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Review Article

REVIEW ON DEVELOPMENT OF AN AUTOMATED SYSTEM FOR GAS DISTRIBUTION TEST OF ESP

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An Electrostatic precipitator is a large, industrial emission control unit, which is designed to trap and remove dust particles from the exhaust gas stream of an industrial process. Precipitators are used in industries like Power, Electric, Cement, Chemicals, Metals and Paper industries. In many industrial plants, particulate matter created in the industrial process is carried as dust in the hot exhaust gases. These dust-laden gases pass through an Electrostatic precipitator that collects most of the dust. Cleaned gas then passes out of the precipitator and through a stack to the atmosphere. Precipitators typically collect 99.9% or more of the dust from the gas stream. A unidirectional high voltage is applied between these electrodes, connecting its negative polarity to collecting electrodes, which are also earthed. The charged particles are then attracted to and deposited on plates. When enough dust has accumulated, the collectors are shaken to dislodge the dust below. The dust is then removed by a conveyor system for disposal or recycling. In this review paper present designing an automated system for measuring the gas distribution throughout the cross-section of the ESP, then the experimentation with wind velocity sensors (hot wire anemometer type) and also design of overhead travelling mechanism for horizontal and vertical motions to carry the sensors and to capture the wind velocity data, using wired/wireless network system for capturing the data from the sensors to a database pc and also the development of application software's for creating a database for each trial.

Keywords: Gas distribution test, ESP, Automate system

INTRODUCTION

Electrostatic Precipitator Operation

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 US Environmental Protection Agency (EPA) has regulated particulate emissions and why industry has responded with various control devices. Of the major particulate collection devices used

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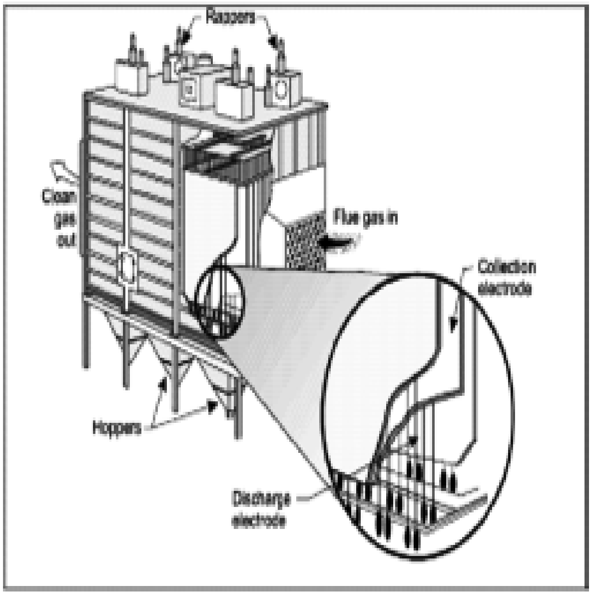
today, Electrostatic Precipitators (ESPs) are one of the more frequently used (Figure 1). They can handle large gas volumes with a wide range of inlet temperatures, pressures, dust volumes, and acid gas conditions. They can collect a wide range of particle sizes, and they can collect particles in dry 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).

Figure 1: Typical Dry Electrostatic Precipitator

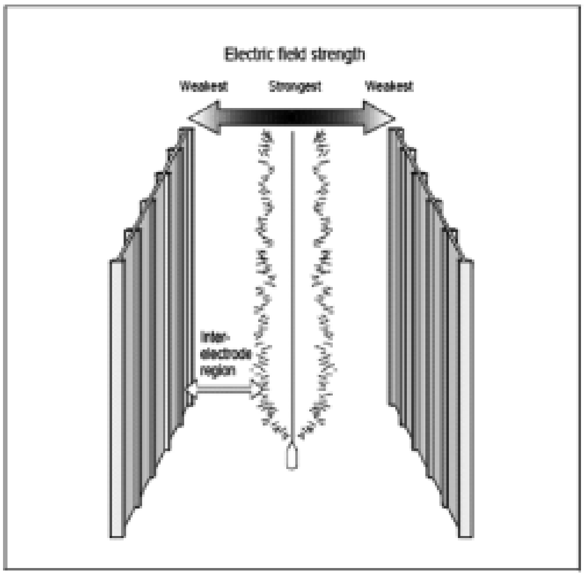


Every particle either has or can be given a charge—positive or negative. Impart a negative charge to all the particles in a gas stream, then set up a grounded plate having a positive charge. The negatively charged particle would migrate to the grounded collection plate and be captured. The particles would quickly collect on the plate, creating a dust layer. The dust layer would accumulate until removed.

Particle Charging

Typical ESP is shown in Figure 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 2).

Figure 2: ESP Electric Field



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 several things happens 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. The result of losing an electron (which is negative), the gas molecules become positively charged, that is, they become positive ions (Figure 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 4).

Figure 3: Corona Generation

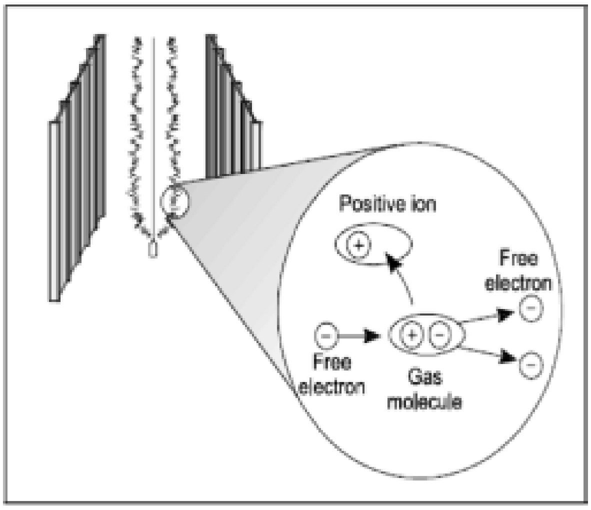
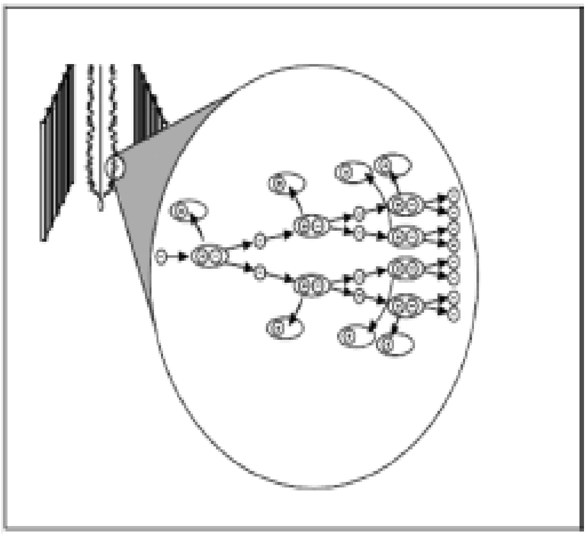


Figure 4: Avalanche Multiplication of Gas Molecules

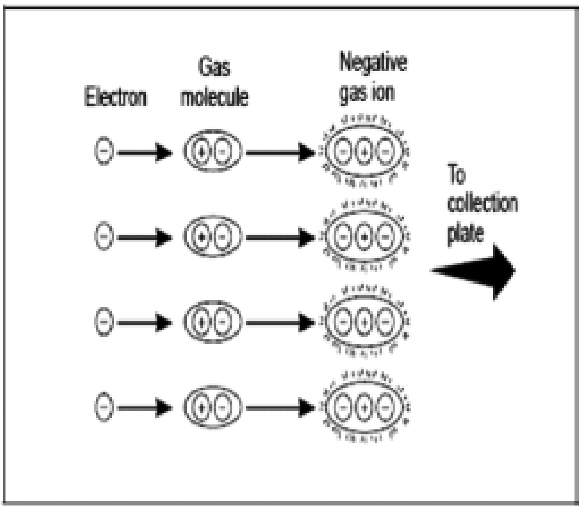


The electrons bump into gas molecules and create additional ionized molecules. The positive ions, on the other hand, are drawn back toward the negative discharge electrode. The molecules are hundreds of times bigger than the tiny electrons and move slowly, but they do pick up speed. In fact, many of 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

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 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 discharge electrode are positive and remain in that area.

Figure 5: Negative Gas Ions Formed in the Inter-Electrode Region



The ions in the middle area are negative and move away, along the path of invisible electric field lines, toward the collection electrode.

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 ions near the discharge electrode are positive and remain in that area. The ions in the middle area are negative 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 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 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.

Figure 6: Particle Charging

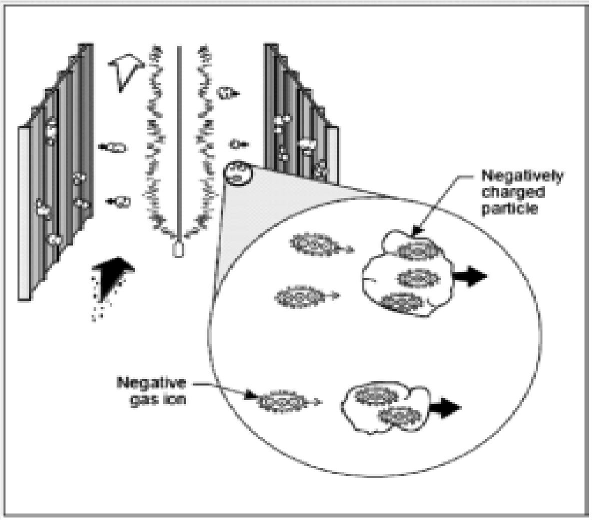
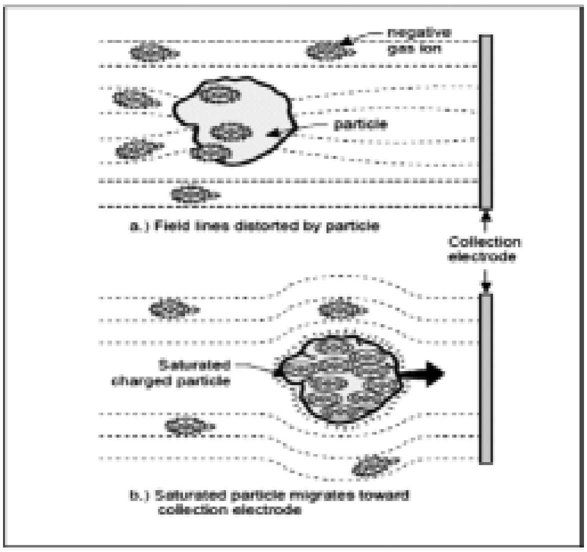


Figure 7: Field Charging



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 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.

Diffusion Charging

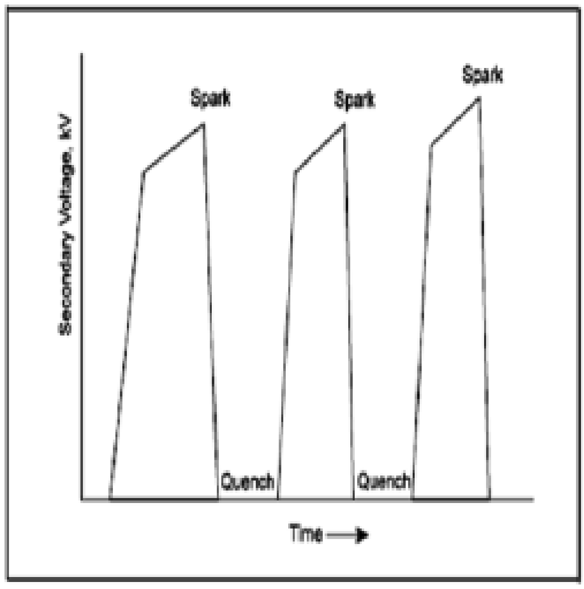
It is associated with the random Brownian motion of the negative gas ions. The random motion is related to the velocity of the gas ions due to thermal effects: the higher the temperature, the more movement. Negative gas ions collide with the particles because of their random thermal motion and impart a charge on the particles. Because the particles are very small (sub micrometer), 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 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 (Figure 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 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 efficiency associated with increased voltage compensates for decreased gas ionization due to collapse of the electric field.

Figure 8: Spark Generation Profile



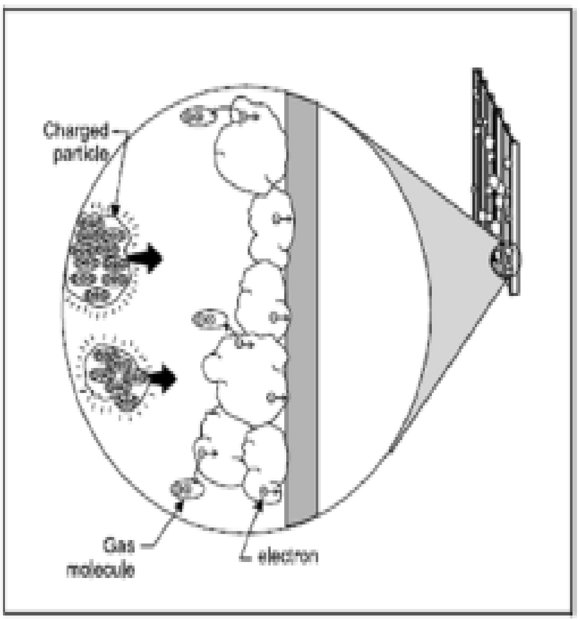
Particle Collection

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 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.

Particle Removal

Dust that has accumulated to a certain thickness on the collection electrode is

Figure 9: Particle Collection at Collection Electrode



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.

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 precipitators consist of cylindrical collection electrodes (tubes) with discharge electrodes (wires) located in the center of the cylinder (Figure 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.

Figure 10: Gas Flow Through a Tubular Precipitator

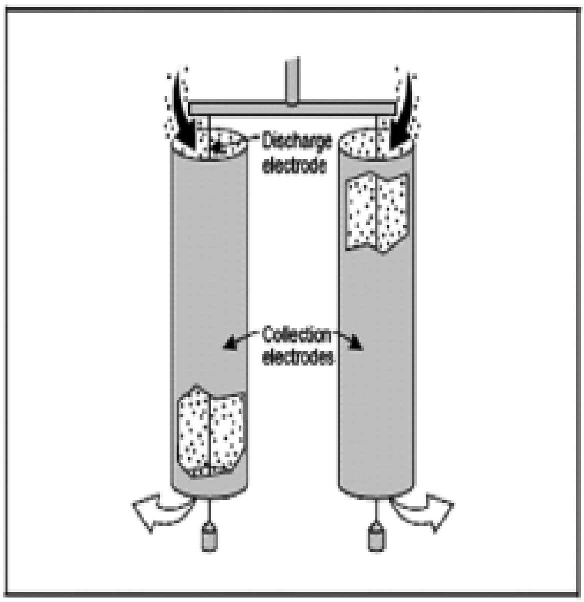
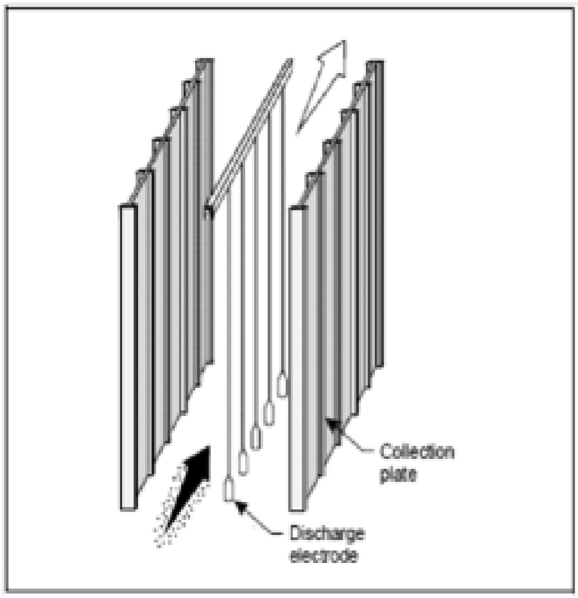


Figure 11: Gas Flow Through a Plate Precipitator



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.). 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 sulphuric acid plants, coke oven by-product gas cleaning (tar removal), and iron and steel sinter plants.

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 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.

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.

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

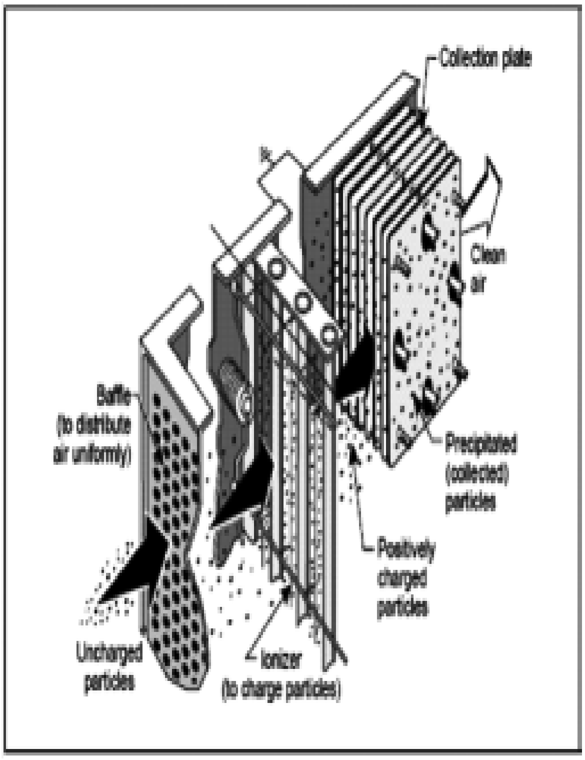
Most ESPs that reduce particulate emissions from boilers and other industrial processes are single-stage ESPs (these units will be emphasized in this course). Single stage ESPs use very high voltage (50 to 70 kV) to charge particles. After being charged, particles move in a direction perpendicular to 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 10 shows a single stage tubular precipitator. A single-stage plate precipitator is shown in Figure 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 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.

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.

Figure 12: Representation of Gas Flow in a Two-Stage Precipitator



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 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.

Hot Side

Hot-side ESPs (Figure 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)

Figure 13: Cold-Side ESP

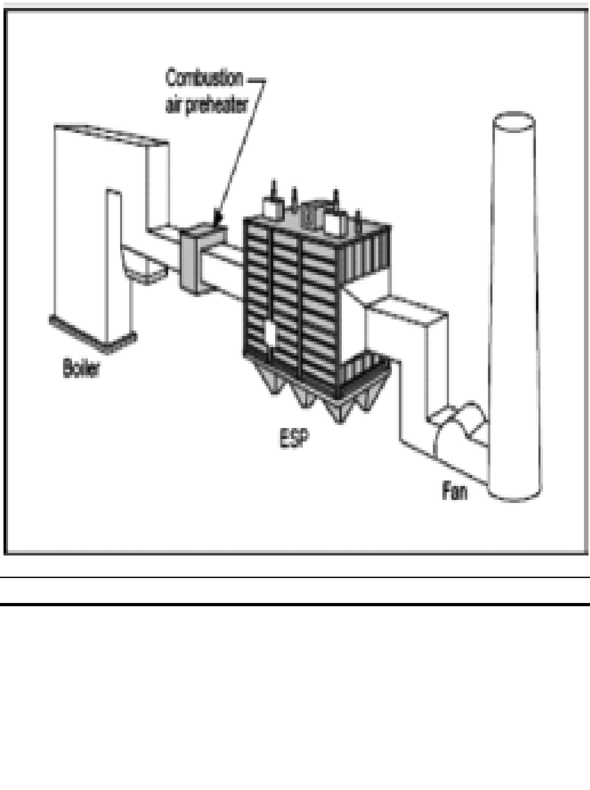
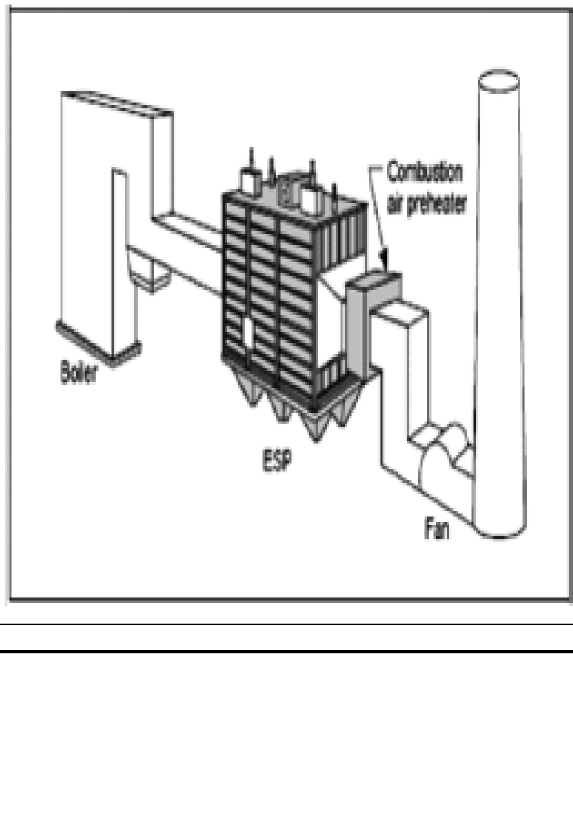


Figure 14: Hot Side ESP



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-sulphur coal. However, during the 1970s when utilities switched to burning low-sulphur coal, cold side ESPs were no longer effective at collecting the fly ash. Fly ash produced from low sulphur 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 sulphur 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 sulphur 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.

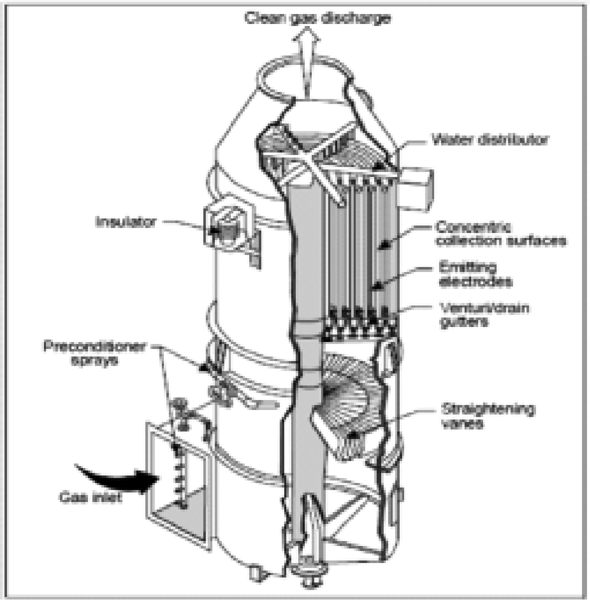
Wet and Dry ESPs

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 re-entrainment or with back corona.

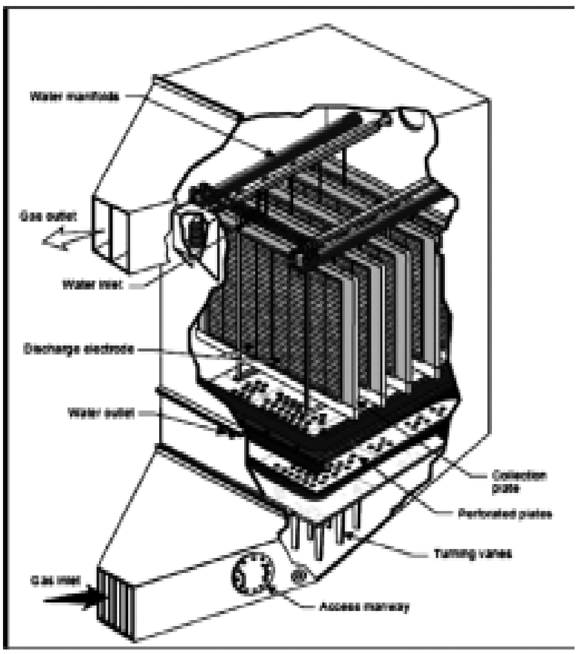
Figures 15 and 16 shows two different wet ESPs. The casing of wet ESPs is made of steel or fiberglass and the discharge electrodes are made of carbon steel or special alloys, depending on the corrosiveness of the flue gas stream. In a circular-plate wet ESP, shown in Figure 15, the circular collection plates are sprayed with liquid continuously.

Figure 15: Circular Plate Wet ESP



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 cm. 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. Rectangular flat-plate wet ESPs, shown in Figure 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 16: Flat Plate Modular Wet ESP



CONCLUSION

- ESP is more effective to remove very small particles like smoke, mist and fly ash. Its range of dust removal is sufficiently large (0.01 micron to 1.00 micron). The small dust particles below 10 microns cannot be removed with the help of mechanical separators and wet scrubbers cannot be used if sufficient water is now available. Under these circumstances, this type is very effective.
- It is also most effective for high dust loaded gas (as high as 100 grams per cu. meter).
- The draught loss of this system is the least of all forms (1 cm of water).
- It provides ease of operation.
- The dust is collected in dry form and can be removed either dry or wet.

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