainment. Most precipitators have adjustable rappers so that rapper intensity and frequency can be changed according to the dust concentration in the flue gas. Installations where the dust concentration is heavy require more frequent rapping.

Dislodged dust falls from the plates into the **hopper**. The hopper is a single collection bin with sides sloping approximately 50 to 70° to allow dust to flow freely from the top of the hopper to the discharge opening. Dust should be removed as soon as possible to avoid (dust) 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 lined landfills for proper ultimate disposal.

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, or 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)

These categories are not mutually exclusive. For example, an ESP can be a rigid-frame, single-stage, cold-side, plate-type ESP as described below.

Tubular and Plate ESPs

Tubular

Tubular precipitators consist of cylindrical collection electrodes (tubes) with discharge electrodes (wires) located in the center of the cylinder (Figure 1-10). 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. The tubes may be formed as a circular, square, or hexagonal honeycomb with gas flowing upward or downward. A tubular ESP is tightly sealed to minimize leaks of collected material. Tube diameters typically vary from 0.15 to 0.31 m (0.5 to 1 ft), with lengths usually varying from 1.85 to 4.0 m (6 to 15 ft).

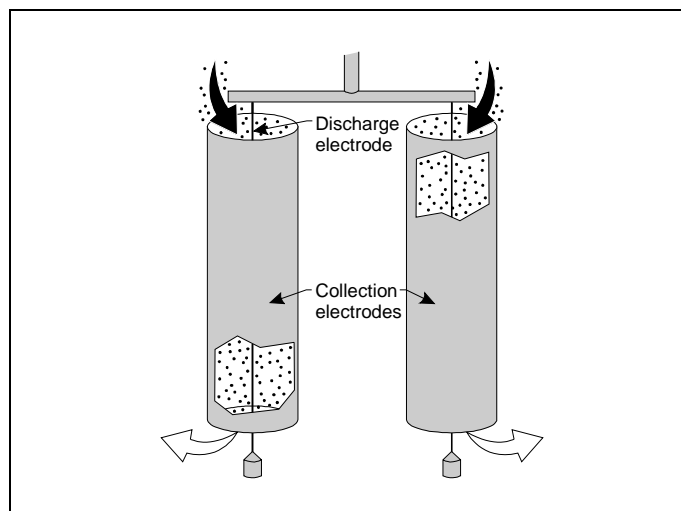


Figure 1-10. Gas flow through a tubular precipitator

Tubular precipitators are generally used for collecting mists or fogs, and are most commonly used when collecting particles that are wet or sticky. Tubular ESPs have been used to control particulate emissions from sulfuric acid plants, coke oven by-product gas cleaning (tar removal), and iron and steel sinter plants.

Plate

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. Figure 1-11 shows a plate ESP with wire discharge electrodes. Dirty gas flows into a chamber consisting of a series of discharge electrodes that are equally spaced along the center line between adjacent collection plates. Charged particles are collected on the plates as dust, which is periodically removed by rapping or water sprays. Discharge wire electrodes are approximately 0.13 to 0.38 cm (0.05 to 0.15 in.) in diameter. Collection plates are usually between 6 and 12 m (20 and 40 ft) high. For ESPs with wire discharge electrodes, the plates are usually spaced from 15 to 30 cm (6 to 12 in.) apart. For ESPs with rigid-frame or plate discharge electrodes, plates are typically spaced 30 to 38 cm (12 to 15 in.) apart and 8 to 12 m (30 to 40 ft) in height.

Plate ESPs are typically used for collecting fly ash from industrial and utility boilers as well as in many other industries including cement kilns, glass plants and pulp and paper mills.

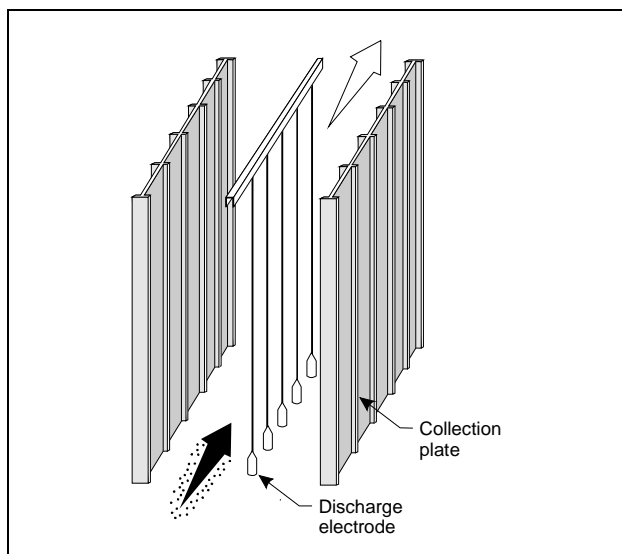


Figure 1-11. Gas flow through a plate precipitator

Single-stage and Two-stage ESPs

Another method of classifying ESPs is by the number of stages used to charge and remove particles from a gas stream. 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. 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.

Single Stage

Most ESPs that reduce particulate emissions from boilers and other industrial processes are single-stage ESPs (these units will be emphasized in this course). Single-stage ESPs use very high voltage (50 to 70 kV) to charge particles. After being charged, particles move in a direction perpendicular to the gas flow through the ESP,

and migrate to an oppositely charged collection surface, usually a plate or tube. Particle charging and collection occurs in the same stage, or field; thus, the precipitators are called single-stage ESPs. The term *field* is used interchangeably with the term *stage* and is described in more detail later in this course. Figure 1-10 shows a single-stage tubular precipitator. A single-stage plate precipitator is shown in Figure 1-11.

Two Stage

The two-stage precipitator differs from the single-stage precipitator in both design and amount of voltage applied. The two-stage ESP has separate particle charging and collection stages (Figure 1-12). The ionizing stage consists of a series of small, **positively** charged wires equally spaced 2.5 to 5.1 cm (1 to 2 in.) from parallel grounded tubes or rods. A corona discharge between each wire and a corresponding tube charges the particles suspended in the air flow as they pass through the ionizer. The direct-current potential applied to the wires is approximately 12 to 13 kV.

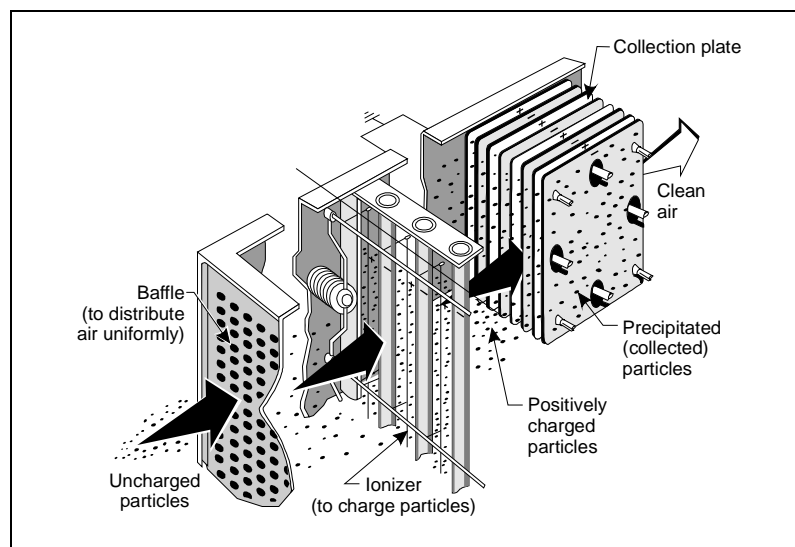


Figure 1-12. Representation of gas flow in a two-stage precipitator

The second stage consists of parallel metal plates less than 2.5 cm (1 in.) apart. The particles receive a positive charge in the ionizer stage and are collected at the negative plates in the second stage. Collected smoke or liquids drain by gravity to a pan located below the plates, or are sprayed with water mists or solvents that remove the particles and cause them to fall into the bottom pan.

Two-stage precipitators were originally designed for air purification in conjunction with air conditioning systems. (They are also referred to as electronic air filters). Two-stage ESPs are used primarily for the control of finely divided liquid particles. Controlling solid or sticky materials is usually difficult, and the collector becomes ineffective for dust loadings greater than $7.35 \times 10^{-3} \text{g/m}^3$ (0.4 gr/dscf). Therefore, two-stage precipitators have limited use for particulate-emission control. They are used almost exclusively to collect liquid aerosols discharged from sources such as meat smoke-houses, pipe-coating machines, asphalt paper saturators, high speed grinding machines, welding machines, and metal-coating operations.

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, or municipal waste combustors using heat recovery equipment, *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. The air preheater is a tube section that preheats the combustion air used for burning fuel in a boiler. When hot flue gas from an industrial process passes through an air preheater, a heat exchange process occurs whereby heat from the flue gas is transferred to the combustion air stream. The flue gas is therefore "cooled" as it passes through the combustion air preheater. The warmed combustion air is sent to burners, where it is used to burn gas, oil, coal, or other fuel including garbage. APTI Course SI:428A *Introduction to Boiler Operation* describes boilers and heat recovery equipment in greater detail.

Cold Side

Cold-side ESPs (Figure 1-13) have been used for over 50 years with industrial and utility boilers, where the flue gas temperature is relatively low (less than 204°C or 400°F). Cold-side ESPs generally use plates to collect charged particles. Because these ESPs are operated at lower temperatures than hot-side ESPs, the volume of flue gas that is handled is less. Therefore, the overall size of the unit is smaller, making it less costly. Cold-side ESPs can be used to remove fly ash from boilers that burn high-sulfur coal. As explained in later lessons, cold-side ESPs can effectively remove fly ash from boilers burning low-sulfur coal with the addition of conditioning agents.

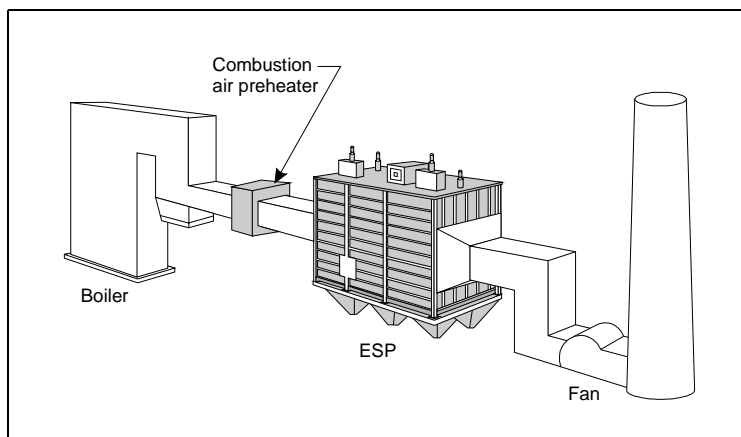


Figure 1-13. Cold-side ESP

Hot Side

Hot-side ESPs (Figure 1-14) are placed in locations where the flue gas temperature is relatively high. Their collection electrodes can be either tubular or plate. Hot-side ESPs are used in high-temperature applications, such as in the collection of cement-kiln dust or utility and industrial boiler fly ash. A hot-side precipitator is located before the combustion air preheater in a boiler. The flue gas temperature for hot-side precipitators is in the range of 320 to 420°C (608 to 790°F).

The use of hot-side precipitators help reduce corrosion and hopper plugging. However, these units (mainly 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 more costly. Other major disadvantages include structural and mechanical problems that occur in the precipitator shell and support structure as a result of differences in thermal expansion.

For years, cold-side ESPs were used successfully on boilers burning high-sulfur coal. However, during the 1970s when utilities switched to burning low-sulfur coal, cold-side ESPs were no longer effective at collecting the fly ash. Fly ash produced from low sulfur coal-fired boilers has high resistivity (discussed in more detail later in the course), making it difficult to collect. As you will learn later, high temperatures can lower resistivity. Consequently, hot-side ESPs became very popular during the 1970s for removing ash from coal-fired boilers burning low sulfur coal. However, many of these units did not operate reliably, and therefore, since the 1980s, operators have generally decided to use cold-side ESPs along with conditioning agents when burning low sulfur coal.

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.

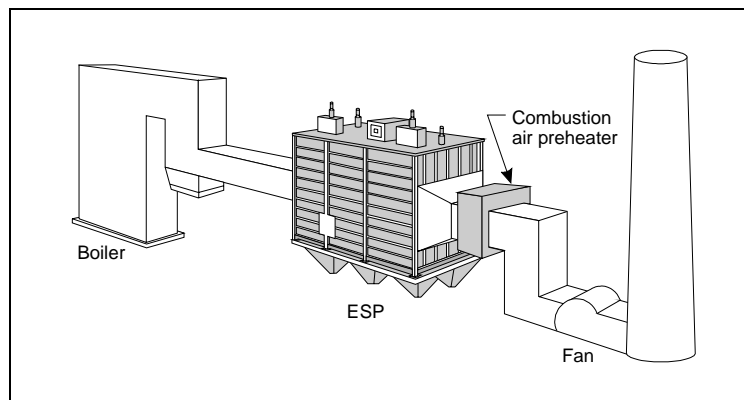


Figure 1-14. Hot-side ESP

Wet and Dry ESPs

Wet ESPs

Any of the previously described ESPs can be operated with a wet spray to remove collected particles. 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 (a basin used to collect liquid). The advantage of using a wet ESP is that it does not have problems with rapping reentrainment or with back corona which are discussed in more detail in Lesson 3.

Figures 1-15 and 1-16 show two different wet ESPs. The casing of wet ESPs is made of steel or fiberglass and the discharge electrodes are made of carbon steel or special alloys, depending on the corrosiveness of the flue gas stream.

In a circular-plate wet ESP, shown in Figure 1-15, the circular collection plates are sprayed with liquid continuously. The liquid provides the electrical ground for attracting the particles and for removing them from the plates. These units can handle gas flow rates of 30,000 to 100,000 cfm. Preconditioning sprays located at the inlet remove some particulate matter prior to the charging stage. The operating pressure drop across these units is typically 1 to 3 inches of water.

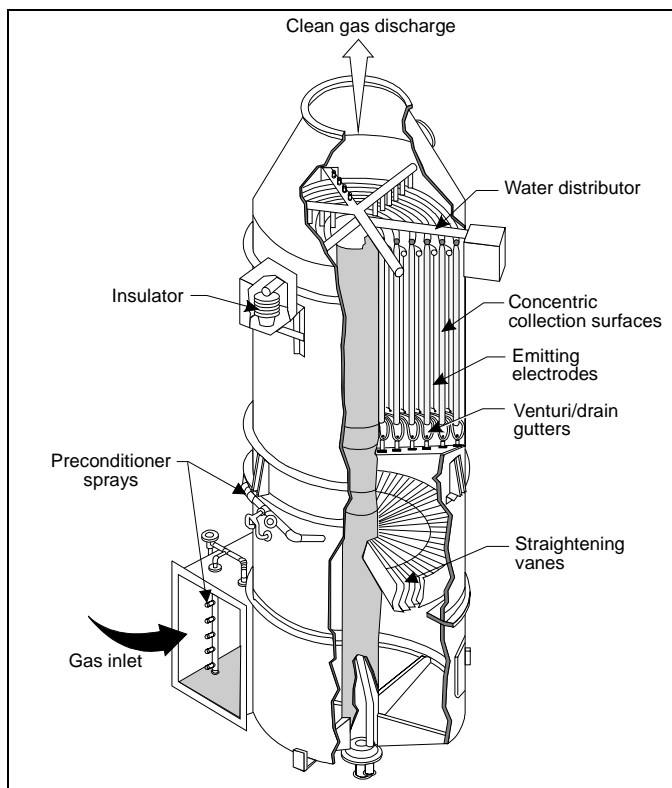


Figure 1-15. Circular-plate wet EPS

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Rectangular flat-plate wet ESPs, shown in Figure 1-16, operate similarly to circular-plate wet ESPs. Water sprays precondition the gas stream and provide some particle removal. Because the water sprays are located over the top of the electrical fields, the collection plates are continuously irrigated. The collected particulate matter flows downward into a trough that is sloped to a drain.

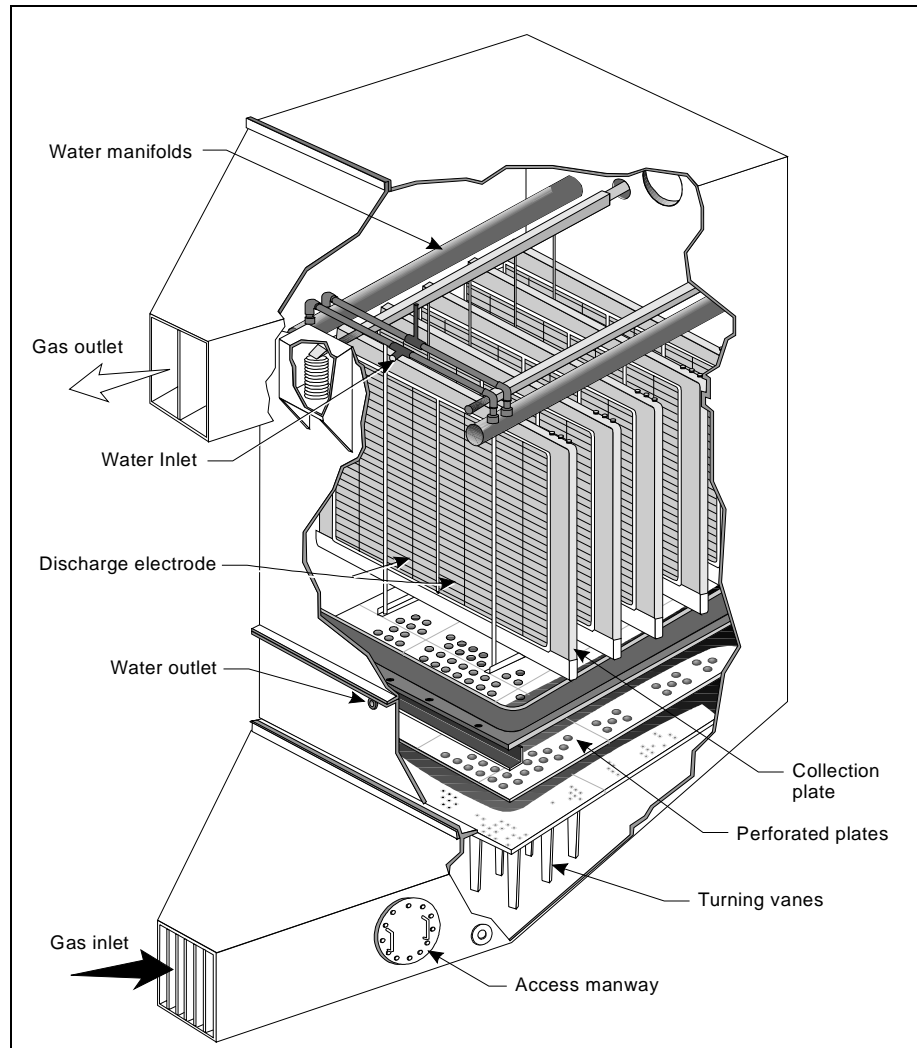


Figure 1-16. Flat-plate modular wet ESP
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Dry ESPs

Most electrostatic precipitators 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. The major portion of this course covers dry ESPs that are used for collecting dust from many industries including steel furnaces, cement kilns and fossil-fuel-fired boilers.

Summary

All ESPs, no matter how they are grouped, have similar components and operate by charging particles or liquid aerosols, collecting them, and finally removing them from the ESP before ultimate disposal in a landfill or reuse in the industrial process.

ESPs are occasionally referred to as cold-side, tubular, or by some other descriptor. ESP designs usually incorporate a number of ESP features into one unit. For example, a typical ESP used for removing particulate matter from a coal-fired boiler will be a cold-side, single-stage, plate ESP. On the other hand, a hot-side, single-stage, tubular ESP may be used to clean exhaust gas from a blast furnace in a steel mill.

Remember that an ESP is specifically designed to collect particulate matter or liquids for an individual industrial application. Vendors use those features, i.e., tubes, plates, etc., that most readily enhance the removal of the pollutants from the flue gas. These features are described in more detail in the remaining lessons.

Review Exercise

1. In an electrostatic precipitator, the _____ electrode is normally a small-diameter metal wire or a rigid frame containing wires.
2. The charged particles migrate to the _____.
3. In a single-stage, high-voltage ESP, the applied voltage is increased until it produces a(an)
 - a. Extremely high alternating current for particle charging
 - b. Corona discharge, which can be seen as a blue glow around the discharge electrode
 - c. Corona spark that occurs at the collection electrode
4. True or False? Particles are usually charged by negative gas ions that are migrating toward the collection electrode.
5. True or False? Large particles move more slowly towards the collection plate than small particles.
6. The average sparkover rate (in sparks per minute) for optimum precipitator operation is between:
 - a. 1 - 25
 - b. 50 - 100
 - c. 100 - 150
 - d. 500 - 1,000
7. As dust particles reach the grounded collection electrode, their charge is:
 - a. Immediately transferred to the collection plate
 - b. Slowly leaked to the grounded collection electrode
 - c. Cancelled out by the strong electric field
8. Particles are held onto the collection plates by:
 - a. A strong electric force field
 - b. A high-voltage, pulsating, direct current
 - c. Intermolecular cohesive and adhesive forces
 - d. Electric sponsors
9. Dust that has accumulated on collection electrodes can be removed either by _____ or a process called _____.
10. True or False? During the rapping process, the voltage is turned down to about 50% of the normal operating voltage to allow the rapped particles to fall freely into the hopper.
11. _____ electrostatic precipitators are used for removing particulate matter from flue gas that usually has a temperature range of 320 to 420° C (608 to 790° F).

12. In a boiler, hot-side ESPs are located _____ air preheaters, whereas cold-side ESPs are located _____ air preheaters.
 - a. In front of, behind
 - b. Behind, in front of
13. True or False? Wet electrostatic precipitators are used when collecting dust that is sticky or has high resistivity.
14. _____ ESPs are units where particle charging occurs in the first stage, followed by collection in the second stage.

Review Exercise Answers

1. **Discharge**

In an electrostatic precipitator, the discharge electrode is normally a small-diameter metal wire or a rigid frame containing wires.

2. **Collection electrode**

The charged particles migrate to the collection electrode.

3. **b. Corona discharge, which can be seen as a blue glow around the discharge electrode**

In a single-stage, high-voltage ESP, the applied voltage is increased until it produces a corona discharge, which can be seen as a blue glow around the discharge electrode.

4. **True**

Particles are usually charged by negative gas ions that are migrating toward the collection electrode.

5. **False**

Large particles move faster towards the collection plate than small particles. Large particles have a higher saturation charge than small particles; consequently, large particles are pulled more strongly to the collection plate.

6. **b. 50 - 100**

The average sparkover rate for optimum precipitator operation is between 50 - 100 sparks per minute.

7. **b. Slowly leaked to the grounded collection electrode**

As dust particles reach the grounded collection electrode, their charge is slowly leaked to the grounded collection electrode.

8. **c. Intermolecular cohesive and adhesive forces**

Particles are held onto the collection plates by intermolecular cohesive and adhesive forces.

9. **Water sprays**

Rapping

Dust that has accumulated on collection electrodes can be removed either by water sprays or a process called rapping.

10. **False**

During the rapping process, the voltage is NOT turned down. Rapping occurs while the ESP remains on-line.

11. **Hot-side**

Hot-side electrostatic precipitators are used for removing particulate matter from flue gas that usually has a temperature range of 320 to 420°C (608 to 790°F).

12. **a. In front of, behind**

In a boiler, hot-side ESPs are located in front of air preheaters, whereas cold-side ESPs are located behind air preheaters. Recall that flue gas is cooled as it passes through the combustion air preheater.

13. **True**

Wet electrostatic precipitators are used when collecting dust that is sticky or has high resistivity.

14. **Two-stage**

Two-stage ESPs are units where particle charging occurs in the first stage, followed by collection in the second stage.

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