Lesson 2

Electrostatic Precipitator Components

Goal

To familiarize you with the components of an ESP.

Objectives

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

1. Identify six major components of an ESP
2. Describe typical discharge electrode designs
3. Describe typical collection electrode designs
4. Identify how discharge electrodes and collection plates are installed in an ESP
5. List three types of rappers and briefly describe how they operate
6. Describe how the high-voltage equipment operates
7. Describe two factors that are important in hopper design
8. Identify two discharge devices used to remove dust from hoppers, and three types of conveyors
9. State the purpose for installing insulation on an ESP

Video Presentation (optional): If you have acquired the video titled, *Electrostatic Precipitators: Operating Principles and Components*, please view it at the end of this lesson.

Precipitator Components

All electrostatic precipitators, regardless of their particular designs, contain the following essential components:

- Discharge electrodes
- Collection electrodes
- High voltage electrical systems
- Rappers
- Hoppers
- Shell

Discharge electrodes are either small-diameter metal wires that hang vertically (in the electrostatic precipitator), a number of wires attached together in rigid frames, or a rigid electrode-made from a single piece of fabricated metal. Discharge electrodes create a strong electrical field that ionizes flue gas, and this ionization charges particles in the gas.

Collection electrodes collect charged particles. Collection electrodes are either flat plates or tubes with a charge opposite that of the discharge electrodes.

High voltage equipment provides the electric field between the discharge and collection electrodes used to charge particles in the ESP.

Rappers impart a vibration, or shock, to the electrodes, removing the collected dust. Rappers remove dust that has accumulated on both collection electrodes and discharge electrodes. Occasionally, water sprays are used to remove dust from collection electrodes.

Hoppers are located at the bottom of the precipitator. Hoppers are used to collect and temporarily store the dust removed during the rapping process.

The *shell* provides the base to support the ESP components and to enclose the unit.

Figure 2-1 shows a typical ESP with wires for discharge electrodes and plates for collection electrodes. This ESP is used to control particulate emissions in many different industries.

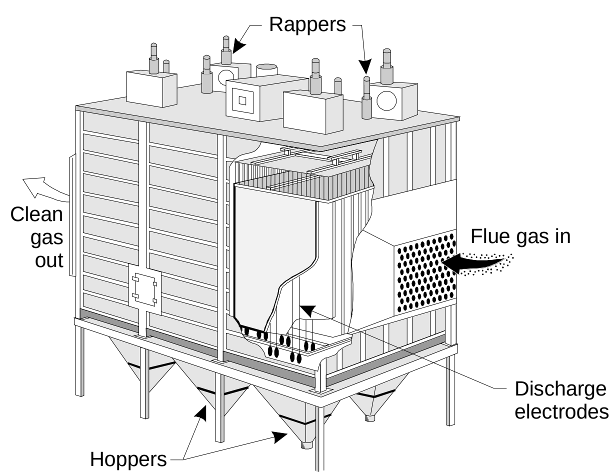

Figure 2-1. Typical dry electrostatic precipitator

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 and are generally 11.4 kg (25 lb) or more.

Discharge wires are supported to help eliminate breakage from mechanical fatigue. The wires move under the influence of aerodynamic and electrical forces and are subject to mechanical stress. 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 (Figure 2-2).

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.

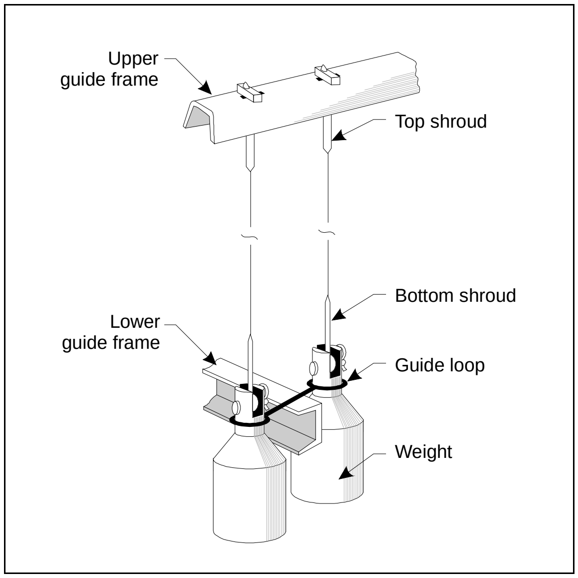

Figure 2-2. Guide frames and shrouds for discharge wires

The size and shape of the electrodes are governed by the mechanical requirements for the system, such as the industrial process on which ESPs are installed and the amount and properties of the flue gas being treated. 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 Figure 2-3.

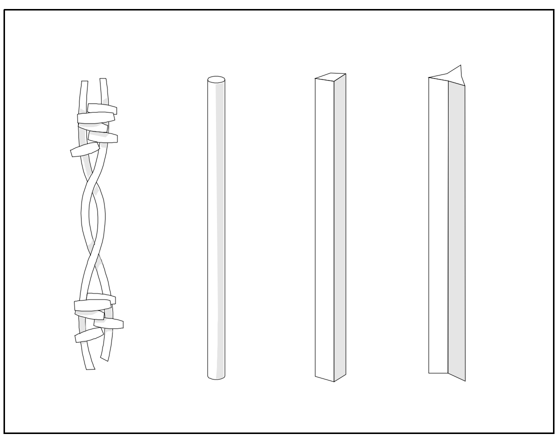

Figure 2-3. Typical wire dischare electrodes

European precipitator manufacturers and most of the newer systems (since the early 1980s) made by U.S. manufacturers use rigid support frames for discharge electrodes. The frames may consist of coiled-spring wires, serrated strips, or needle points mounted on a supporting strip. A typical rigid-frame discharge electrode is shown in Figure 2-4. The purpose of the rigid frame is to eliminate the possible swinging of the discharge wires. Another type of discharge electrode is a rigid electrode that is constructed from a single piece of fabricated metal and is shown in Figure 2-5. Both designs are occasionally referred to as rigid-frame electrodes. They have been used as successfully as the older U.S. wire designs. One major disadvantage of the rigid-frame design is that a broken wire cannot be replaced without removing the whole frame.

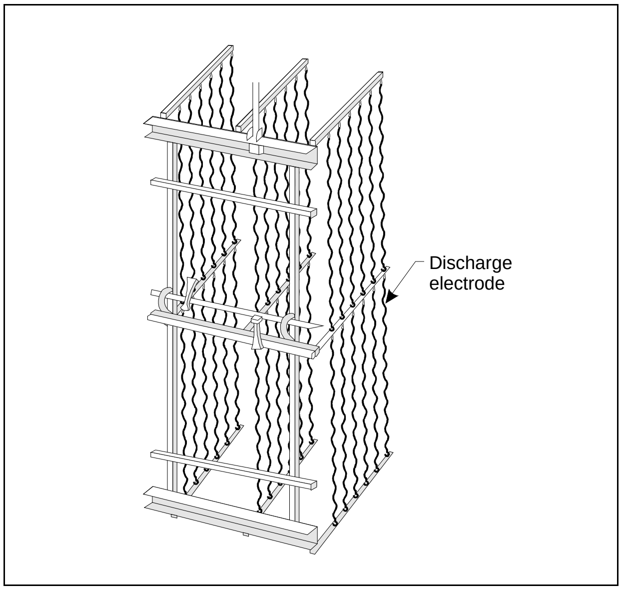

Figure 2-4. Rigid frame discharge electrode design

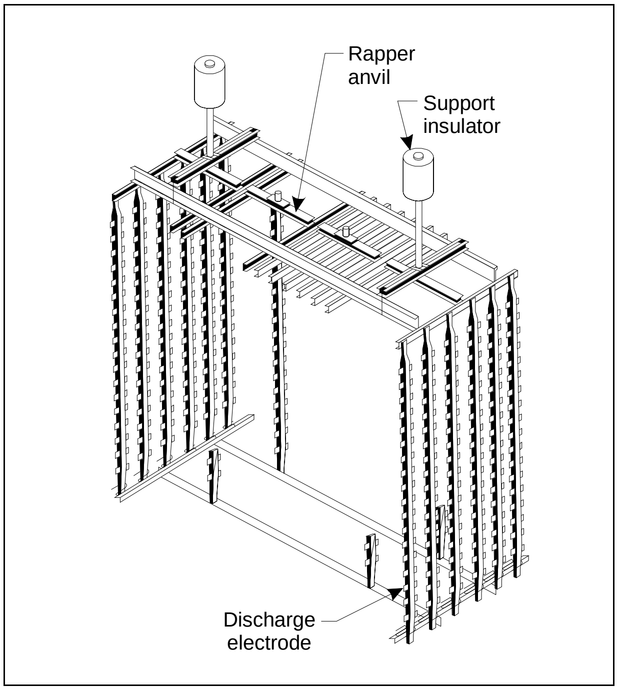

Figure 2-5. Typical rigid discharge electrode

One U.S. manufacturer (United McGill) uses flat plates instead of wires for discharge electrodes. The flat plates, shown in Figure 2-6, increase the average electric field that can be used for collecting particles and provide an increased surface area for collecting particles, both on the discharge and collection plates. The corona is generated by the sharp-pointed needles attached to the plates. These units generally use positive polarity for charging the particles. The units are typically operated with low flue gas velocity to prevent particle reentrainment during the rapping cycle (Turner, et al. 1992).

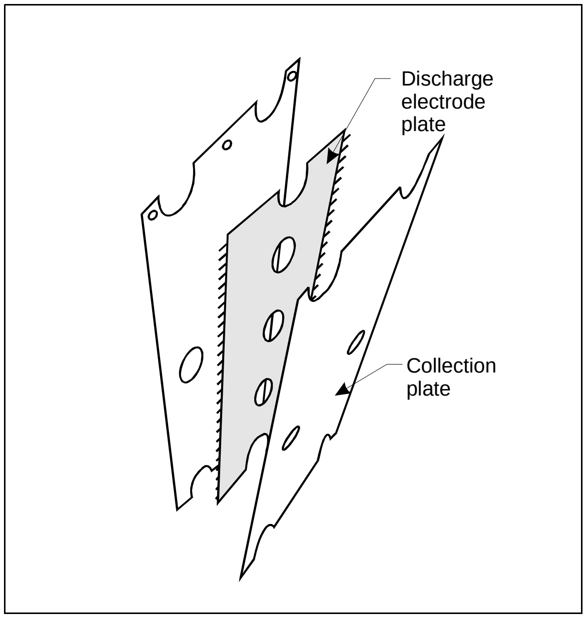

Figure 2-6. Flat-plate discharge electrode (United McGill design)

Collection Electrodes

Most U.S. precipitators use **plate** collection electrodes because these units treat large gas volumes and are designed to achieve high collection efficiency. 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.). Normal spacing for high-efficiency ESPs (using wires) is 20 to 23 cm (8 to 9 in.). For ESPs using rigid-frame or plate discharge electrodes, collection plates are typically spaced 30 to 38 cm (12 to 15 inches) apart. Plates are usually between 6 and 12 m (20 to 40 ft) high.

Collection plates are constructed in various shapes, as shown in Figure 2-7. These plates are solid sheets that are sometimes reinforced with structural stiffeners to increase plate strength. In some cases, the stiffeners act as baffles to help reduce particle reentrainment losses. This design minimizes the amount of excess rapping energy required to dislodge the dust from the collection plates, because the energy is distributed evenly throughout the plate. The baffles also provide a "quiet zone" for the dislodged dust to fall while minimizing dust reentrainment.

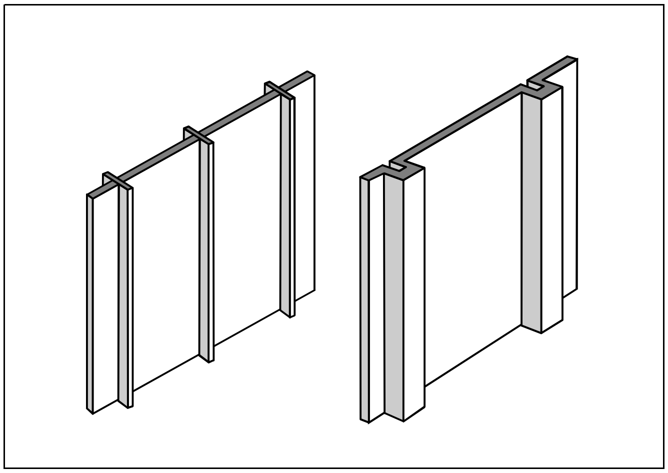

Figure 2-7. Typical collection plates

As stated in Lesson 1, tubes are also used as collection electrodes, but not nearly as often. Tubes are typically used to collect sticky particles and when liquid sprays are used to remove the collected particles.

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 and protection circuitry (automatic circuitry). The power system maintains voltage at the highest level without causing excess sparkover between the discharge electrode and collection plate. These power sets are also commonly called **transformer-rectifier (T-R) sets**.

In a T-R set, the transformer steps up the voltage from 400 volts to approximately 50,000 volts. This high voltage ionizes gas molecules that charge particles in the flue gas. The rectifier converts alternating current to direct current. Direct (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. Meters, also included in the control circuitry, monitor the variations in the electrical power input. A simplified drawing of the circuitry from the primary control cabinet to the precipitator field is shown in Figure 2.8

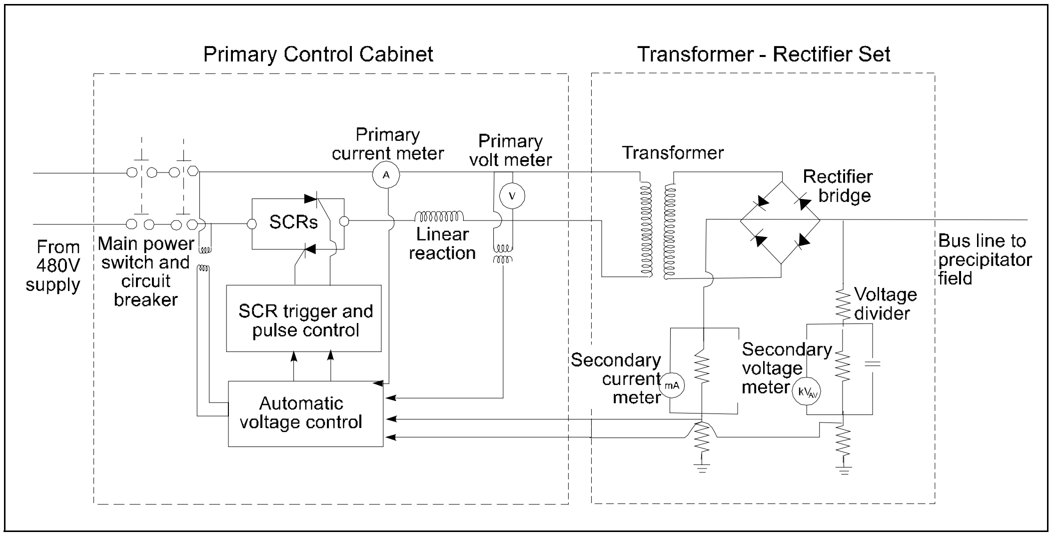

Figure 2-8. Schematic diagram of circuitry associated with precipitators

The most commonly used meters are the following:

Primary voltmeter. This 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.**Primary ammeter.** This meter measures the current drawn across the transformer in amperes. The primary ammeter 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 voltmeter. This meter measures, in 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 ammeter. This meter measures the current supplied to the discharge electrodes in milliamperes. The secondary ammeter is located between the rectifier output and the automatic control module. The combination of the secondary voltage and current readings gives the power input to the discharge electrodes.

Sparkmeter. This 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.

The terms *primary* and *secondary* refer to the side of the transformer being monitored by the meter. Figure 2-9 shows the typical meters used on each ESP field and are located in the control cabinet.

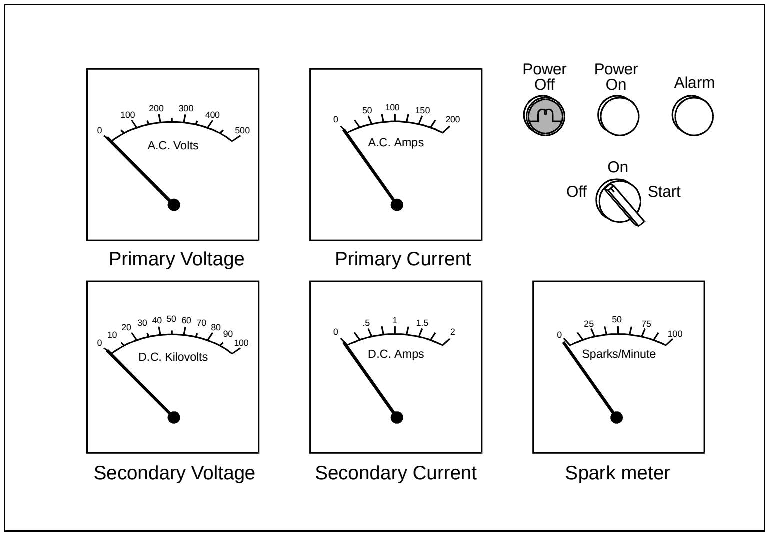

Figure 2-9. Typical gauges (meters) installed on control cabinet for each precipitator field

The transformer-rectifier set ios connected to the discharge electrodes by a **bus line**. A bus line is electric cable that carries high voltage from the transformer-rectifier to the discharge electrodes (Figure 2-10). 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 nonconducting plastic or ceramic material.

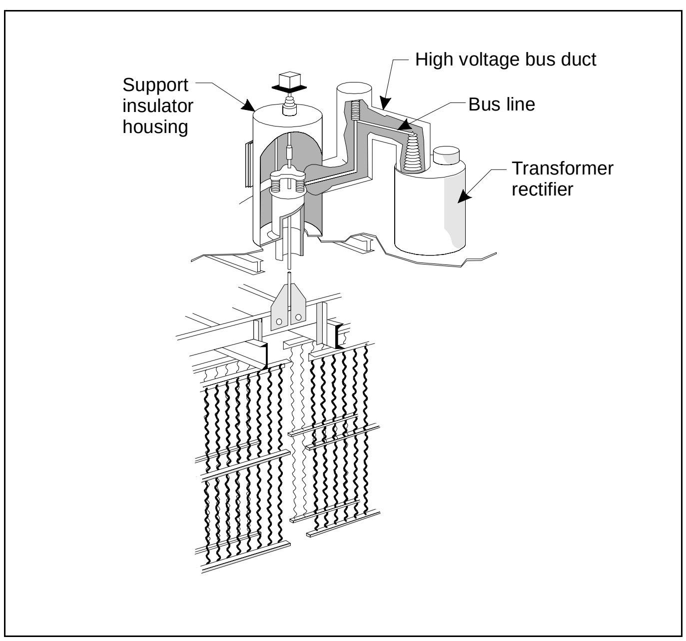

Figure 2-10. High-voltage system

Rappers

Dust that has accumulated on collection and discharge electrodes is removed by rapping. Dust deposits are generally dislodged by mechanical impulses, or vibrations, imparted to the electrodes. A rapping system is designed so that rapping intensity and frequency can be adjusted for varying operational conditions. Once the operating conditions are set, the system must be capable of maintaining uniform rapping for a long time.

Collection electrodes are rapped by **hammer/anvil** or **magnetic impulse** systems. 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.

Hammer/Anvil

Collection plates are rapped by a number of methods. One rapper system uses hammers mounted on a rotating shaft, as shown in Figure 2-11. As the shaft rotates, the hammers drop (by gravity) and strike anvils that are attached to the collection plates. Rappers can be mounted on the top or on the side of 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.

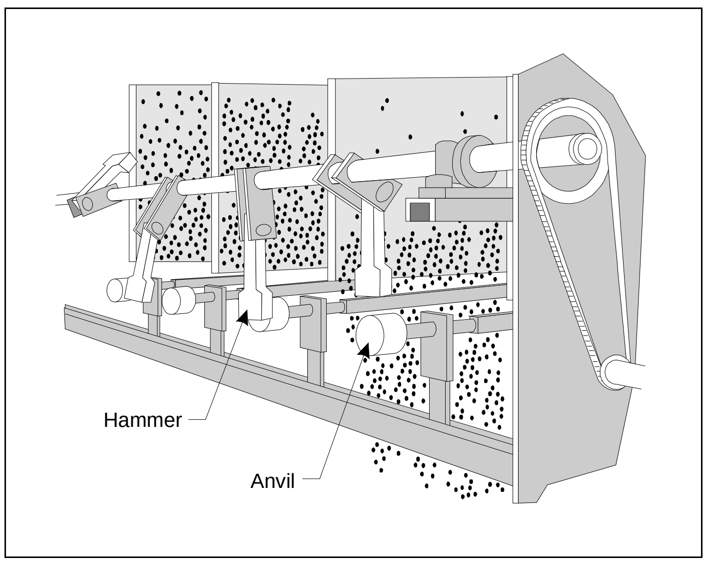

Figure 2-11. Typical hammer/anvil rappers for collection plates

Magnetic Impulse

Another rapping system used for 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 that is raised by a current pulse in a coil. The raised plunger then drops back, due to gravity, striking a rod connected to a number of plates within the precipitator as shown in Figure 2-12. Rapper frequency and intensity are easily regulated by an electrical control system. The frequency could be one rap every five minutes or one rap an hour with an intensity of 10 to 24 g's (Katz 1979). Magnetic-impulse rappers usually operate more frequently, but with less intensity, than rotating hammer and anvil rappers.

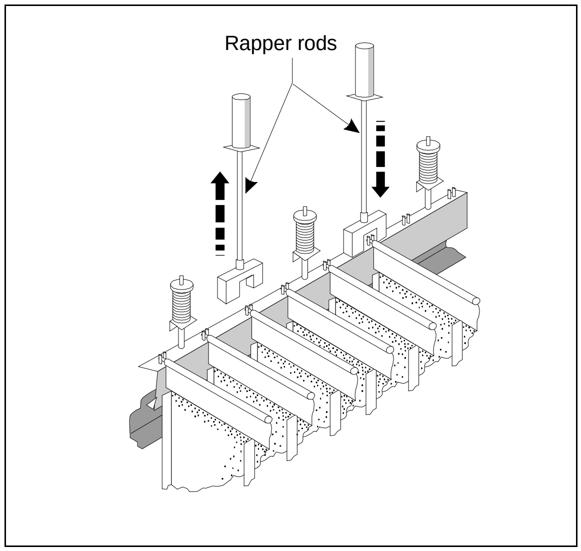

Figure 2-12. Typical magnetic-impulse rappers for collection plates

Tumbling Hammers for Rigid Frame Discharge Electrodes

Rigid frame discharge electrodes are rapped by tumbling hammers. The tumbling hammers operate similarly to the 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 which transfers the shock, or vibration, to the center tubes on the discharge system, causing the dust to fall (Figure 2-13).

Electric Vibrator

Wire discharge (or corona) 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 electric vibrators that gently vibrate the discharge wires. Vibrators are usually mounted externally on precipitator roofs and are connected by rods to the high-tension frames that support the corona electrodes (Figure 2-14). An insulator, located above the rod, electrically insulates the rapper while mechanically transmitting the rapping force.

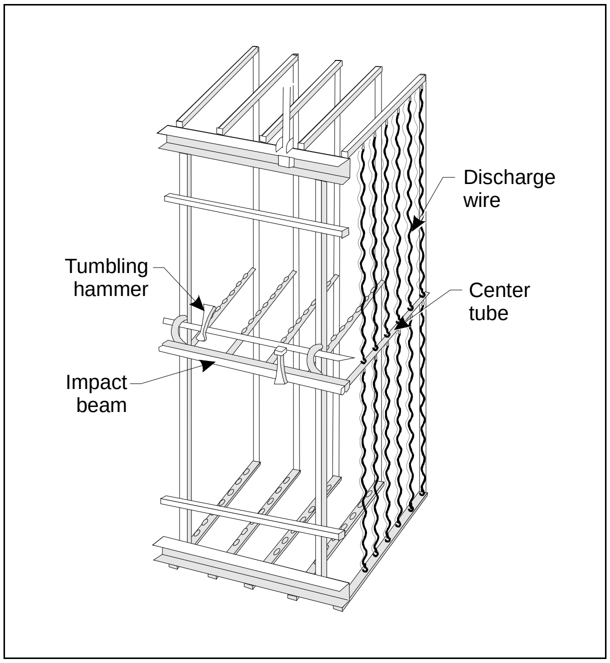

Figure 2-13. Tumbling hammers for rigid-frame discharge electrode

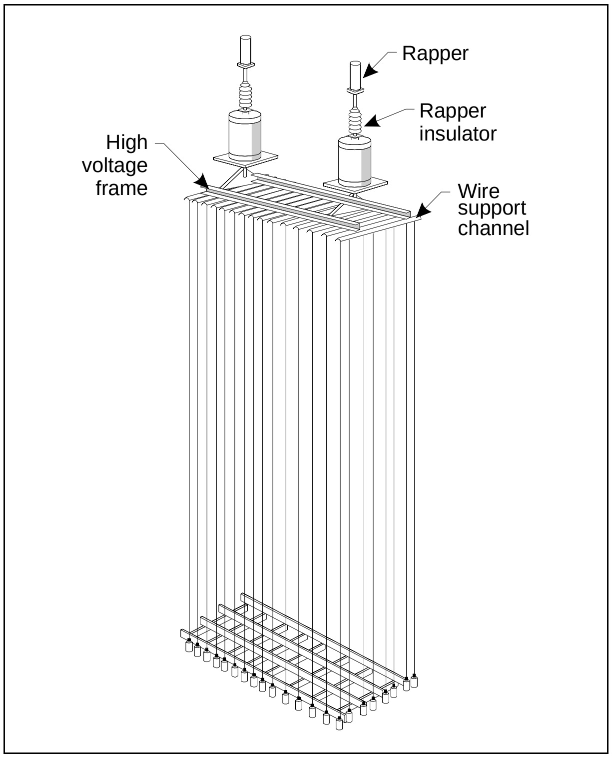

Figure 2-14. Typical electric-vibrator rappers used for wire discharge electrodes

Hoppers

When the electrodes are rapped, the dust falls into hoppers and is stored temporarily before it is disposed in a landfill or reused in the process. Dust should be removed as soon as possible to avoid packing, which would make removal very difficult. Hoppers 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 opening.

Some manufacturers add devices to the hopper to promote easy and quick discharge. These devices include **strike plates, poke holes, vibrators,** and **rappers**. Strike plates 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 strike plate several times with a mallet will free this material. Hopper designs also usually include access doors, or ports. Access ports allow easier access for cleaning, inspection, and maintenance of the hopper (Figure 2-15).

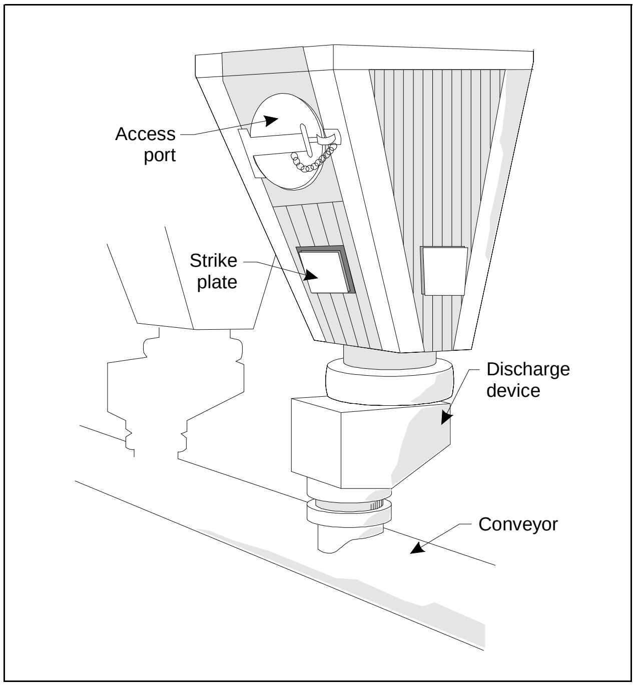

Figure 2-15. Hopper

Hopper vibrators are occasionally used to help remove dust from the hopper walls. Hopper vibrators are electrically operated devices that cause the side walls of the hopper to vibrate, thereby removing the dust from the hopper walls. These devices must be carefully designed and chosen so that they do not cause dust to be firmly packed against the hopper walls, and thereby plug the hopper. Before installing vibrators to reduce hopper plugging, make sure they have been successfully used in other, similar industrial applications.

Hopper Discharge Devices

A **discharge device** is necessary for emptying the hopper and can be manual or automatic. The simplest manual discharge device is the **slide gate**, a plate held in place by a frame and sealed with gaskets (Figure 2-16). When the hopper needs to be emptied, the plate is removed and the material is discharged. Other manual discharge devices include **hinged doors** and **drawers**. The collector must be shut down before opening any manual discharge device. Thus, manual discharge devices are used *only* on very small units that operate on a periodic basis.

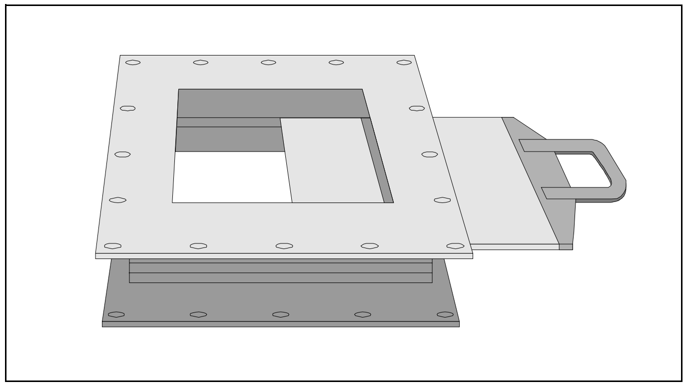

Figure 2-16. Slide-gate

Automatic continuous discharge devices are installed on ESPs that operate continuously. Some devices include double-dump valves (also called double flap or trickle valves), and rotary airlock valves. **Double-dump valves** are shown in Figure 2-17. As dust collects in the hopper, the weight of the dust pushes down the counterweight of the top flap and dust discharges downward. The top flap then closes, the bottom flap opens, and the material falls out. This type of valve is available in gravity-operated and motorized versions.

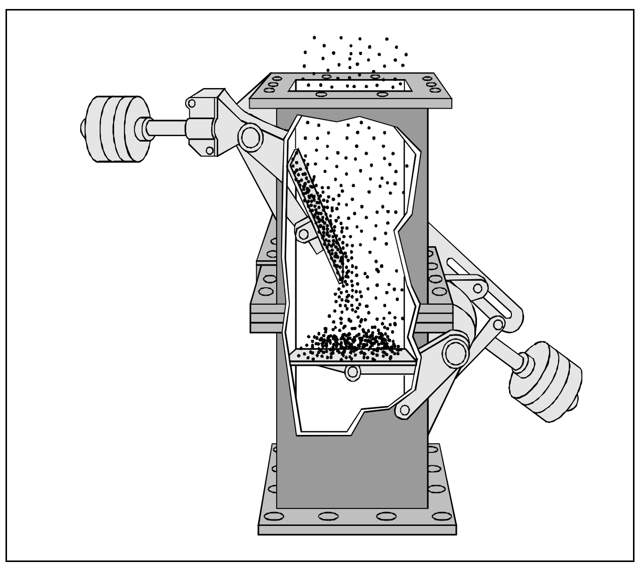

Figure 2-17. Double-dump discharge device

Rotary airlock valves are used on medium or large-sized ESPs. The valve is designed with a paddle wheel that is shaft mounted and driven by a motor (Figure 2-18). The rotary valve is similar to a revolving door; the paddles or blades form an airtight seal with the housing, and the motor slowly moves the blades to allow the dust to discharge from the hopper.

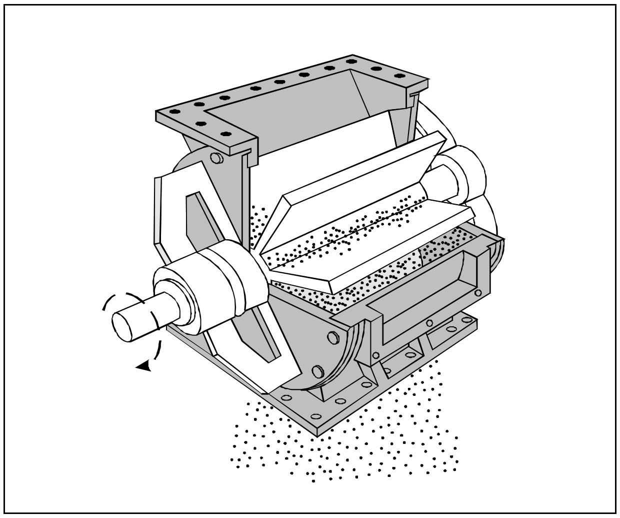

Figure 2-18. Rotary airlock discharge device

After the dust leaves the discharge device it is transported to the final disposal destination by screw, drag, or pneumatic conveyers. Screw conveyors can be used as discharge devices when located in the bottom of the hopper as shown in Figure 2-19 or as a separate conveyor to move dust after it is discharged. **Screw conveyers** employ a revolving screw feeder to move the dust through the conveyor. **Drag conveyors** use paddles, or flaps, that are connected to a drag chain to pull the dust through the conveyor trough (Figure 2-20). Drag conveyors are used frequently for conveying sticky or hygroscopic dusts such as calcium chloride dust generated from municipal waste combustors (collected fly ash/acid gas products). **Pneumatic conveyers** use blowers to blow or move the dust through the conveyor (Figure 2-21). Pneumatic conveyors can be positive pressure (dust is moved by a blower) or vacuum type systems (dust is pulled by a vacuum).

In large ESPs, dust is usually discharged from hoppers by using a combination of devices. Either rotary airlock or double dump valves empty dust into screw, drag, or pneumatic conveyers that move dust for final disposal into trucks or storage bins.

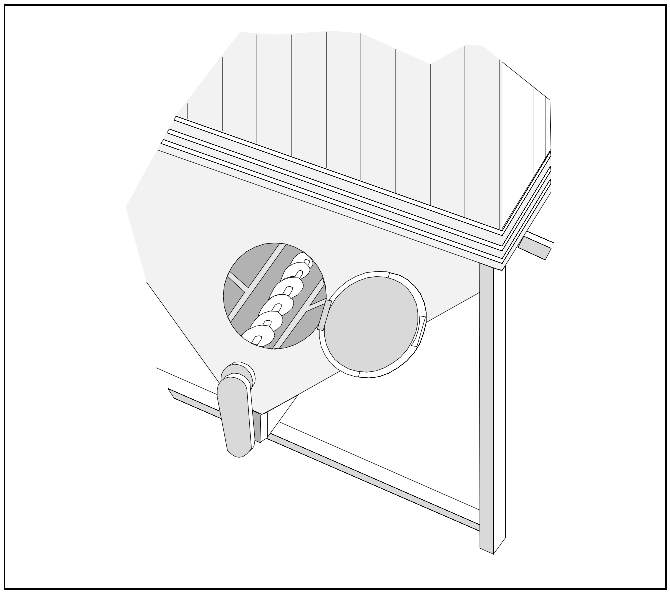

Figure 2-19. Screw conveyor

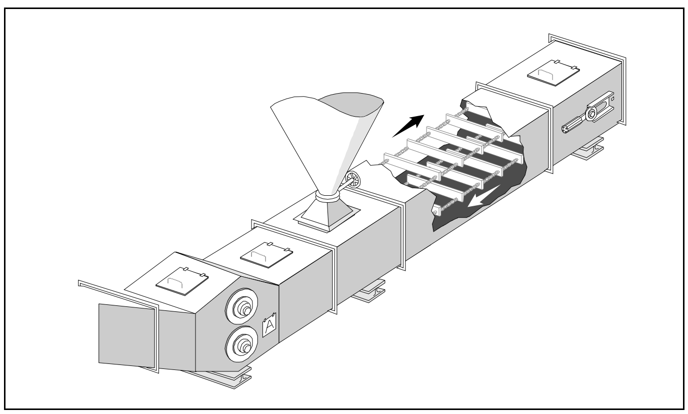

Figure 2-20. Drag conveyor

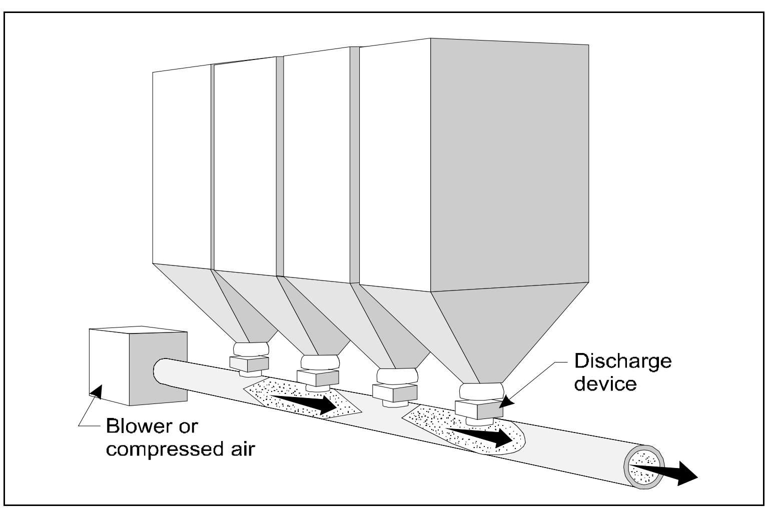

Figure 2-21. Pneumatic conveyor for transporting dust from ESP

Shell

The **shell** structure encloses the electrodes and supports the precipitator components in a rigid frame to maintain proper electrode alignment and configuration (Figure 2-22). 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 literally 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.

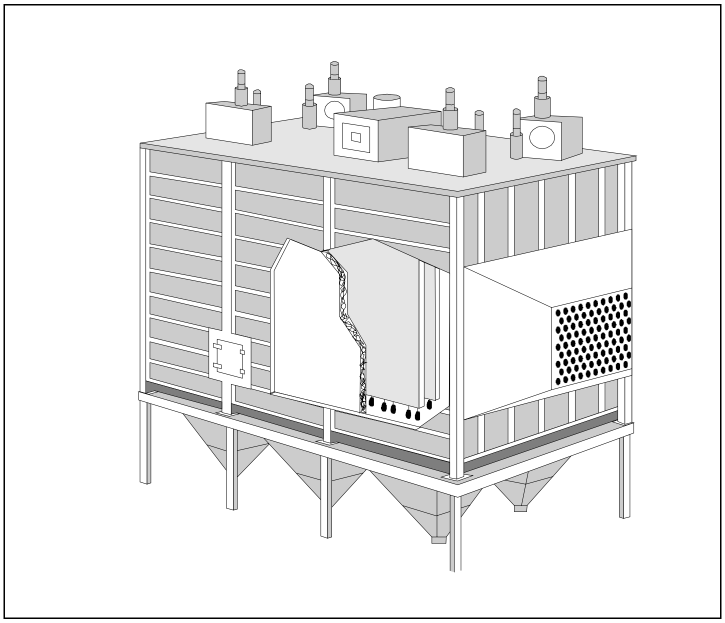

Figure 2-22. ESP shell

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.

Shells, hoppers, and connecting flues should be covered with insulation to conserve heat, and to prevent corrosion resulting from water vapor and acid condensation on internal precipitator components. 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. Insulation will also help minimize temperature-differential stresses, especially on hot-side precipitators. 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.

Summary

The precipitator should be designed to provide easy access to strategic points of the collector for internal inspection of electrode alignment, for maintenance, and for cleaning electrodes, hoppers, and connecting flues during outages. Vendors typically design the ESPs for a specific particulate emission removal efficiency. The overall design, including the specific components, is based on engineering specifications and/or previous experience with the industrial application. These components have an effect on the overall performance and ease of operation of the ESP. These topics are discussed in more detail in the following lessons.

Please view the video titled *Electrostatic Precipitators: Operating Principles and Components* before proceeding to the next lesson.

Review Exercise

1. List the six major components of an ESP.

   ____________________________ ____________________________

   ____________________________ ____________________________

   ____________________________ ____________________________

2. In many U.S. precipitators, the discharge electrodes are thin wires that are approximately ____________________ in diameter.

   a. 2.0 in.
   b. 0.1 in.
   c. 0.01 in.
   d. 15.0 in.

3. The discharge wires are hung vertically in the ESP and are held taut and plumb at the bottom by:

   a. A 25-lb weight
   b. Two 25-lb weights
   c. A 50-lb weight
   d. A 5-lb weight

4. True or False? Accumulated dust can be removed from discharge and collection electrodes by rapping.

5. European precipitators and most new U.S.-designed ESPs use ____________________ for discharge electrodes.

   a. Wires
   b. Rigid frames
   c. Plates with stiffeners

6. Normal spacing for plates used on high-efficiency wire/plate ESPs is generally:

   a. 0.2 to 0.8 in.
   b. 2 to 4 in.
   c. 8 to 9 in.
   d. 24 to 36 in.

7. Normal spacing for plates used on high-efficiency rigid-frame ESPs is generally:

   a. 2-4 in.
   b. 5-7 in.
   c. 8-9 in.
   d. 12-15 in.

8. In ESPs, plates are usually between ____________________ high.
   a. 4 to 12 in.
   b. 20 to 40 ft
   c. 40 to 60 ft

9. Collection electrodes can be constructed in two general shapes: ____________________ and ____________________.

10. Collected dust is removed from tubular ESPs using:
    a. Magnetic impulse rappers
    b. Water sprays
    c. Hammer and anvil rappers
    d. Electric vibrator rappers

11. ESPs control the strength of the electric field generated between the discharge and collection electrodes by using:
    a. Transformer-rectifier sets
    b. Meters
    c. Capacitors
    d. Insulators

12. In a T-R set, the transformer ____________________ while the rectifier____________________.
    a. Steps down the voltage, converts direct current into alternating current
    b. Converts alternating current into direct current, steps up the voltage
    c. Steps up the voltage, converts alternating current into direct current

13. In the control circuitry on an ESP, the primary voltmeter measures the:
    a. Number of sparks
    b. Input voltage (in a.c. volts) coming into the transformer
    c. Output voltage from the rectifier
    d. Operating d.c. voltage delivered to the discharge electrodes

14. The combination of the ____________________ voltage and current readings gives the power input to the discharge electrodes.
    a. Primary
    b. Sparking
    c. Secondary
    d. Tertiary

15. An electric cable that carries high voltage from the T-R set to the discharge electrode is called a(an):
    a. Bus line
    b. Pipe
    c. Duct
    d. Electric vibrator

16. Most precipitators use ____________________ or ____________________ to remove accumulated dust from collection plates.

    a. Air-vibrator rappers (or) water sprays
    b. Hammer and anvil (or) magnetic-impulse rappers
    c. Electric-vibrator (or) magnetic-impulse rappers

17. Which rappers are commonly used for removing dust from discharge electrodes?

    a. Hammer
    b. Electric-vibrator and tumbling-hammer
    c. Magnetic-impulse
    d. Water-spray

18. The dust is temporarily stored in a ____________________.

19. A ____________________ ____________________ discharge device works similarly to a revolving door.

20. A ____________________ ____________________ uses a screw feeder located at the bottom of the hopper to remove dust from the bin.

21. A ____________________ ____________________ uses a blower or compressed air to remove dust from the hopper.

22. A ____________________ ____________________ uses paddles or flaps connected to a drag chain to move dust from the ESP to its final destination.

23. In a precipitator, shells and hoppers should be covered with ____________________ to conserve heat and prevent corrosion.

Review Exercise Answers

1. **discharge electrodes**
   collection electrodes
   high voltage electrical systems
   rappers
   hoppers
   shell
   The six major components of an ESP are discharge electrodes, collection electrodes, high voltage electrical systems, rappers, hoppers, and the shell.

2. **b. 0.1 in.**
   In many U.S. precipitators, the discharge electrodes are thin wires that are approximately 0.1 inch in diameter.

3. **a. A 25-lb weight**
   The discharge wires are hung vertically in the ESP and are held taut and plumb at the bottom by a 25-lb weight.

4. **True**
   Accumulated dust can be removed from discharge and collection electrodes by rapping.

5. **b. Rigid frames**
   European precipitators and most new U.S.-designed ESPs use rigid frames for discharge electrodes.

6. **c. 8 to 9 in.**
   Normal spacing for plates used on high-efficiency wire/plate ESPs is generally 8 to 9 inches.

7. **d. 12 to 15 in.**
   Normal spacing for plates used on high-efficiency rigid-frame ESPs is generally 12 to 15 inches.

8. **b. 20 to 40 ft**
   In ESPs, plates are usually between 20 to 40 ft high.

9. **Plates**
   Tubes
   Collection electrodes can be constructed in two general shapes: plates and tubes.

10. **b. Water sprays**
    Collected dust is removed from tubular ESPs using water sprays.

11. **a. Transformer-rectifier sets**
    ESPs control the strength of the electric field generated between the discharge and collection electrodes by using transformer-rectifier sets.

12. **c. Steps up the voltage, converts alternating current into direct current**
In a T-R set, the transformer steps up the voltage while the rectifier converts alternating current into direct current.

13. **b. Input voltage (in a.c. volts) coming into the transformer**
In the control circuitry on an ESP, the primary voltmeter measures the input voltage (in a.c. volts) coming into the transformer.

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

15. **a. Bus line**
An electric cable that carries high voltage from the T-R set to the discharge electrode is called a bus line.

16. **b. Hammer and anvil (or) magnetic-impulse rappers**
Most precipitators use hammer and anvil or magnetic-impulse rappers to remove accumulated dust from collection plates.

17. **b. Electric-vibrator and tumbling-hammer**
For removing dust from discharge electrodes, electric-vibrator rappers (for wires) and tumbling-hammer rappers (for rigid frames) are commonly used.

18. **Hopper**
The dust is temporarily stored in a hopper.

19. **Rotary airlock**
A rotary airlock discharge device works similarly to a revolving door.

20. **Screw conveyor**
A screw conveyor uses a screw feeder located at the bottom of the hopper to remove dust from the bin.

21. **Pneumatic conveyor**
A pneumatic conveyor uses a blower or compressed air to remove dust from the hopper.

22. **Drag conveyor**
A drag conveyor uses paddles or flaps connected to a drag chain to move dust from the ESP to its final destination.

23. **Insulation**
In a precipitator, shells and hoppers should be covered with insulation to conserve heat and prevent corrosion.

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