Electrostatic Percipitator Design & Operation

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Neundorfer Engineered Systems

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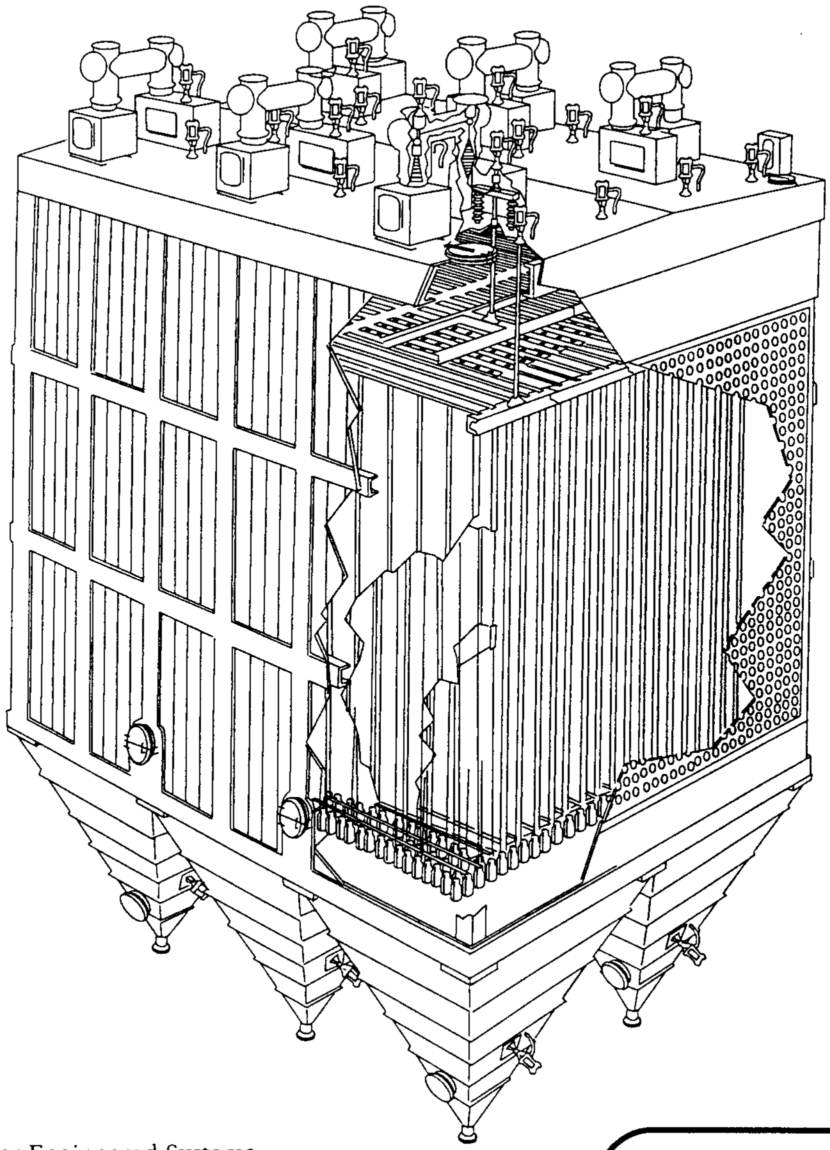
Electrostatic Precipitator Manual



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Important Notice:

The material in this document is a reference for precipitator users, and does not supersede or include plant or legislated rules and regulations. It is the user's responsibility to know and follow rules of law and plant operating procedure.

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Contents

1. INTRODUCTION

The success of an air pollution abatement or product recovery program ultimately depends upon effective operation and maintenance (O&M) of the installed air pollution control equipment. Regardless of how well an air pollution control system is designed, poor O&M will lead to the deterioration of its various components and a resulting decrease on its particulate collecting efficiency.

Effective O&M also affects equipment reliability, on-line availability, continuing regulatory compliance, and regulatory agency/source relations. Lack of timely and proper O&M leads to a gradual deterioration in the equipment, which in turn increases the probability of equipment failure and decrease both its reliability and on- line availability. These latter two items can decrease plant productivity if process operations are forced to be curtailed or shut down to minimize emissions during air pollution control equipment outages. Frequent violations of emission limits can result in more inspections, potential fines for noncompliance, and in some cases, mandatory shutdown until emission problems are solved.

This manual focuses on the operation and maintenance of typical electrostatic precipitators (ESP's). Numerous documents are available if the reader desires a more rigorous treatment of ESP theory and design.

Although O&M-related air pollution problems cannot be completely eliminated, they can be minimized by the conscientious application of a well-planned O&M program. The causes of such problems often vary widely, and their effects on deteriorating performance may be direct, indirect, or synergistic.

Process, particle, mechanical, environmental, and gas-flow dynamics factors dictate that O&M programs and troubleshooting actions be approached from a total process/plantwide viewpoint. The variable nature of these factors also requires that O&M programs be individualized and specifically tailored to the needs of the process and installation served.

2. Fundamental Principles

2.1. Terminology

- An electrostatic precipitator is a particulate emission control device that uses electrical forces to move particles out of a flowing gas stream to a collecting surface.
- It consists of a small surface (point) acting as an emitter located opposite a large surface acting as a collector.
- Electrical charging and precipitation of particles occurs between these two surfaces.

2.2 History

Electrostatic precipitation of particulates was first observed in laboratories in the 19th century.

Practical application in a lead smelter in England failed in 1885.

First successful industrial application to collect sulfuric acid fumes by F.G. Cottrell in 1907.

The cement industry is historically the second oldest application for electrostatic precipitators starting with a cement kiln in Riverside, CA.

Other pioneer installations were supplied to the non-ferrous metallurgical industry for a copper smelter in Utah (1911), for a lead blast furnace (1913), for a smelter in Trail, BC, in 1914 and the Anaconda Copper Smelter in 1916.

Steel industry applications started in 1920 followed by utility boiler installations in 1922.

2.3 Basic Principles

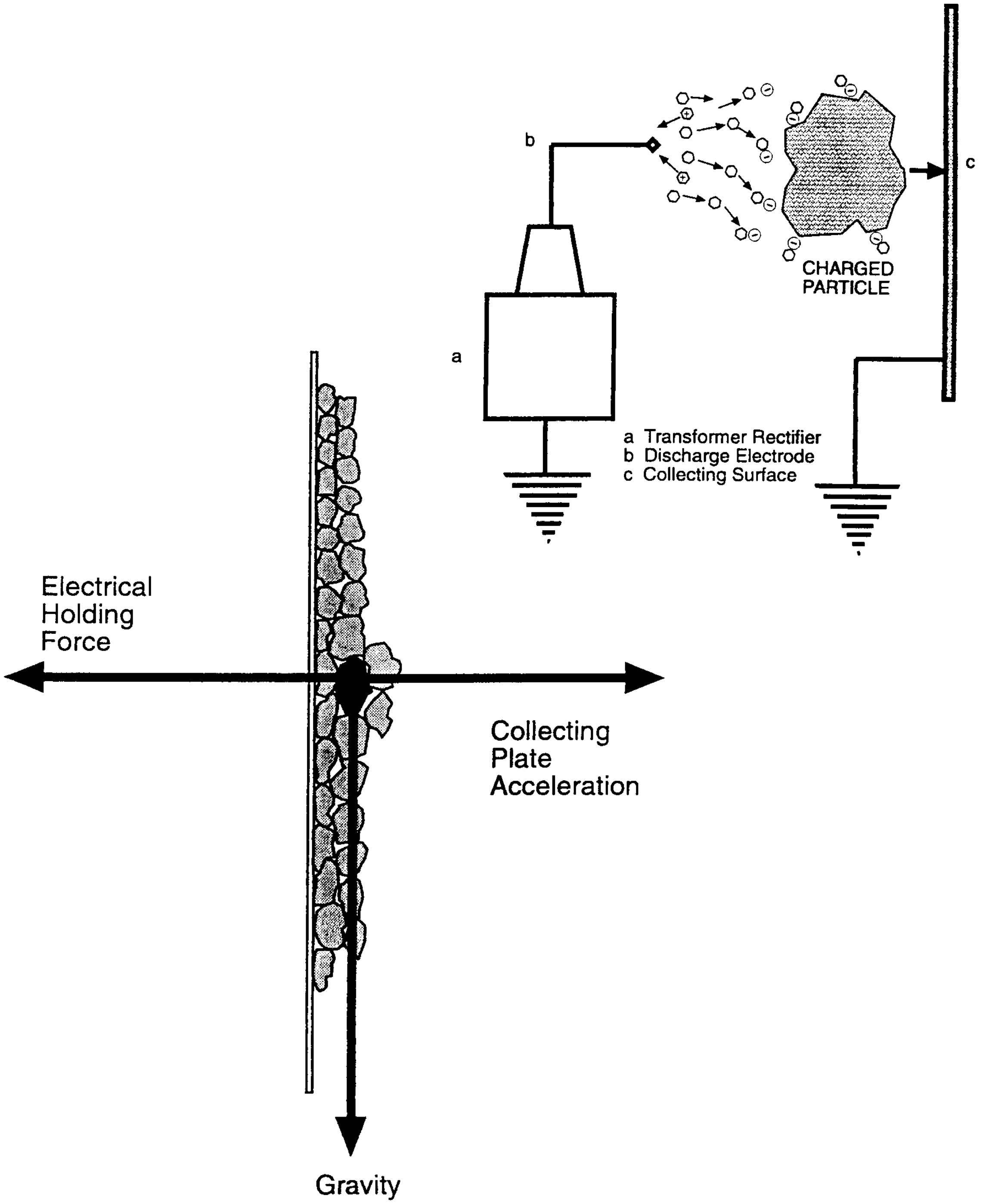
This section outlines the basic principles of electrostatic precipitation in sufficient detail to provide the background for an understanding of the manual sections that follow:

Electrostatic precipitation of particles requires the following steps (Figure 1):

- **Ionization:**	charging of particles
- **Migration:**	transporting the charged particles to the collecting surface
- **Collection:**	precipitation of the charged particles on the collecting surface
- **Particle dislodging**:	removing the particles from the collecting surface to the hopper
- **Particle removing**:	conveying the particles from the hopper to a disposal point

As the charged dust particles contact the collecting plate (or discharge electrode in the case of positively charged particles) they gradually loose their electrical charge and can be removed by rapping. (Figure 1a)

Figure 1: Particle Charging



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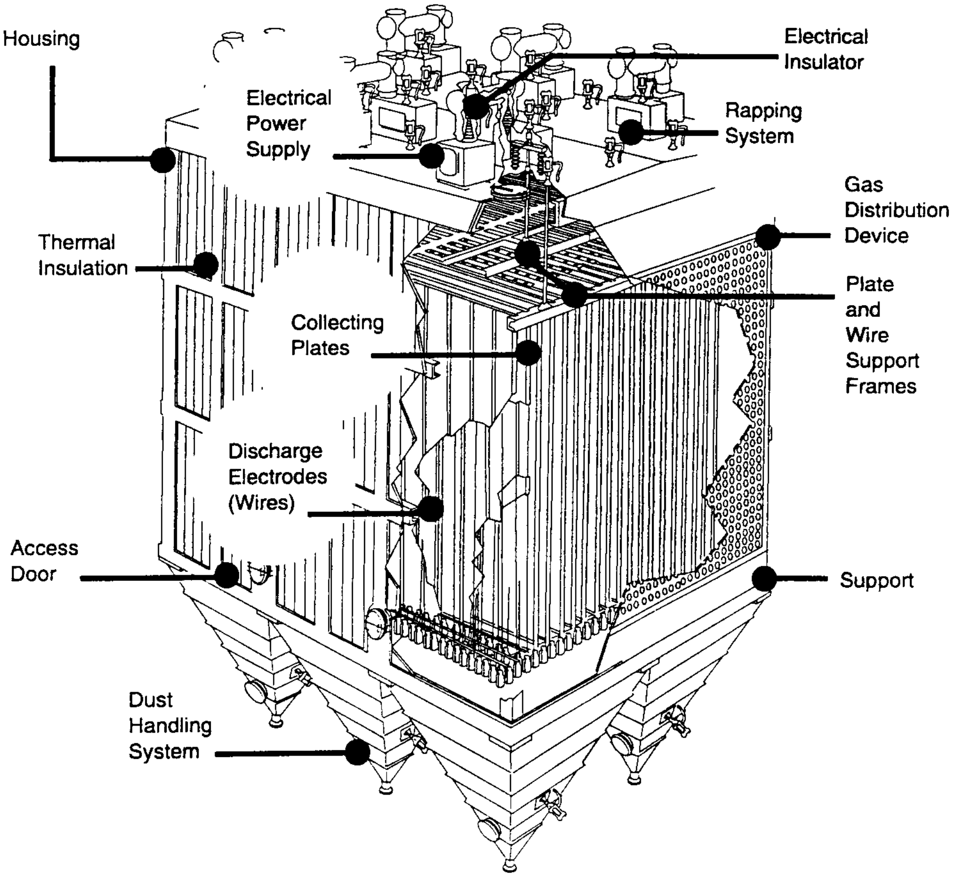
Precipitator components needed to accomplish each of these steps are: (Figure 2):

- discharge electrodes
- electrical power supply
- collecting surfaces
- rapping systems
- precipitator hopper
- dust discharge conveyor

Other components are a housing to confine the gas flow, gas distribution devices to provide a “uniform” flow of gas and particles through the precipitator, support systems for collecting plates and discharge electrodes including insulators, heating and ventilating devices, access facilities, structural support, and thermal insulation.

Figure 2: Electrostatic Precipitator



2.4 General Design Considerations

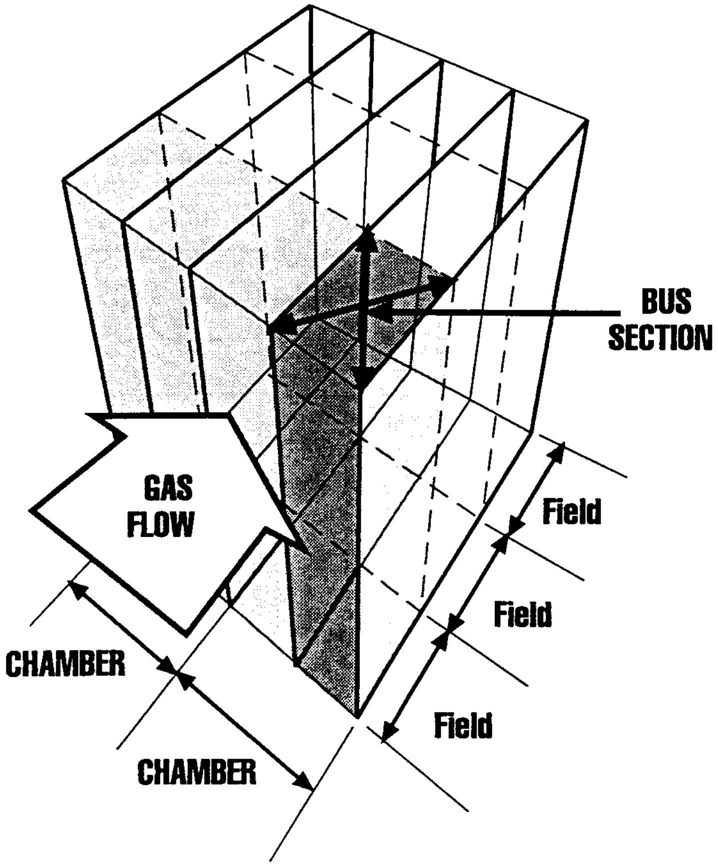
General design considerations for a precipitator are:

- Process variables
- Performance requirements
- Available space limitations

2.4.A. Process Variables

Several important gas stream and particulate properties dictate how well an ESP will collect a given particulate matter. They include particle size distribution, flow rate, and resistivity which is influenced by the chemical composition, density of particulate, and process temperature. These factors can also affect the corrosiveness of the dust and the ability to remove the dust from the plates and wires. Following are brief discussions of some of these properties.

Figure 2a: Sectionalization



2.4.A.a. Gas Volumetric Flow Rate

An ESP will operate best when the gas volume keeps the velocity within a typical range of 3.5 to 5.5 ft/s. Designers usually calculate a hypothetical average value for gas velocity from the gas flow and the cross section of the precipitator, ignoring the localized variances within the precipitator. The primary importance of the hypothetical gas velocity is to minimize potential losses through rapping and reentrainment. Above some critical velocity, these losses tend to increase rapidly because of the aerodynamic forces on the particles. This critical velocity is a function of gas flow, plate configuration, precipitator size, and other factors, such as resistivity. Figure 3 illustrates the effect of higher-than-optimum gas volume, using an outlet loading of 0.01 gr/acf as the base point. As shown, a gas volume of 10 percent over design increases the outlet loading by 50 percent, to 0.015 gr/acf.

Many ESP's are designed with some redundancy in treating the expected amount of flue gas. Nevertheless, the source should be aware of the design limits of the gas volume and take this information into account when considering process changes that will increase gas flow. Excessive air inleakage can also cause higher-than-expected gas volumes, but this problem can be remedied by proper design and maintenance of seals and expansion joints. A final consideration is that of low gas volumes. If velocity is allowed to drop below 2 to 3 ft/s, performance problems can occur as a result of maldistribution of gas flow and dropout of dust in the ducts leading to the ESP.

Building sufficient flexibility into the design of the ESP (e.g., a dampering system that allows a portion of the ESP to be closed off during periods of low gas flow) can minimize the problem.

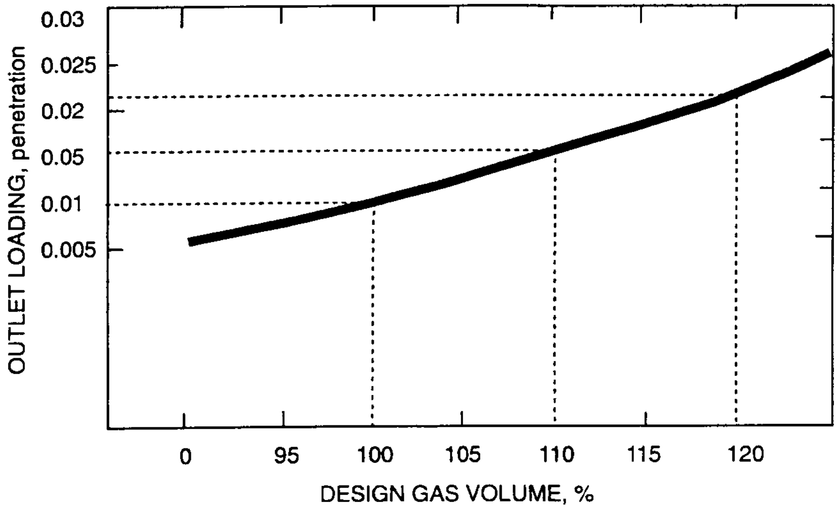


Figure 3: Effect of Gas Volume (Reduced by SCA) on Outlet Load

2.4.A.b. Gas Temperature

The effect of temperature on resistivity and (ultimately on ESP collection efficiency) can be significant in some processes. Figure 4 illustrates the variation in resistivity with temperature for several different industrial dusts. Figure 5 shows the effect of temperature on ESP efficiency in a cement preheat kiln application in which the gas stream is normally conditioned and the temperature is reduced by a water spray tower. This figure illustrates the effect of temperature that is allowed to rise. Although not all temperature effects are this dramatic, the source should be aware of how resistivity varies with temperature in their particular process application.

Figure 4: Resistivity of Several Dusts at Various Temperatures

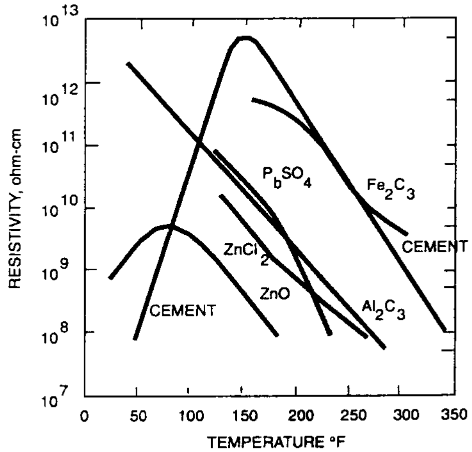
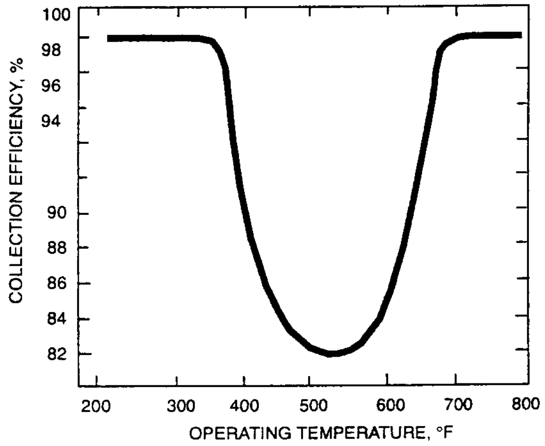


Figure 5: Effect of Temperature on Collection Efficiency ESP Cement Kiln Preheat



2.4.A.c. Dust Particle Size

The coarser the size of a particle, the easier it is for an ESP to collect it . Particles in the 0.2- to 0.4-um diameter range are the most difficult to collect because in this size range, the fundamental field charging mechanism gives way to diffusion charging by thermal ions (random collisions as a charging mechanism for very small particles.

A large percentage of small particles (<1 um) in the gas stream can suppress the generation of the charging corona in the inlet field of an ESP, and thus reduce the number of particles collected. Source personnel should have a good idea of the expected particle size of the particulate before purchasing an ESP, and the particle size distribution should be determined for the full range of the operating conditions. Performance as a function of particle size can be predicted by use of a computer model, as discussed later in this section. Figure 6 presents a typical plot of particle size versus efficiency.

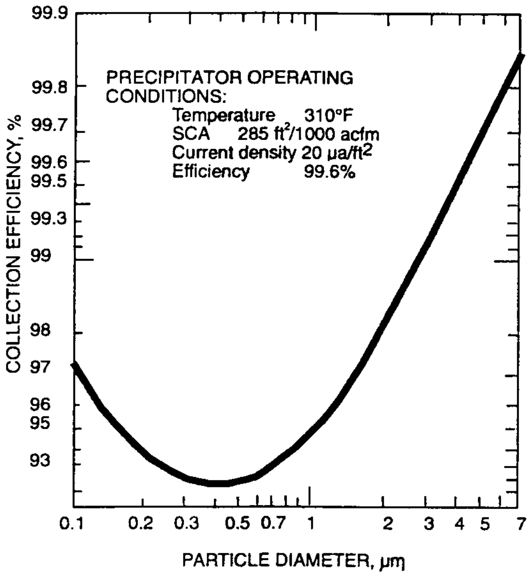


FIGURE 6: TYPICAL CURVE SHOWING EFFICIENCY AS A FUNCTION
PARTICLE SIZE FOR AN ESP COLLECTING FLY ASH

Figure 6: Efficiency Curve as Function of Particle Size in Fly Ash ESP

2.4.A.d. Dust Resistivity

This parameter is a measure of how easy or difficult it is for a given particle to conduct electricity. The higher the measured resistivity (the value being expressed in ohm-cm), the harder it is for the particle to transfer the charge. Resistivity is influenced by the chemical composition of the gas stream and particulate, the moisture content of the gas stream, and the temperature.

Resistivity must be kept within reasonable limits for the ESP to perform as designed. The preferred range is 10+E8 to 10+E10 ohm-cm. Table I presents the effects of various levels of resistivity on ESP operating characteristics.

Table 1: ESP Characteristics Associated with Different Levels of Resistivity

Resistivity level, ohm-cm	ESP characteristics
Less than 10^8	(1) Normal operating voltage and current levels unless dust layer is thick enough to reduce plate clearances and cause higher current levels (2) Reduced electrical force component retaining collected dust, vulnerable to high reentrainment losses (3) Negligible voltage drop across dust layer (4) Reduced collection performance due to (2)
10^8 to 10^{10}	(1) Normal operating voltage and current levels (2) Negligible voltage drop across dust layer (3) Sufficient electrical force component retaining collected dust (4) High collection performance due to (1), (2), and (3)
10^{11}	(1) Reduced operating voltage and current levels with high spark rates (2) Significant voltage loss across dust layer (3) Moderate electrical force component retaining collected dust (4) Reduced collection performance due to (1) and (2)
Greater than 10^{12}	(1) Reduced operating voltage levels; high operating current levels if power supply controller is not operating properly (2) Very significant voltage loss across dust layer (3) High electrical force component retaining collected dust (4) Seriously reduced collection performance due to (1), (2), and probable back corona

This discussion on resistivity applies to dry ESP' s only; resistivity is not important to the operation of a wet ESP.

2.4.A.e. Other Factors Affecting Precipitator Collecting Efficiencies

Process conditions to be considered for optimum performance of an electrostatic precipitator are process conditions, such as:

- *Gas volume*
- *Inlet dust loading*
- *Gas temperature*
- *Dust characteristics*
- *Gas characteristics.*

Also critical are precipitator inlet conditions, such as:

- *Gas velocity distribution*
- *Gas temperature distribution*
- *Dust distribution.*

The design of the precipitator itself is an important factor in its performance (collecting efficiency, reliability and availability).

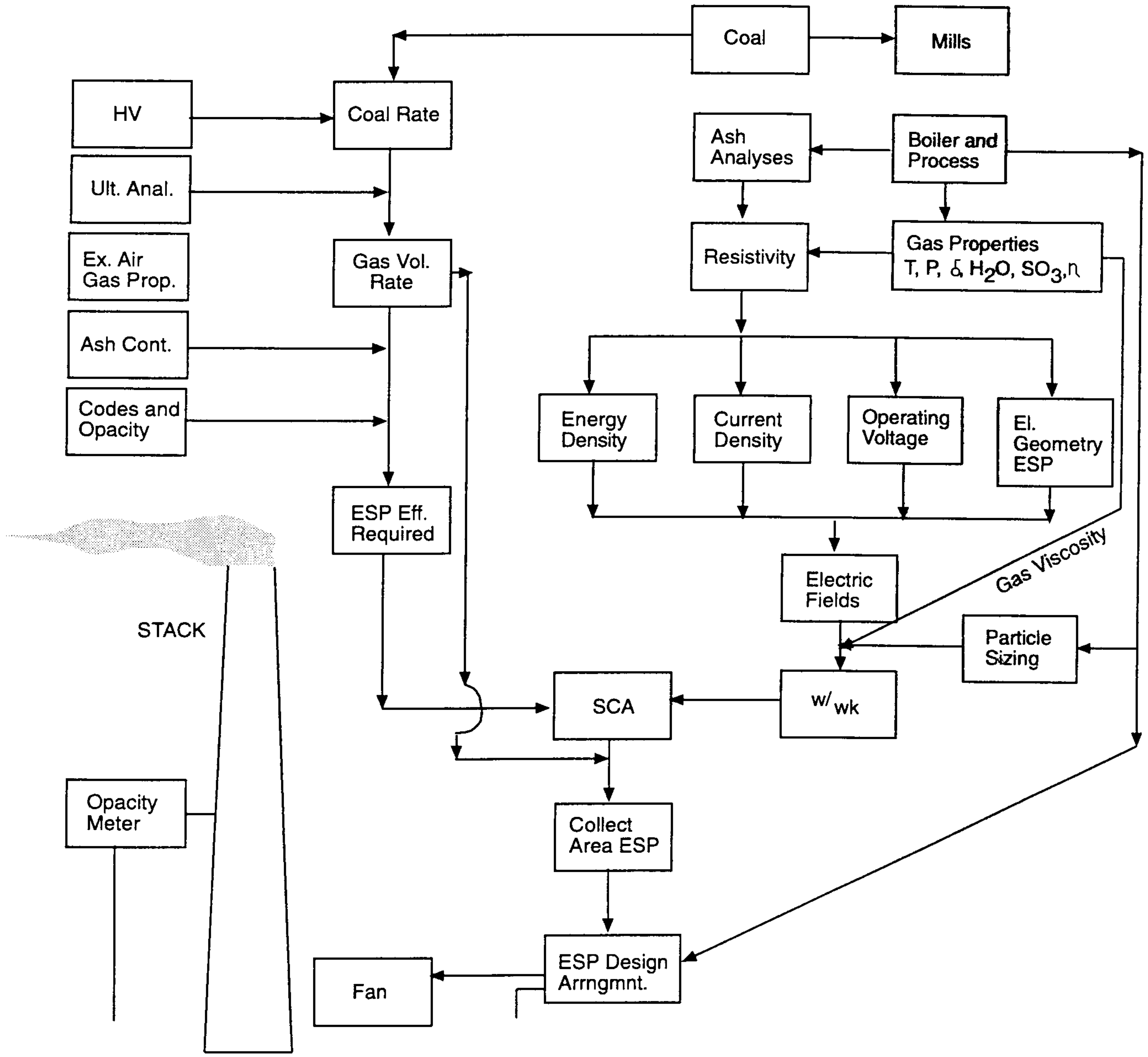
Key areas are:

- Size - Dimensions - Design.

Finally, the operation of the following components and systems of the precipitator has to be considered:

- Power supply - Rapping systems - Dust handling system.

Factors Affecting Precipitator Collecting Efficiencies



2.4.B. Performance Requirements

Performance requirements are:

- Collecting efficiency
- Precipitator size
- Precipitator design

2.4.B.a. Collecting Efficiency

Predicting the required size of an electrostatic precipitator to achieve a desired collecting efficiency when treating a specific gas volume and dust load.

2.4.B.b. Precipitator Size

Collecting efficiency, gas volume and precipitator are related by equations which were established by Anderson (1919), Schmidt and Deutsch (1922):

$E = 1 — K^t$

E = collecting efficiency
K = process constant
t = treatment time

Schmidt:

$E = 1 = K_S{}^f$
K_S = process constant
f = specific collecting area
(collecting area/gas volume/time)

Deutsch:

$E = 1 - \exp - (WxA/Q)$

A = collecting area
Q = gas volume
W = migration velocity

2.4.C. Precipitator Design

The electrostatic precipitation process occurs within an enclosed chamber; a high-voltage transformer (to step up the line voltage) and a rectifier (to convert AC voltage to DC) provide the power input. The precipitation chamber has a shell made of metal, tile, or Fiberglass Reinforced Plastic (FRP). Suspended within this shell are the grounded collecting electrodes (usually plates), which are connected to the grounded steel framework of the supporting structure and to an earth-driven ground. Suspended between the collecting plates are the discharge electrodes (also known as corona electrodes, which are insulated from ground and negatively charged with voltages ranging from 20 kV to 100kV. The large difference in voltage between the negatively charged discharge electrode and positively charged collection electrode creates the electric field that drives the negatively charged ions and particles toward the collection electrode. The particles may travel some distance through the ESP before they are collected or they may be collected more than one time. Some particles lose their charge rapidly after being collected and are lost through reentrainment in the gas stream.

The last segment of the process covers the removal of the dust from the collection electrodes. In dry ESP's, this is accomplished by periodic striking of the collection and discharge electrode with a rapping device which can be activated by a solenoid, air pressure, or gravity after release of a magnetic field, or mechanically through a series of rotating cams, hammers, or vibrators. The particulate is collected in hoppers and then conveyed to storage or disposal.

In wet ESPs, the collected particulate is removed by an intermittent or continuous stream of water or other conducting fluid that flows down over the collection electrodes and into a receiving sump.

Design requirements are:

- Adequate Precipitator size
- Optimum Electrode Alignment
- Acceptable Gas Distribution
- Efficient Rapping Systems
- Adequate Electrical Energization
- Proper Collecting Surface Design
- Proper Discharge Electrode Design
- Sectionalization
- Acceptable Gas Velocity

2.5 Collecting Efficiency

Over the past 85+ years of applied ESP technology, a number of techniques have been used to estimate the amount of collection area required to produce the desired collection efficiency. All of these techniques, however, are based on the original Deutsch-Anderson equation, which is as follows:

$E = 1 - \exp - (W\ A/Q)$

where E = ESP collection efficiency
A = Total collection electrode surface area
Q = Gas flow rate
W = Migration velocity of the particles
exp = Base of natural logarithms

The main problem with the Deutsch-Anderson equation (and the reason so many attempts have been made to modify it) is that it does not take into account the fact that

1) industrial process particulate matter is not monodisperse, and

2) the particle size distribution of dust suspended in the gas stream (and thus the migration velocity, i.e., how quickly the charged gas particles move to the grounded collection electrode) changes as the gas stream moves through the ESP. Also the equation does not account for other nonideal occurrences (such as gas turbulence and particle reentrainment) and assumes uniform electrical conditions throughout the ESP. When W is determined empirically, of course, these nonideal factors are accounted for.

The most well-known and frequently used variation on the Deutsch-Anderson equation is the Matts-Ohnfeldt version, which is derived as:

$E = 1 - \exp - ((W_k x A/Q)^k)$
e = ESP collection efficiency
A = Total collection electrode surface area
V = Gas flow rate
W_k = Modified migration velocity of particles
K = Dimensionless parameter related to particle size $(0.4<k<0.6)$

The value of the exponent k depends on the process being evaluated (most commonly 0.5 for typical fly ash application). When k = 1, the Matts-Ohnfeldt again becomes the Deutsch-Anderson equation. The W_k value in the Matts- Ohnfeldt equation can be assumed to be independent of charging voltage and current levels and of particle size distribution within an ESP as the gas stream moves through it. If other gas stream changes occur, however, such as chemical composition, resistivity, or particle size distribution, W_k will be affected just as the conventional w is affected. These relatively simple equations are very useful in estimating the current performance of an ESP in comparison with a baseline estimate by using the same equation in conjunction with a stack test.

Although the above equations form the basis of most sizing techniques, the total sizing procedure is much more involved. Each manufacturer has its own method of sizing, often involving the use of computer models, and always involving the use of some judgment because no model is capable of accounting for all of the variables that affect ESP performance.

Buyer participation also varies. Whereas some buyers rely heavily on the ESP manufacturer for determining proper sizing, in recent years other buyers have begun to take a more active role either directly or through use of their A/E. In fact, the A/E may make the final decision on what the minimum size of the ESP will be, as well as the types of components to be used.

Common to most of these equations are gas volume and installed collecting area which are readily available.

More difficult is the prediction of the achievable migration velocity (w or W_K). It is known, that migration velocity can be described by:

$$W = E_o * E_p * a / 2 / \pi / \mu$$

W = Migration Velocity
Eo = Electrical Charging Field
Ep =Electrical Collecting Field
a = particle radius
π = 3.14....
μ = gas viscosity

The strength of the electrical charging and collecting fields depend on many factors, such as

- collecting efficiency
- particle size
- electrical current
- precipitator design
- dust analysis
- dust load
- dust resistivity
- precipitator geometry
- gas velocity

and many others

Thus, the power input (electrical field or voltage and current) into the precipitators becomes the key to its performance.

Or, in other words, increasing the power input into the precipitator improves its collecting efficiency.

The size of the precipitator, or the ratio size-to-gas volume, becomes the second factor in determining its collecting efficiency.

$f = A/Q$

f = specific collecting area

A = collecting area

Q = gas volume/time

Rearranging the above equation results in:

$f = L / b / v = t/b$

L = total field length
b = plate-to-wire spacing
v = average gas velocity
t = treatment time

A graph showing collecting efficiency as a function of specific collecting area and migration velocity using the "Deutsch" equation is included as Figure 7, using the extended "Deutsch" formula (Matts-Oehnfeldt) is included as Figure 8.

Regression analysis has been used to project the collecting efficiency of an electrostatic precipitator, mostly in the form of

$E = 1 - \exp (K\ A, B,,A_2{}^{B}2,...)$

with inputs for gas volume, precipitator size, precipitator voltage, current etc.

Figure 7: "Deutsch" equation

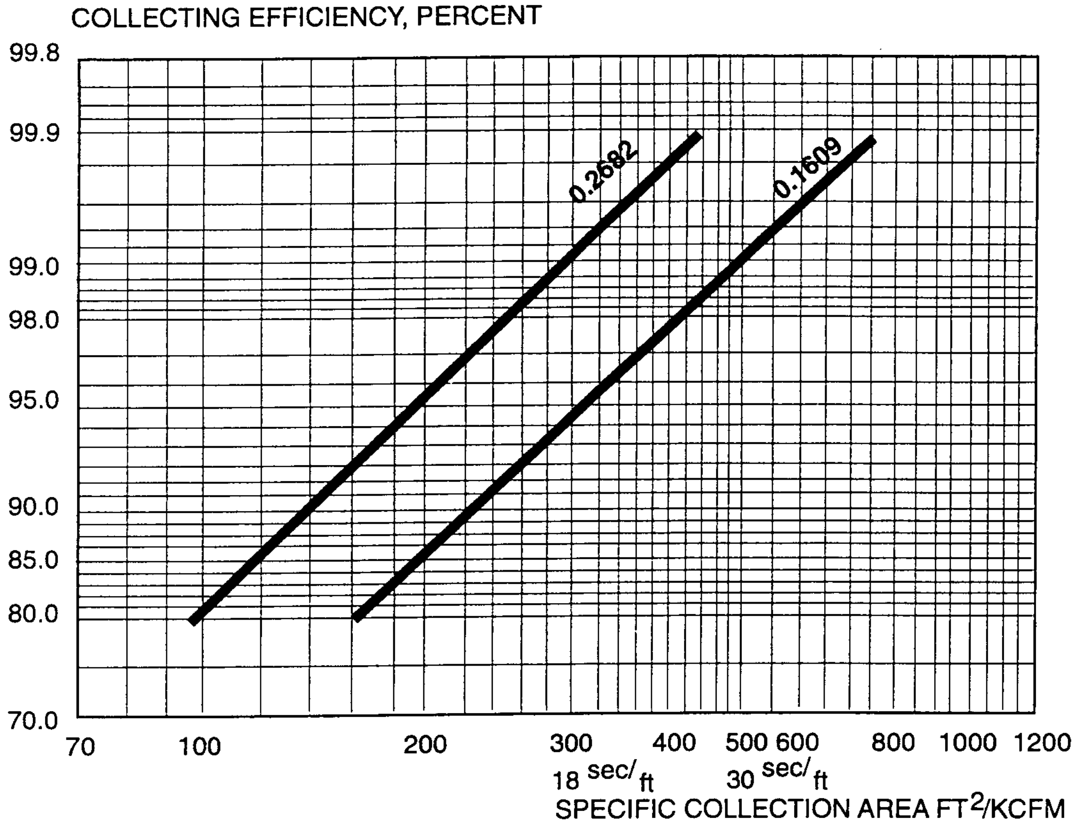


Figure 7: Collection Efficiency as a Function of Specific Collection Area

Figure 8: Extended "Deutsch" formula (Matts-Oehnfeldt)

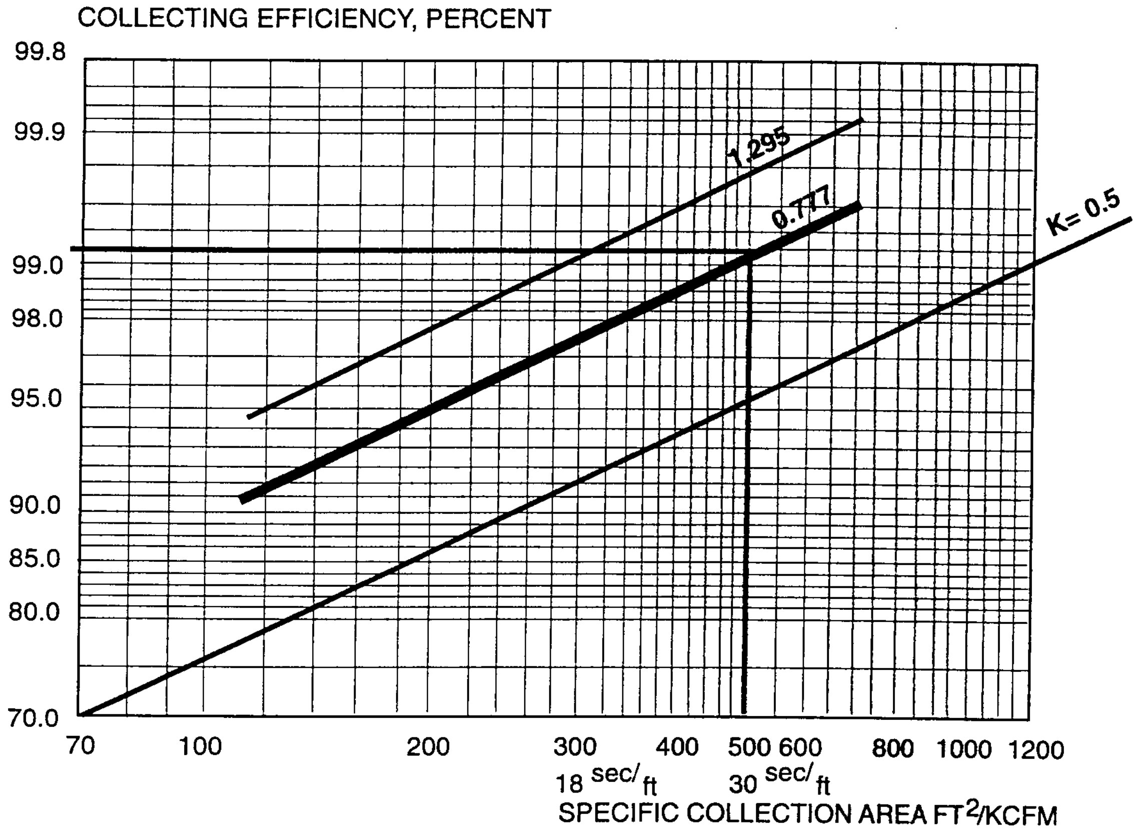


Figure 8: Collection Efficiency as a Function of Specific Collection Area

EPA/Southern Research Model—

The best known and most widely used performance model for ESP's is one developed and refined by Southern Research Institute (SoRI) for the U.S. Environmental Protection Agency over the past 15 years.

The EPA/SoRI ESP model is a valuable tool for examining and evaluating 1) gas/particulate characteristics, 2) design specifications, and 3) low or reduced process operating conditions that affect precipitator performance. Based on the inputs presented in Table II, the model also can study typical problems and deficiencies of precipitator performance in light of actual performance results. The model is designed to accomplish the following:

- Predict collection efficiency as a function of particle size, electrical operating conditions, and gas/particulate properties.
- Calculate clean-plate, clean-air, and voltage-current characteristics.
- Determine particle charging levels by unipolar ions.
- Use empirical correction factors to adjust migration velocity results.
- Account for nonideal effects of gas distribution, gas bypass, and reentrainment from nonrapping sources.
- Account for rapping reentrainment.
- Predict trends caused by changes in specific collection area, voltage, current, particulate loading, size.

Give accurate input data, the model usually can estimate emissions within +/- 20 percent of measured values. Such predictions are possible because a relationship can be established between secondary voltage and current levels (corona power) and emission levels through iterative computation by the model. Once the empirical factors are adjusted and agreement is reached, reasonable estimates of emission levels under other ESP conditions can be made. Although this model is obviously not simple, its complexity has been reduced sufficiently for it to be used with a programmable calculator. The calculator version, although not always as accurate as the full-size model, is still a useful tool, especially for installations that do not have complex O&M problems.

TABLE II: INPUT DATA FOR EPA/SORI ESP COMPUTER MODEL

ESP specifications

- Estimated efficiency
- Precipitator length
- Superficial gas velocity
- Fraction of sneakage/reentrainment
- Normalized standard deviation of gas velocity distribution
- Number of stages for sneakage/reentrainment
- Number of electrical sections in directionof gas flow
- For each electrical section
  - Length
  - Area
  - Applied voltage
  - Current
  - Corona wire radius
  - Corona wire length
  - Wire-to-wire spacing (1/2)
  - Wire-to-plate spacing
  - Number of wires per linear section

Gas/particulate specifications

- Gas flow rate
- Gas pressure
- Gas temperature
- Gas viscosity
- Particulate concentration
- Particulate resistivity
- Particulate density
- Particle size distribution
- Dielectric constant
- Ion speed

Other Sizing Techniques—

The use of pilot-scale ESP's can help in sizing a full-scale unit and also for modeling flow patterns. The main problem with use of pilot-scale units is the scaleup factor because pilot-scale units usually perform better than full-scale units. This presents some uncertainty in the choice of proper scaleup factor.

Combustors are also useful for characterization of potential coal to be used in boilers. The installation available in the United States are small, and the data they provide are qualitative. Much additional information is needed for use with full-scale units.

2.6 Advantages of Electrostatic Precipitators

- Handles large gas volume
- High collecting efficiency for fine particles
- Dry material recovery
- Separation of collected materials
- Handles saturated gases
- Handles high-temperature and high-pressure gas
- Handles sticky materials
- Handles pyrophore materials
- Energy-efficient
- Separation forces applied directly to particles
- Low pressure drop
- Low operating costs
- Low temperature drop
- Adaptable to various types of effluents
- Fully automatic, continuous operation

2.7 Disadvantages of Electrostatic Precipitators

Limiting factors:

- Dust resistivity
- Particle size
- Space charge effects
- Back corona
- Gas velocity distribution
- Dust distribution
- Temperature distribution
- Electrode alignment
- Transmission of rapping forces
- Support of high-voltage systems
- Collects only particulates
- Requires relatively constant operating conditions
- High first (capital)

3. Mechanical Design

Dry ESP's are used in all basic industries and also in some specialized applications. The electric utility industry is the biggest user, but other large users include the cement industry (rotary kilns), the pulp and paper industry (kraft recovery boilers, coal, and hogged fuel boilers), municipal incinerators, ferrous metallurgical applications (BOF, sinter, scarfing), nonferrous metallurgical applications (copper, lead, zinc, and aluminum smelting). the petroleum industry (fluid catalytic crackers, detarring), the chemical industry (sulfuric acid plants, and industrial boilers of all types. The particulate matter from these sources can generally acquire an electrical charge quite well, and an ESP can be designed to treat large gas volumes at high temperature (up to 2000°F) and several atmospheres of pressure.

The major distinction between different types of dry ESP's is the type of corona discharge system used. The three most common discharge electrode configurations used are

1) wires suspended or tensioned by weights (weighted wire),
2) wires suspended in a rigid frame, and
3) rigid electrode.

The rigid electrode does not utilize wires but creates a corona on spikes welded or otherwise attached to a rigid mast support. Fiqures 9 through ll show a typical wire-weight (American type) ESP, a rigid-frame (European type) ESP, and rigid electrode type ESP, respectively. Other differences in the design of wire-weight and rigid-type ESP's are discussed under the appropriate component (e.g., rapping equipment, etc.).

The wire-weight design was the typical American ESP from the late 1950's to the mid-1970's. Since then, users have shown an overall preference (heavily influenced by the utility industry) for rigid-type ESP's, because of their more conservative and higher cost design, the ability to provide longer discharge electrodes (generally greater than 36 ft) without an increase in breakage rate, and their ability to provide higher rapping force without damage to internal components (especially important in removing the highly resistive fly ash generated by low-sulfur coal). U.S. manufacturers are now offering ESP's of rigid-frame design and some of the so-called "hybrid" design in which a rigid-type electrode is combined with an American-type rapping system (e.g., magnetic impulse, gravity impact, pneumatic impact instead of the European-type mechanical hammers. In 1980, more than 75 percent of all ESP orders in the United States were for rigid-frame ESP's. Today, the trend is toward rigid discharge electrodes (RDEs).

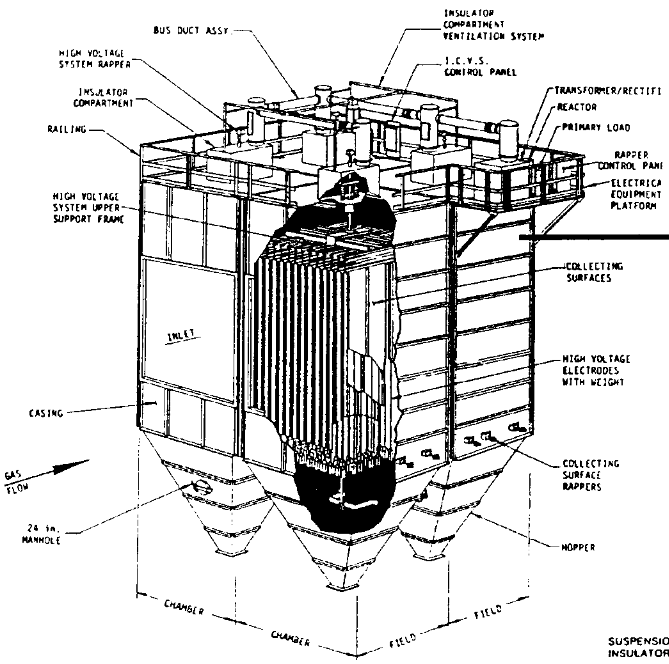


Figure 9: Typical wire-weight electrostatic precipitator with top housing

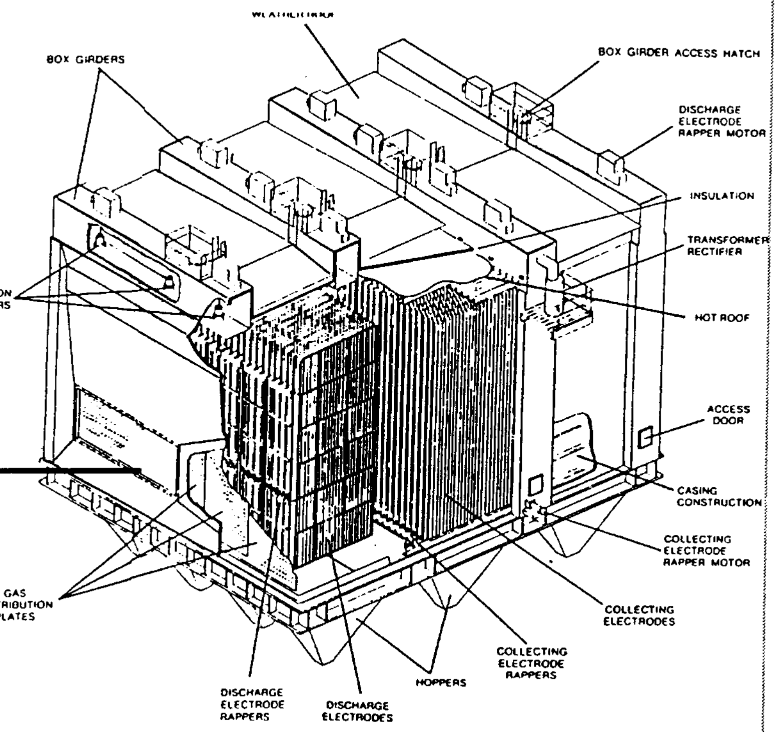


Figure 10: Typical Rigid Frame (European Design) electrostatic precipitator

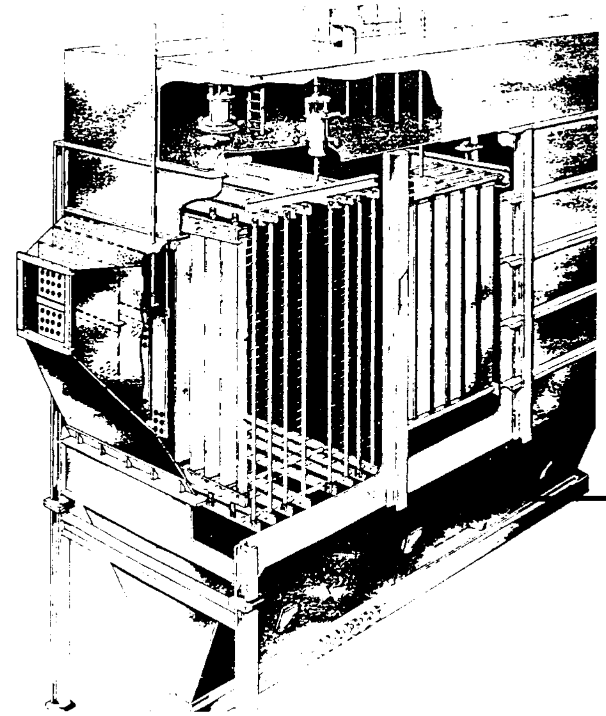


Figure 11: Typical Rigid Electrode Type electrostatic precipitator

The ESP's casing is gas-tight and weatherproof . The inlet and outlet connections, the shell, hoppers, inspection doors, and insulator housing are the major casing parts. The shell and insulation housing form a grounded steel chamber that completely encloses all the high-voltage equipment to ensure the safety of personnel.

The casing for most applications is fabricated of a steel suitable for the application (especially for the particular process and heat range). The shell is reinforced to handle maximum positive or negative environmental stresses, such as those imposed by wind, snow, and earthquake.

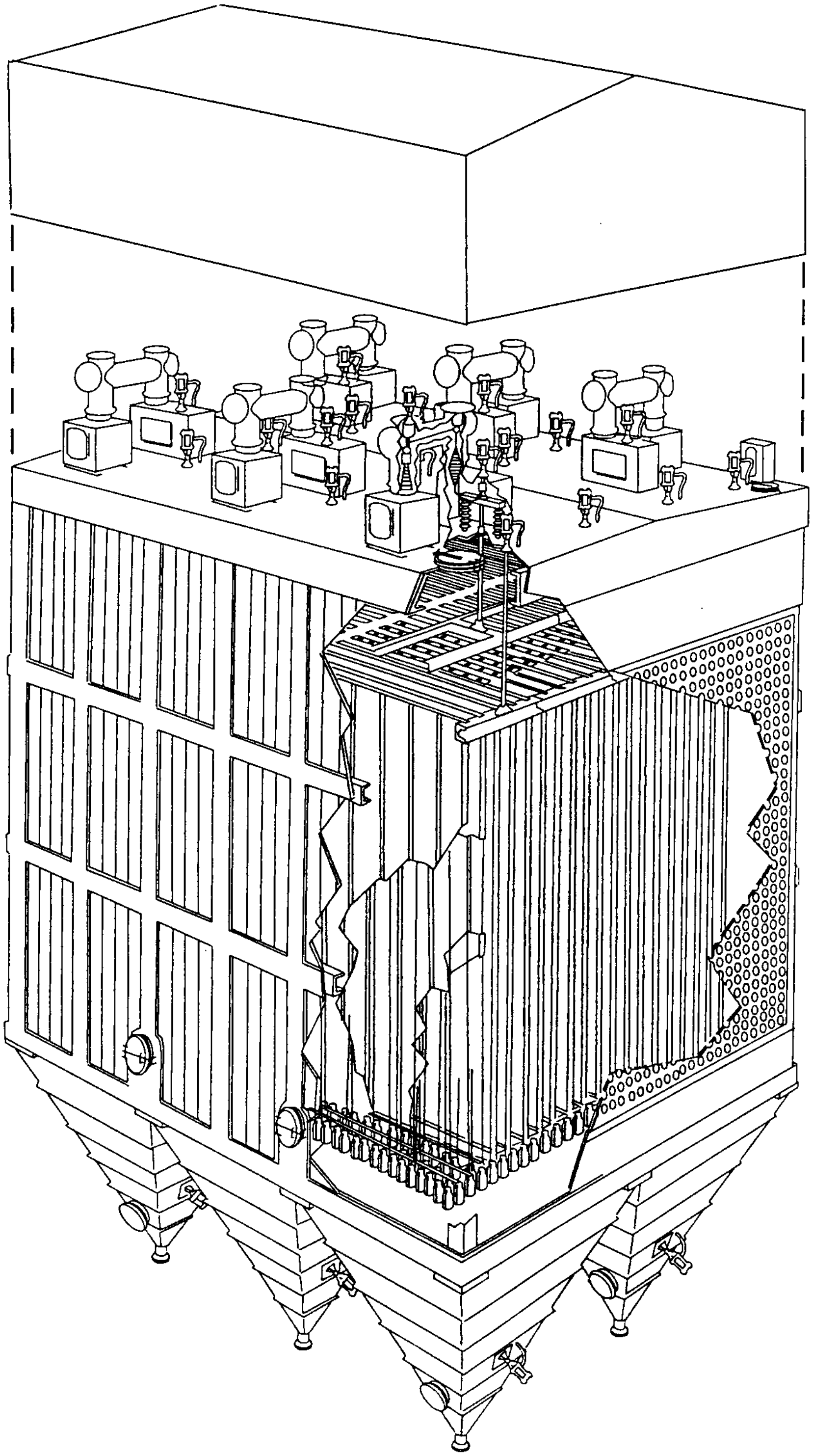
If inspection and maintenance of both collection and discharge electrode systems are made through the roof casing (usually one door per dust-plate section), as it is many wire-weight designs, the operator must crawl under the casing stiffeners and over and around the suspension hardware. Because the floor of the crawl space is usually the discharge electrode support system, inspection may be difficult. Thus, if the buyer specifies minimum clearances, he/she will eliminate the tendency among manufacturers (for competitive reasons) to reduce casing, rapper shaft, and suspension hardware costs by providing uncomfortably low headroom. Walkways and access doors between fields are a worthwhile investment for inspection, cleaning, and general maintenance of the ESP's internals, but these additional shell penetrations also increase the potential for inleakage and corrosion.

If the design provides separate insulator compartments, a roof casing covered by insulation, and a walkway surface deck plate, the plate must be watertight and sloped for drainage, and the entire structure must be adequately supported either through rigid insulation or metal framing.

Clearances must also be provided for movement of the insulator compartments, rapper shafts, or any other equipment or supports that will move as the ESP casing and structure expand.

The provision of weather enclosure or superstructure should be encouraged to facilitate routine inspections. Care must be taken to provide for differential movements in the casing and proper ventilation.

Precipitator Weather Enclosure facilitates routine inspections



Important Notice:The material in this document is a reference for precipitator users, and does not supersede or include plant or legislated rules and regulations. It is the user's responsibility to know and follow rules of law and plant operating procedure.

3.2 Hoppers

Hoppers collect the precipitated dust and deliver it to a common point for discharge. The most common hoppers are pyramidal and converge to a round or square discharge If the dust is to be removed by screw conveyor, the hopper usually converges to an elongated opening that runs the length of the conveyor. Hoppers are not recommended for applications where the dust is very sticky and may build up on sloping surfaces. Instead, the casing should be extended to form a flat-bottomed box under the ESP. The dust is removed by drag conveyors.

Hopper plugging is a major problem. Although manufacturers have produced designs incorporating vibrators, heaters, poke holes, baffles (emphasis on proper location, large discharge flanges, and steep hopper wall angles (55 to 65 degrees) to reduce these problems, they still persist.

A number of improvements could be made in the design of hoppers. The first consideration should be to provide continuous evacuation of the hopper so it will not be used as a storage device. Hopper aspect ratio (height to width) is another important consideration; the correct ratio will minimize reentrainment caused by gas sneakage to the hoppers. Low aspect ratio hoppers can be corrected by vertical baffling.

In the sizing of hoppers, consideration should be given to the fact that 80 to 90 percent of the collected dust is removed in the first field. A conservatively designed dust-removal system will keep pluggage to a minimum. The trend is toward large-sized hoppers so that operators can respond to hopper plugging before electrical grounding or physical damage is done to the electrodes. Although this trend is a valid one, some thought must be given to the time required to remove the accumulated ash. It is probably better not to specify a certain storage time. Stainless steel fillets or lower end cladding also should be considered to reduce dust bridging in these larger size hoppers.

Some manufacturers offer a high dust level, fail-safe system that automatically phases back or deenergizes high-voltage equipment when high ash levels are detected. Some kind of reliable ash-level detection, either the nuclear or capacitance type, is recommended for all hopper designs. If the preliminary design indicates a potential for problems with ash discharge, the discharge flange should be no less than 12 in. in diameter. Heaters in the discharge throat and up to one-third the height of the hopper have proved to be especially beneficial. A low-temperature probe and alarm also might be considered.

During construction, checks should be made to determine if the transition from a rectangular hopper to a round outlet is accomplished without ledges or projections; this will help to reduce plugging. Baffles should not extend too far into the hopper (which can increase plugging), and vibrators should be mounted at the baffle line to eliminate the formation of rat holes. The rapping controls should be interlocked with the ash- removal system so that rapping cannot occur unless the hopper is being evacuated.

External key interlocks should be installed to provide safe access to hoppers. Bolt-on doors through baffles should not be installed because they can cause dangerous dust accumulation on the interior side of the door. Enough "poke hole" ports should be provided to allow for cleaning a blockage at the discharge. Enclosing the hopper areas will help to reduce heat loss in the hopper and discharge system. Alignment of conveyors is very important, and depends on the alignment of hopper connections.
Field-adjustable flange connections are recommended.

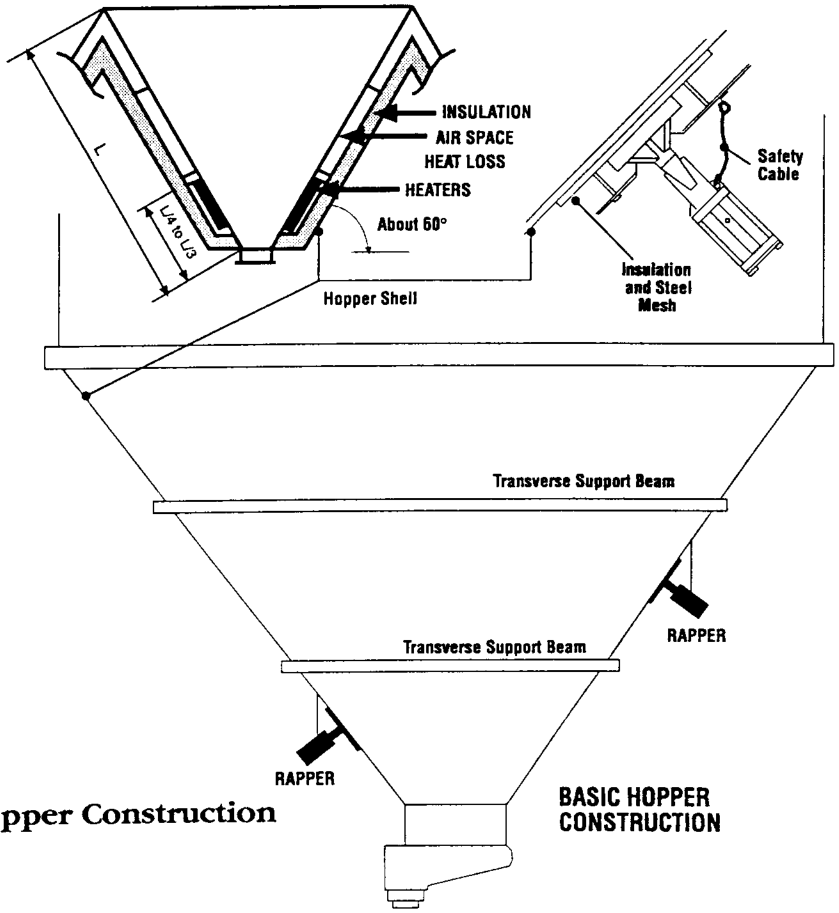


Illustration: Basic Hopper Construction

3.3 Collecting Plates

Collecting electrodes (plates) are the grounded components on which the dust collects. Many shapes of flat collecting electrodes are used in ESP's, as shown in Figure 12. Some ESP's are designed with cylindrical collection surfaces.

Collecting plates are commercially available in lengths of 3 to 12 ft (wire weight), or 6 to greater than 15 ft (rigid frame) and heights of 9 to 36 ft (wire weight) or as high as 50 ft for rigid frame designs. These panels generally are grouped with ESP to form independently rapped collecting modules. A variety of plates are commercially available, but their functional characteristics do not vary substantially. When assembled, collecting plates should be straight and parallel with the discharge electrodes. Correct alignment requires that care be exercised during fabrication, shipping, storage in the field, and erection.

The plate support system must be rugged because in many designs it must also transmit rapper energy to the plates. Each design should be examined with regard to its operating limits with various types of rappers. The effects of vibration and impact loading at all welded points should be considered. Consideration should also be given to the adjustment of any necessary plate alignment after shakedown. Enough spacers should be provided to maintain alignment and allow for temperature variations.

Rapper anvils attached to either plate supports or rapper header beams should be durable enough to withstand the stress of rapping and to maintain alignment (no bending of flanges or other local deformations).

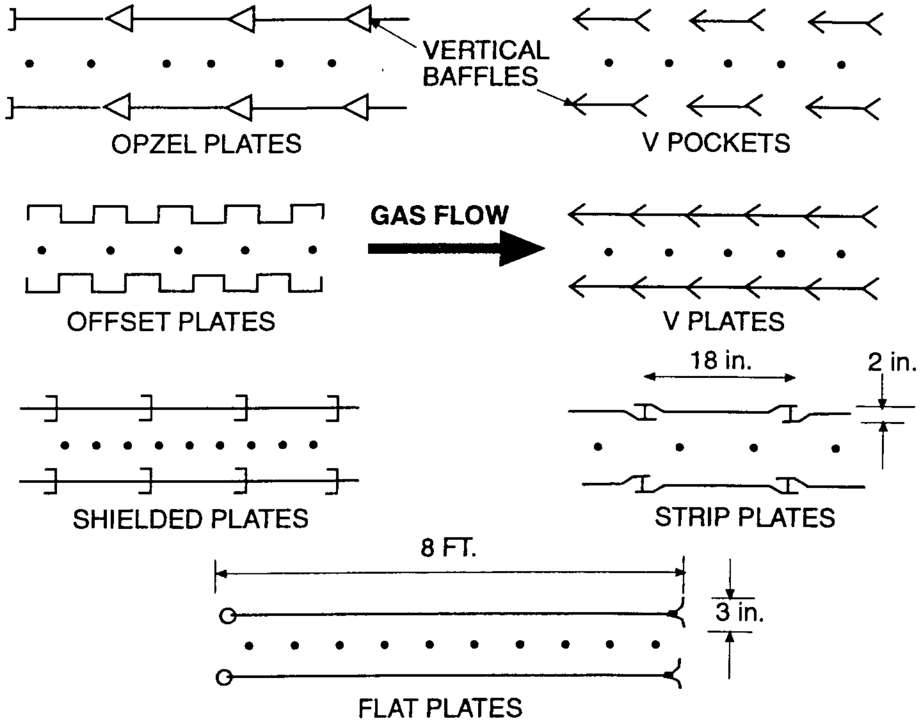
If an ESP is installed properly, collecting plates pose no maintenance problems during normal operation. Replacement or repair of a collecting plate because of warpage or breakage time-consuming and expensive task.

The following items should be considered in the erection of collecting plates:

- Collection plate - The trueness of the dust plate depends on the care exercised in fabrication, packaging, storage, and handling in the field. Most damage occurs while plates are being unpacked and raised.
- Collecting plate support structure - The design of this structure must be flexible enough that the structure can be adjusted and readjusted for proper alignment during construction and shakedown. Proper alignment is critical for the rapping anvils.

- Baffles - Baffles are installed between the casing and the outermost collection plate to prevent gas sneakage out of the main zone of precipitation. Enough room should be left for installation and inspection of these baffles to ensure proper closing of the space.

Figure 12: Various Designs of Collecting Plates



3.4. Discharge Electrodes

Discharge electrodes are metal, and the type is determined by the composition of the gas stream. The electrodes may be cylindrical or square wire, barbed wire, or stamped or formed strips of metal of various configurations (as shown in Figure 13). The shape of these electrodes determines the current voltage characteristics; the smaller the wire or the more pointed its surface, the greater the value of current for a given voltage.

Discharge electrodes are mounted in various ways. They may be suspended from an insulating superstructure with weights at the bottom holding them tightly in place, or they may be rigidly mounted on masts or frames. The advantage of the rigid-type discharge electrode system over a wire-weight system is that it lessens the chance of a broken wire falling against a plate and shorting out that section of the ESP. The weighted-wire type must be stabilized to avoid its swinging in the gas stream. Examples of the wire-weight and rigid-wire systems are shown in Figure 14.

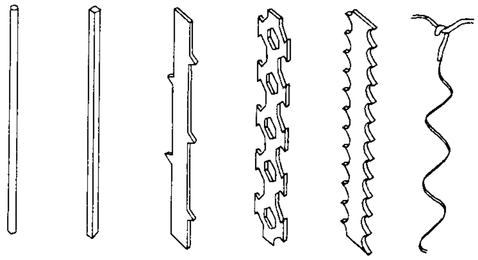
When properly designed, both wire-weight and rigid frame discharge electrode configurations have excellent collection capability. The low initial cost of a weighted-wire design is typically offset by high maintenance costs resulting partially from wire breakage. The reverse is true of rigid-frame designs; in this case, the high initial costs are usually offset by low maintenance costs. Warping of the discharge electrode frame caused by wide thermal swings is generally not a problem if a unit is properly designed. Both designs can deliver similar electrical power levels to the ESP for particulate matter collection. Generally, however, rigid frame ESP's operate at higher voltages and lower current densities than wire-weight ESP's in a given application because of the wider spacing between the discharge electrodes and the collecting electrodes. These voltage-current characteristics may be better suited to collection of high-resistivity dusts.

Because of problems with discharge electrodes design is especially important in areas related to electrical erosion mechanical fatigue corrosion, and inadequate rapping. When high-current sparks or continuous sparking must be tolerated, the use of large, formed discharge electrodes will provide much better protection against erosion of the discharge electrode than will smaller sizes (of either wire weight or rigid-frame electrodes). Shrouds should be included at both the top and bottom of wire-weight electrodes, and all inter-electrode high-voltage and grounded surfaces should have smooth surfaces to minimize sparkover.

Transformer-rectifier sets should be well matched to the ESP load, and automatic spark controllers should keep voltage close to the sparking threshold. Contact between the electrode and the stabilizing frame should be solid to prevent sparking. For rigid-frame discharge electrodes, substantial reinforcement is required at the point where the electrodes, substantial reinforcement is required at the point where the electrode is attached to the support frame, to ensure that a significant amount of metal must be lost before failure occurs. The use of alloyed metals is recommended for all discharge electrodes to minimize corrosion and fatigue.

Mechanical connections in the discharge electrode structure should be designed so that flexing and reduction in cross-sectional area at junction points are minimized. Connections should be vibration-and stress-resistant, and electrodes should be allowed to rotate slightly at their mounting points. Keeping the total unbraced length of electrode as short as possible will minimize mechanical fatigue.

Figure 13: Typical Discharge Wire Shapes



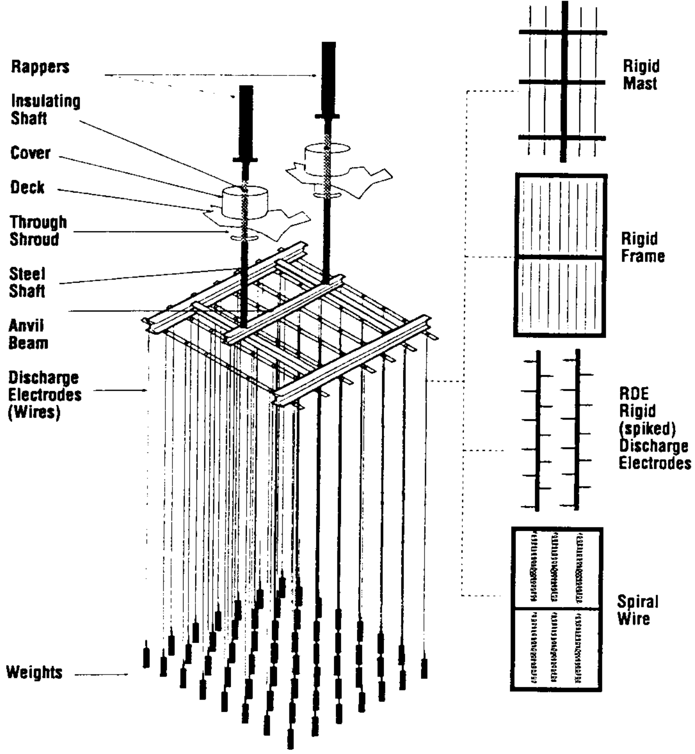


Figure 14: Typical Weighted Wire Arrangement and Other styles of discharge electrode configurations

3.5 Rappers/Vibrators

Rappers are categorized according to their use on wire-weight or rigid-frame ESP's. On wire-weight ESP's, rapping impulses are provided by either single-impulse or vibratory rappers, which are activated either electrically or pneumatically. Figures 15 and 16 show examples of typical rappers for wire-weight ESP's.

Electromagnetic or pneumatic impulse-type rappers usually work better on collecting electrodes and in difficult applications because a vibrator generally cannot generate sufficient operating energies without being damaged. The magnetic-impulse, gravity-impact rapper is a solenoid electromagnetic consisting of a steel plunger surrounded by a concentric coil; both are enclosed in a watertight steel case. The control unit contains all the components (except the rapper) needed to distribute and control the power to the rappers for optimum precipitation.

During normal operation, a d.c. pulse through the rapper coil supplies the energy to move the steel plunger. The magnetic field of the coil raises the plunger, which is then allowed to fall back and strike a rapper bar connected to the collecting electrodes within the ESP. The shock transmitted to the electrodes dislodges the accumulated dust.

The electromagnetic rappers also have a coil (energized by alternating current). Each time the coil is energized, vibration is transmitted to the high-tension wire-supporting frame and/or collecting plates through a rod. The number of vibrators applied depends on the number of high-tension frames and/or collecting plates in the system. The control unit contains all the components necessary for operation of the vibrators, including a means of adjusting the vibration intensity and the length of the vibration period. Alternating current is supplied to the discharge-wire vibrators through a multiple-cam timer that provides the sequencing and time cycle for energization of the vibrators.

Nonmalleable high-strength alloyed steels should be used for the hardware components because their resonance properties and strengths match those required to receive and deliver impacts with few mechanical failures.

Figure 15: Typical Magnetic Impulse Rappers on roof

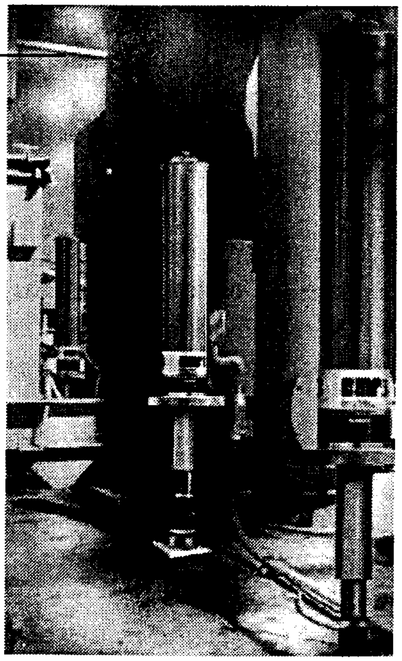
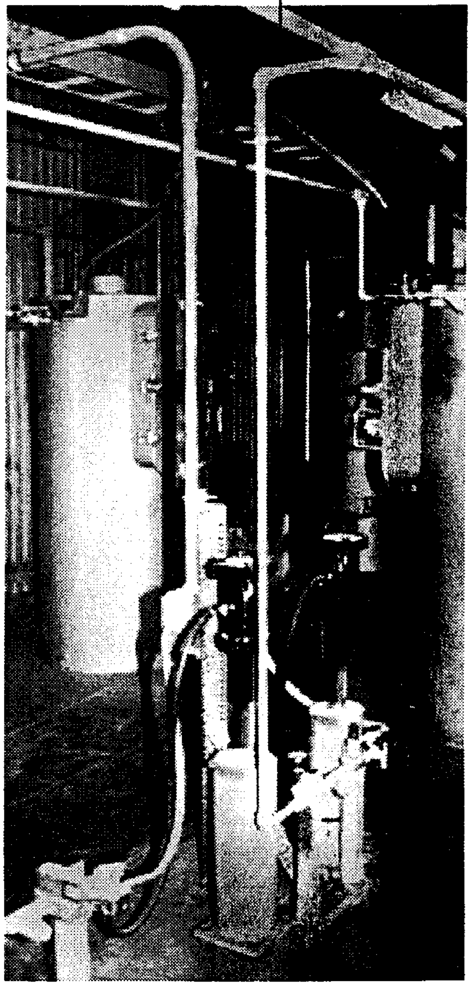
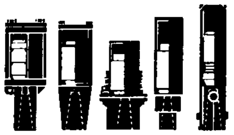
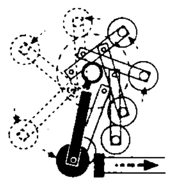


Figure 16: Typical Pneumatic Rappers in Penthouse



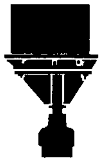
Typical Pneumatic Rappers

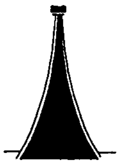




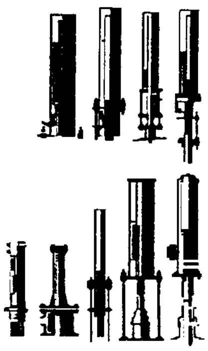
Typical Tumbling Hammers

Typical Electric Vibrator





Typical Sonic Horn



Typical Electric Rappers

The electrical controls should be adjustable so that the rappers can be assembled into different groups and each group can be adjusted independently for optimum rapping frequency and intensity. The controls should be manually adjustable so they can provide adequate release of dust from collecting plates and simultaneously prevent undesirable stack puffing.

Failures of rapper rod connections to carbon steel electrode systems can be minimized by designing welds that are large and strong enough to withstand impacts and by careful welding. Proper selection of rod material and protective shrouding in sealed areas will minimize corrosion problems.

Problems related to ground faults also occur in the ESP's conduit system because of lack of seals at connections, poor-quality wire terminations, and use of low-quality wire.

In some applications, the magnetic-impulse, gravity-impact rapper is also used to clean the ESP's discharge wires. In this case, the rapper energy is imparted to the electrode-supporting frame in the normal manner, but an insulator isolates the rapper from the high voltage of the electrode-supporting frame.

The number of rappers, size of rappers, and rapping frequencies vary according to the manufacturer and the nature of the dust. Generally, one rapper unit is required for 1200 to 1600 ft of collecting area. Discharge electrode rappers serve from 1000 to 7000 ft. of wire per rapper. Intensity of rapping generally ranges from about 5 to 50 ft/lb, and rapping intervals are adjustable over a range of approximately 30 to 600 seconds.

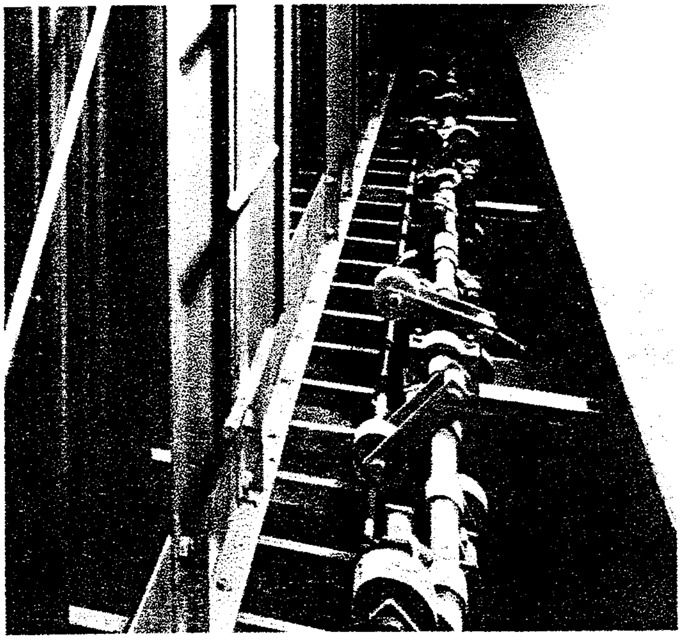


Figure 17a: Tumbling Hammers

Rigid-frame ESP's generally have mechanical-hammer rappers. Each frame is rapped by one hammer assembly mounted on a shaft. (See Figure 17). A low-speed gear motor is linked to the hammer shaft by a drive insulator, fork, and linkage assembly. Rapping intensity is governed by the hammer weight, and rapping frequency is governed by the speed of the shaft rotation.

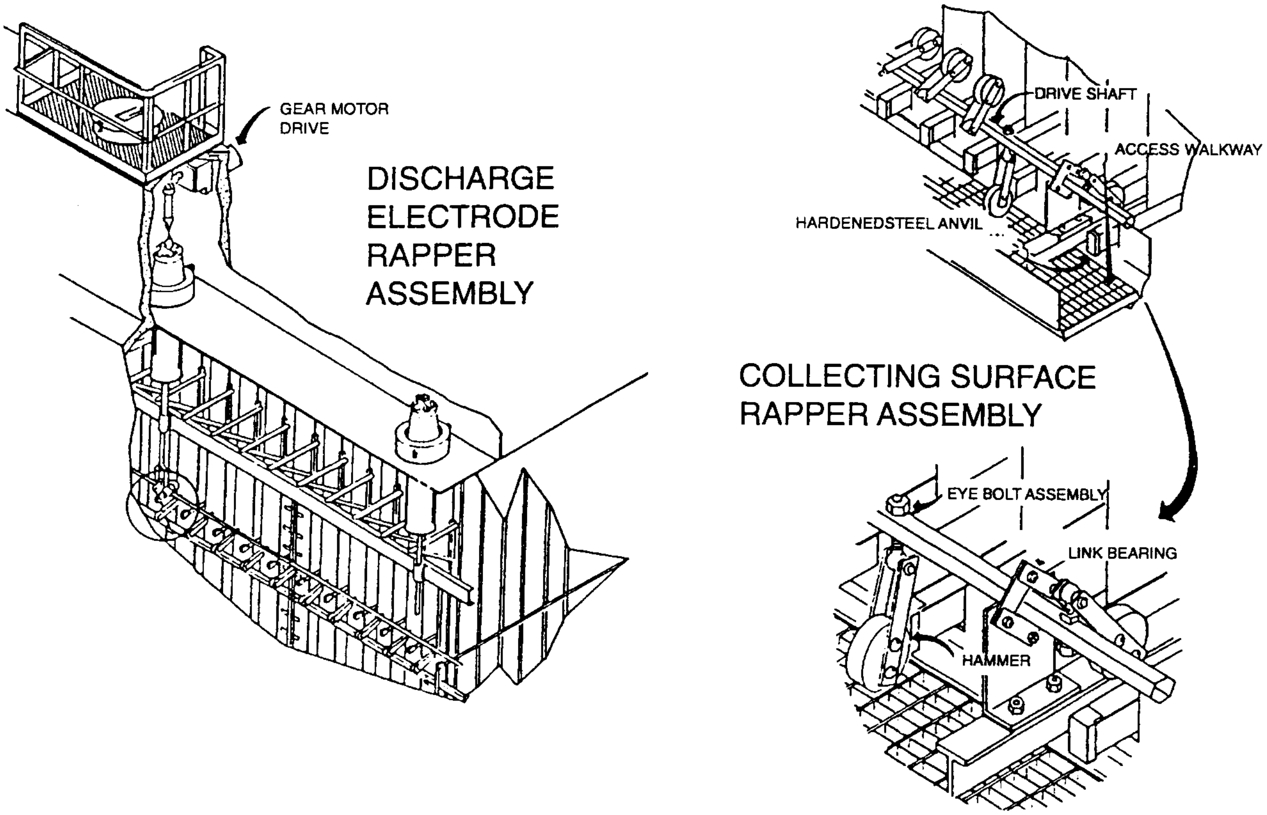


Figure 17: Tumbling hammer assembly for use with rigid frame discharge and collecting surface rapping systems

Acceleration forces in discrete places on the collecting surface plates should be measured and mathematical relationships between hammer weights, lift angles, and plate dimensions should be established and confirmed in laboratory and field testing. Uniform acceleration on the discharge wire frame is also important for efficient dust removal without the wire being destroyed by its own vibrations.

3.6 Dust Removal Equipment

In large systems such as those in utility applications, solids can be removed from ESP's by a pressure or vacuum system. A screw conveyor can be used for this purpose in many smaller industrial applications. Dust can also be wet sluiced directly from the hoppers. Once conveyed from the hoppers, the dust can be disposed of dry, or it can be recycled into the system.

3.6.A. Removal from the Hopper

An air seal is required at each hopper discharge. Air locks provide a positive seal, but tipping or air-operated slide-gate check valves are also used for this purpose. The use of heaters, vibrators, and/or diffusers is often considered because of the occasional bridging that occurs in the hoppers. In trough-type hoppers, a paddle-type conveyor provides the best means of transporting the dust to the air lock. Dust valves are often oversized to help facilitate removal of dust from the hopper.

3.7 Gas Distribution Equipment

Proper gas flow distribution is critical for optimum precipitator performance. Areas of high velocity can cause erosion and reentrainment of dust from collecting surfaces or can allow gas to move through the ESP virtually untreated. Improper distribution of gas flow in ducts leading to the ESP causes dust to accumulate on surfaces and results in high pressure losses.

Devices such as turning vanes, diffusers, baffles, and perforated plates are used to maintain and improve the distribution of the gas flow. A diffuser consists of a woven screen or a thin plate with a regular pattern of small openings. A diffuser breaks large-scale turbulence into many small-scale turbulent zones, which, in turn, decay rapidly and within a short distance coalesce into a relatively low-intensity turbulent flow field. The use of two or three diffusers in series provides better flow than only one diffusion plate could achieve. Cleaning of the gas distribution devices may entail rapping.

The design of inlet and outlet nozzles of ESP plenums and their distribution devices must be uniform. Poor design of inlet plenums can result in pluggage such as that shown in Figure 18. Figure 19 shows examples of poorly designed inlet plenums. Figure 20 shows two methods of improving gas distribution at the inlet plenum.

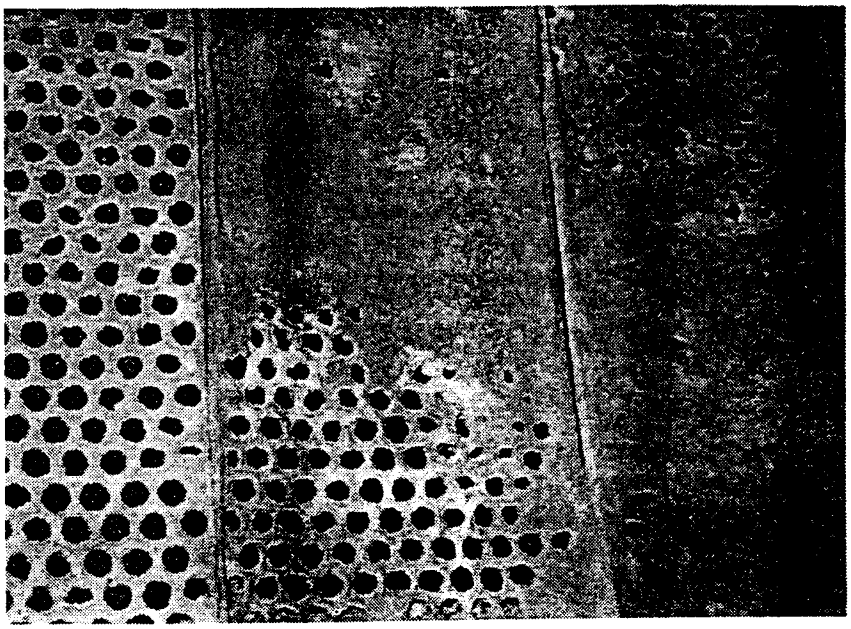


Figure 18: Pluggage of Perforated Plates at Inlet to ESP

Figure 19: Two inlet plenum designs that generally cause gas distribution problems

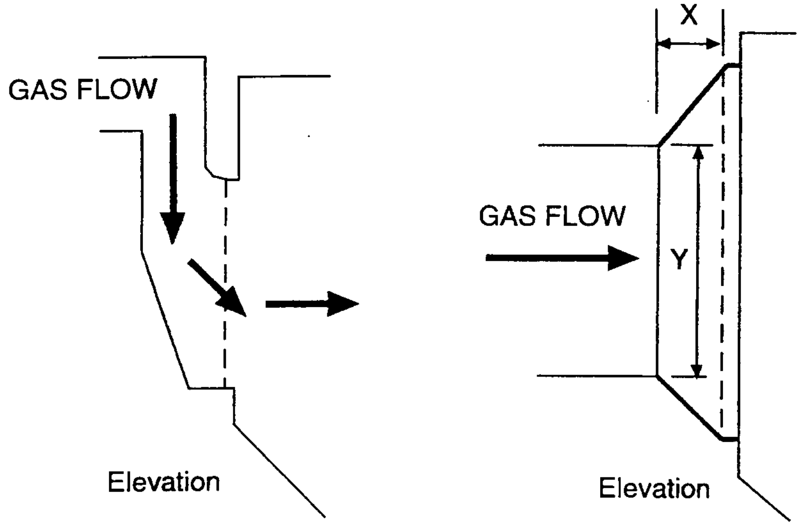
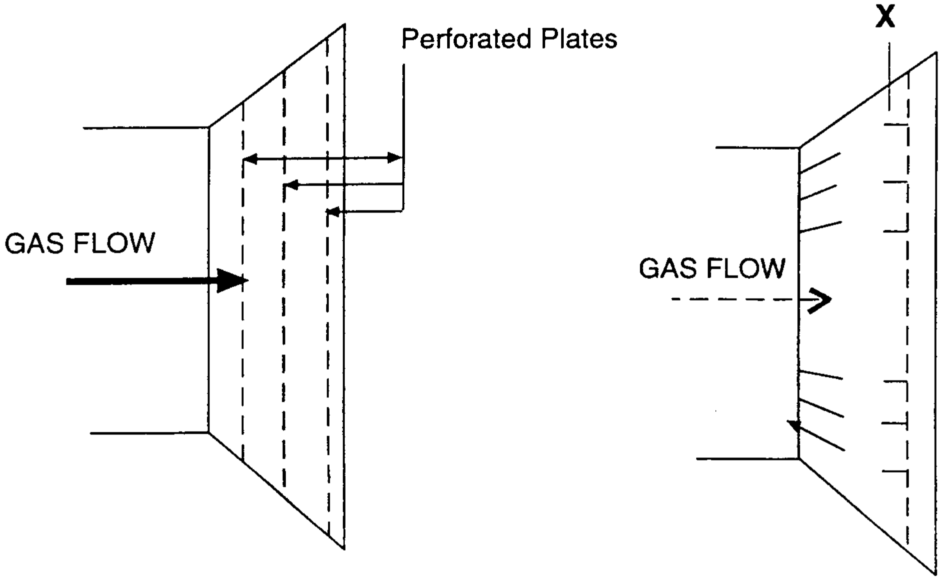


Figure 20: Two methods of spreading the gas pattern at expansion inlet plenums



In multiple-chamber ESPs, louver-type dampers should be used for gas proportioning instead of guillotine shutoff dampers, because guillotine-type dampers tend to destroy proper gas distribution to a chamber.

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

3.7.A. Gas Flow Models

Gas flow models are used to determine the location and configuration of gas flow control devices. Although flow mode studies are not always able to develop the desired distribution, they can at least provide a qualitative indicator of the distribution.
Temperature and dust loading distributions are also important to efficient ESP operations. Although the temperature of the flue gas is generally assumed to be uniform, this is not always true. The effects of gas temperature on ESP electrical characteristics should be a design consideration, as well as modeling of dust distribution.

If dust loading distributions are not modeled, the dust is assumed to be distributed evenly in the gas; as long as the gas distribution is of a predefined quality, no dust deposition problems should occur. Nevertheless, problems such as poor duct design, poor flow patterns at the inlet nozzle of the ESP plenum, and flow and wall obstructions can cause unexpected dust deposition.

3.7.B. Field Measurements

Early field velocity distribution tests lacked sufficient accuracy due to use of inadequate instrumentation and test procedures. The validity of field test data improved with technical improvements, most significantly in the area of velocity measuring instruments.

Appropriate velocity measuring instrumentation coupled with the development of procedures for on-site anemometer calibrations eliminated most of the experimental error found in earlier field velocity distribution tests.

Some guidance for the proper conduct of field velocity distribution testing may be found in IGCI Publication No. EP-7, Revision 4. The following procedures, which are routinely practiced by the majority of the precipitator suppliers, are suggested:

- It is important for model verification that field testing be performed at the exact measurement locations that correspond to flow model testing. This is especially critical for velocity surveys at the inlet and outlet of a precipitation chamber.
- When a severe flow maldistribution is discovered at the inlet or outlet of a precipitator chamber, additional velocity surveys should be performed to determine the extent of maldistributed flow penetration into the center of the precipitator chamber. This is needed to evaluate the effects of flow maldistribution on precipitator performance.
- Pitot tube traverses should be conducted in the ductwork, specifically at the inlet to a precipitator. This data can be used to verify ductwork velocity distributions measured during the model study.

Verification of an acceptable degree of hopper flow activity should be made by setting off smoke bombs in the outlet row of precipitator hoppers and observing the resulting smoke traces. This also serves as full-scale verification of smoke testing conducted during the model study. The interpretation of an acceptable degree of hopper flow activity should be by mutual agreement of the utility and supplier.

4. ELECTRICAL DESIGN

4.1 Power Supplies

The power supply to an ESP consists of four basic components: a step-up transformer, a high voltage rectifier, a control element, and a control system sensor. The system is designed to provide voltage at the highest level possible without causing arc-over (sustained sparking) between the discharge electrode and the collection surface.

The T-R set converts low-voltage alternating current to high-voltage unidirectional current suitable for energizing the ESP. The T-R sets and radio-frequency (RF) choke coils are submerged in a tank filled with a dielectric fluid. The RF chokes are designed to prevent high-frequency transient voltage spikes caused by the ESP from damaging the silicon diode rectifiers. The automatic control system is designed to maintain optimum voltage and current in response to changes in the characteristics and concentrations of the dust. Figure 21 shows the components of a typical automatic voltage control system.

Figure 21a: ESP Power Supply Scheme

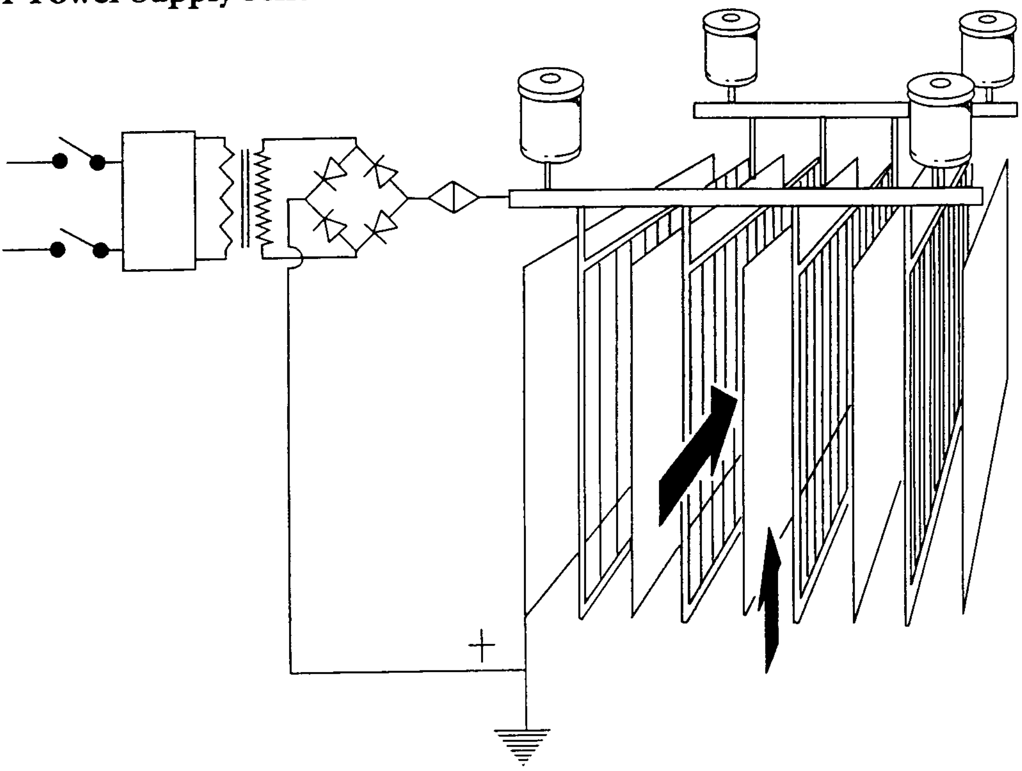
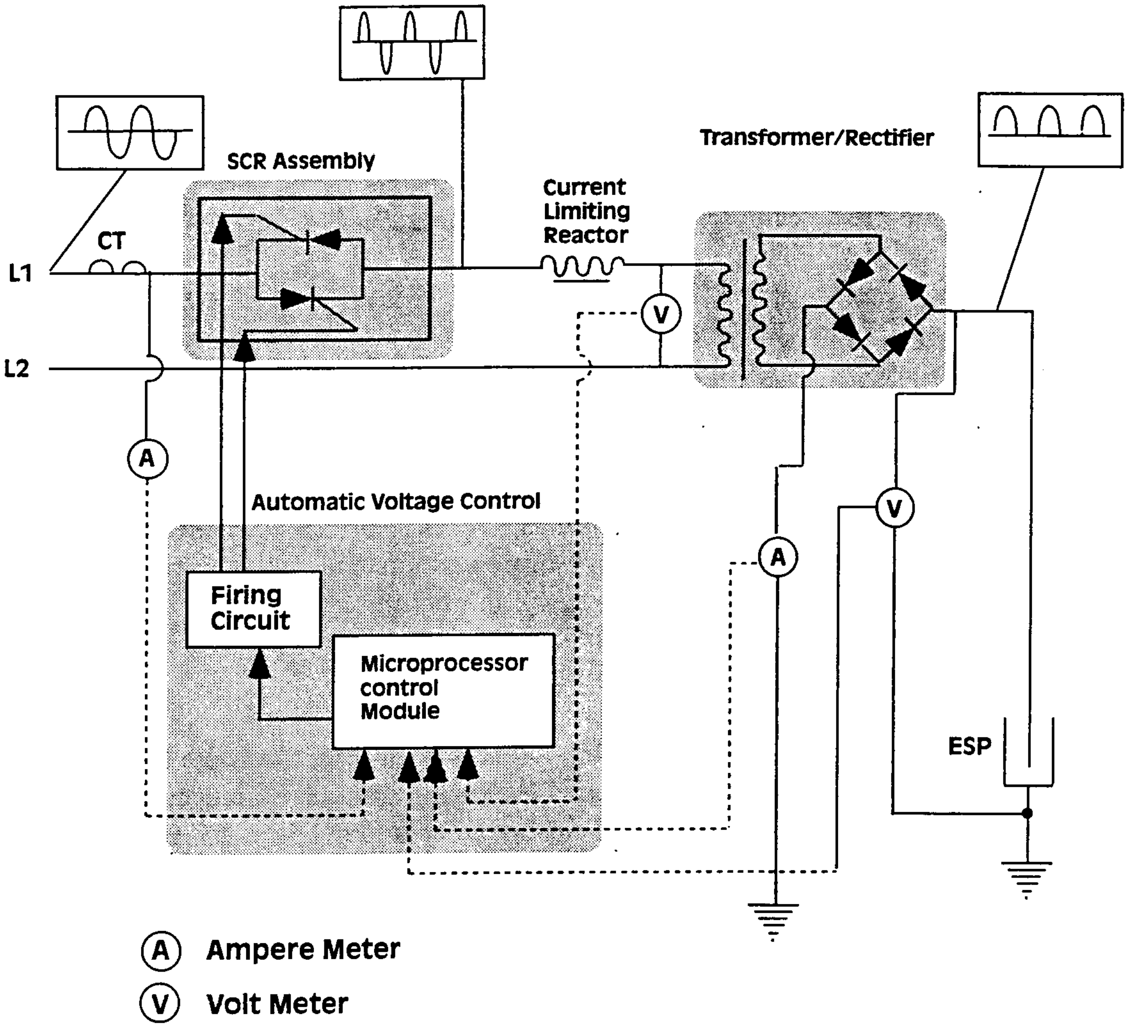


Figure 21: Automatic Voltage Control Schematic



4.1.A. Transformer-Rectifiers

The T-R sets should be matched to ESP load. The ESP will perform best when all T-R sets operate at 70 to 100 percent of the rated load without excessive sparking or transient disturbances, which reduce the maximum continuous-load voltage and corona power inputs. Over a wide range of gas temperatures and pressures in different applications, practical operating voltages range from 15 to 80 kV at average corona current densities of 10 to 70 mA/1000 ft of collecting area.

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

- 70 kVp, 45 kV avg. 250 to 1500 mA D.C., 16 to 100 kV, 9-to 10-in. ducts
- 78 kVp, 50 kV avg. 250 to 1500 mA D.C., 18 to 111 kVa, 11- to 12-in. ducts
- 80 kVp, 55 kV avg. 250 to 1500 mA D.C., 12-in. ducts (from some vendors)

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

High temperature gases (700° to 800°) require T-R sets with lower voltage because the density of the gas is lower. High-pressure gases in corona quench situations [high space charge in the interelectrode space; e.g., acid-mist or very wide (15- to 25- in.) ducts] require extra high voltage (lower current ratings than in conventional use); conversely, low gas density and/or low dust concentrations require higher currents at lower voltages. In general, current ratings should increase from inlet to outlet fields (3 to 5 times for many fly ash ESP's).

Generally, name-brand T-R sets rarely fail. Problems are generally related to quality control: defective components; moisture in oil due to improper coil baking or vacuum fill techniques; metal bits, rust, or scale in tanks; incompatibility of solid insulation materials with certain cooling liquids; overfilling with oil and insufficient expansion space; poor mechanical bracing or mounting of transformer coils and other components; internal sparking due to inadequate spacing and electrical field concentration points; and mishandling in shipment or installation.

Hand hold-cover plates should be provided for access to rectifiers, radio frequency (RF) diodes, and voltage dividers. Also desirable (and expensive) are large crane trolley systems for quick replacement of T-R sets. Another alternative is to include some additional redundancy of plate area in the design to compensate for T-R set outages.

Silicon-controlled rectifiers should be carefully mounted in suitable heat sink assemblies and tightened with a torque wrench to manufacturer's specifications. All sensitive leads from the T-R sets to the automatic voltage-control cabinet should be shielded in coaxial cable.

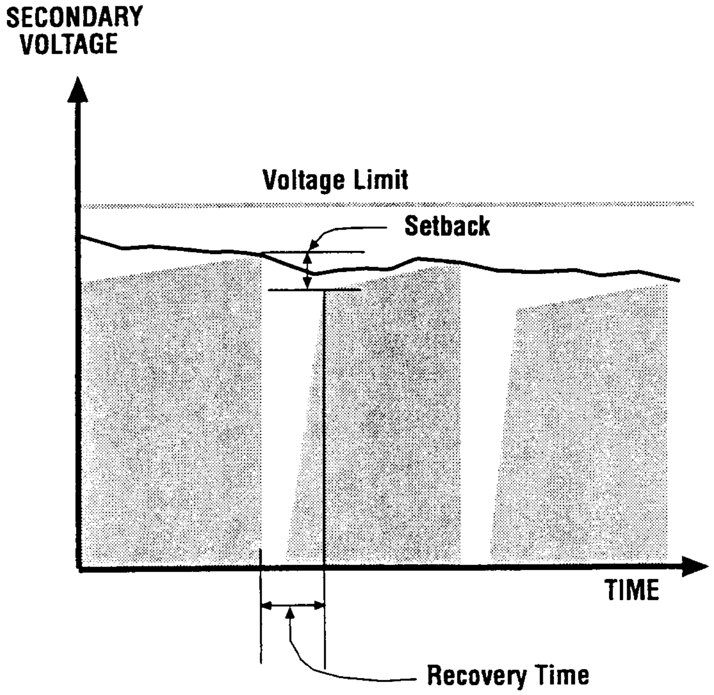
4.1.B. Automatic Voltage Controls

The Automatic Voltage Control (AVC) varies the power to the transformer-rectifier (T-R) set in response to signals received from the precipitator and from the transformer-rectifier itself. It monitors electrical conditions inside the precipitator, protects the electrodes, the T-R set and itself. Its goal is to achieve maximum collecting efficiency by keeping precipitator voltage as high as possible.

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

This spark signals the AVC to reset its command lower. The Automatic Voltage Control again commands an increasing output from this new starting point, and the cycle is repeated (See Figure 22).

Figure 22: Automatic Voltage Control Operation



4.1.C. Instrumentation

Instrumentation necessary for proper monitoring of ESP operation can be categorized by location; i.e., T-R sets, rappers/vibrators, hoppers/dust removal systems, and external items.

4.1.C.a. Transformer-Rectifiers

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

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

These meters are considered essential for performance evaluation and troubleshooting.

Data loggers (mainly for digital automatic control systems) are available to help speed up troubleshooting and reduce operating labor. Oscilloscopes are also useful in evaluating power supply performance and identifying the type of sparking (multiple-burst versus single-arc).

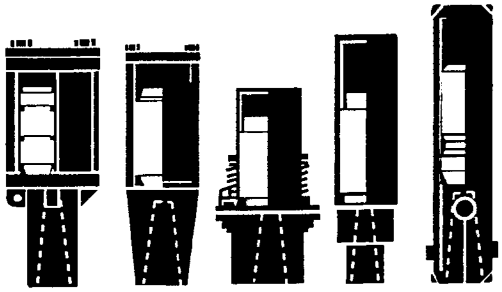
It is also possible to use feedback signals from transmissometers, full hopper detectors, gas conditioning systems, rappers, and suitable process fault indicators in conjunction with the automatic control unit to achieve optimum performance under all conditions. An example of this is automatic phase-back of T-R sets when hoppers are overfilled, which prevents discharge wires from burning.

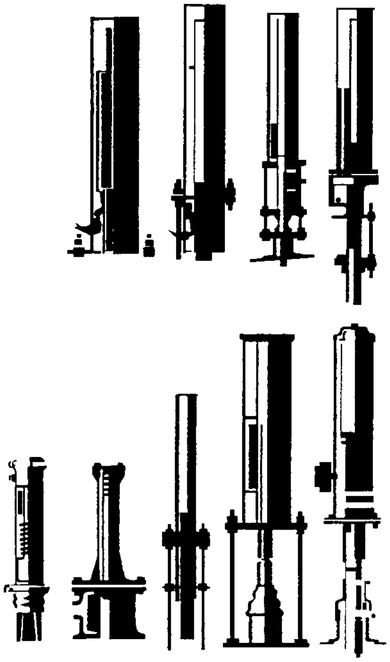
4.1.C.b. Rappers/Vibrators

Microprocessor-type technology is available for a high degree of rapper control flexibility and ease of maintenance. For example, new controls can test each circuit before energizing it and thus prevent control damage from ground faults. If a ground fault does occur, the control will automatically bypass the grounded circuit and indicate the problem on a Light Emitting Diode (LED) display. This permits early location of the problem and expedites its solution.

Instrumentation should be used in conjunction with a transmissometer for troubleshooting ESP problems. Separate rapping instrumentation should be provided for each field. In the case of wire-weight electrodes readings of frequency, intensity, and cycle time can be used with T-R set controls for proper setting of rapper frequency and intensity. In the case of rigid-frame, mechanical rappers, cycle time and rap frequency of both internal and external rappers are easy to measure. Individual operation of internal rappers is not easily instrumented, nor is intensity control possible without a shutdown of the ESP.

Typical Pneumatic Rappers





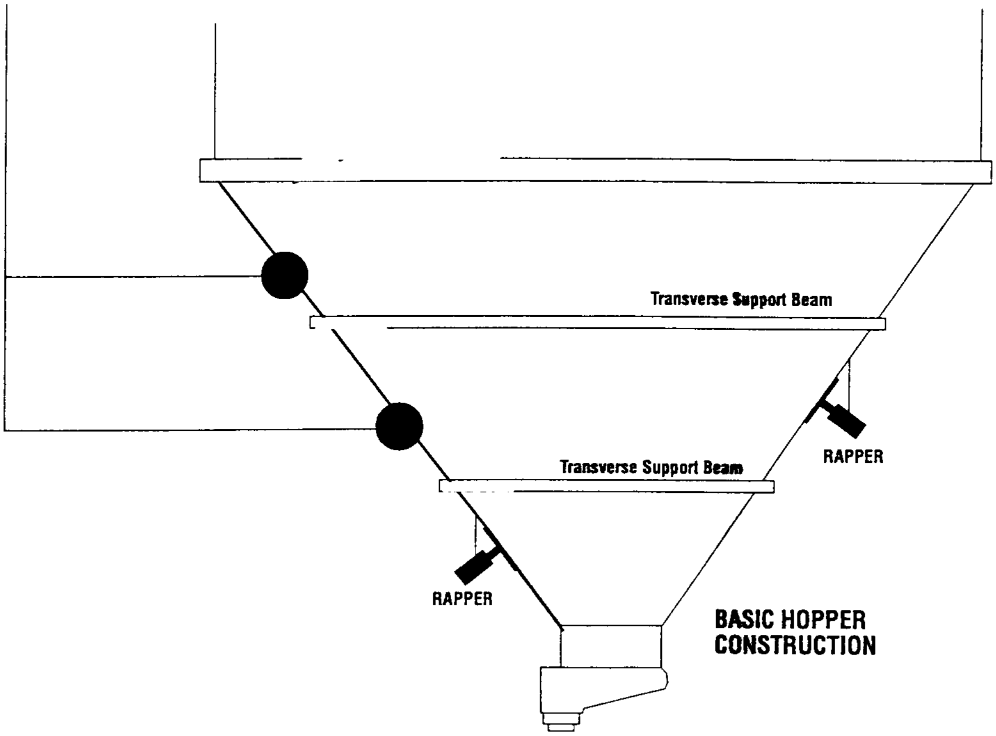
Typical Electric Rappers

4.1.C.c. Hoppers

Instrumentation should be provided for detecting full hoppers, for the operation of the dust valve, and for the dust-removal system. Level detectors can utilize gamma radiation, capacitance, pressure differential, or temperature. Alarms should be located such that hoppers never become completely filled, but frequent alarms should be avoided. A low-temperature probe and alarm can be used in conjunction with the level detector. Control panel lights indicate the operation of hopper heaters and vibrators.

Zero-motion switches are used on rotary air lock valves and on screw conveyors to detect malfunctions. Pressure switches and alarms are normally used to detect operating problems in pneumatic dust handling systems.

Hopper level detectors can utilize gamma radiation, capacitance, pressure differential or temperature



BASIC HOPPER CONSTRUCTION

5. Safety Considerations

It is highly recommended that plant personnel follow established safety procedures regarding the handling of electrical and mechanical equipment. Further, due to the high voltages experienced in the field of Electrostatic Precipitators, additional safeguards should be implemented.

The following is the suggested sequence of procedures to follow for preventative safety of maintenance and inspection personnel:

- An "Electrical Safety Access and Exit Log Book" must be used at all times by personnel wishing to gain access, inspect or work on any equipment owned by the plant. Signatures and the required access permit must be readily available through the responsible person's designated for this duty.

- Prior to the issue of any such clearance document the Electrical/Mechanical engineer will check the log book and ensure that the designated area is safe. On completion of the task, the permit must be cleared prior to restarting.

Warning Signs must be placed on all isolators/switches locked out for the purpose of the work to be done.

The Safety Key Interlock System must be implemented when entering the precipitator. This system ensures that a correct sequential procedure is followed for switching-off and earthing the precipitator. The Key System cannot be by-passed.

Should a key be lost the only means of obtaining a replacement is by application, with the inclusion of a signed document, stating the facts surrounding the loss of the key to the supplier.

After unlocking the access doors a further precautionary step to ensure safety must be undertaken. Local grounding straps are connected to the outside of each door. The door is then opened and by means of a "hot-stick" the other end of the cable is clamped to the nearest high voltage component inside of the precipitator.

- Prior to entering the precipitator a check must be done to ensure that the interior is free of gas.

- It is good practice to ensure that there are always two people present when entering the precipitator. For safety at least two people should inspect.

Safe, convenient access (walkways, hatches, etc.) must be provided for entry and servicing of ESP's and ancillary equipment during shutdown. Sometimes the design of the ESP should be such that individual chambers can be prepared for safe entry while the balance of the chambers are on line. Items to which access is needed are discharge wire mountings, hoppers, penthouses, rappers, instrumentation, etc. For rigid- frame ESP's, adequate clearance should be provided between collecting surfaces and interior walkways for the replacement of rigid electrodes through side doors. Access to collection plates and inlet baffles is necessary to allow cleaning during shutdown. Such accessibility requires the proper location of hatches, walkways, ladders, and handrails. Hopper access doors should be wide enough for ladders to be placed in the hoppers, and maintenance personnel should be able to reach the bottom of the discharge electrode frame by ladder from the hopper access platform. All potential electrical shock hazards must be addressed by the use of grounding devices and electrical system lockout procedures. Measures also must be taken to purge enclosures of hot toxic gases before entrance of maintenance personnel.

6. OPERATION

Electrostatic precipitator installation is different in its application and also in its design. Therefore, it is necessary to tailor operating procedures to a specific installation. General guidelines for startup and shutdown can be used as skeletons for more complete instructions. The following procedures imply that the precipitator has already been in operation at least once.

6.1 Pre-Startup

It is necessary to inspect the precipitator for materials, tools, etc., left inside. Inspection doors are locked after double-checking that nobody is left inside. Key interlock procedures are followed, and all keys are returned to their operation location. All rapping and heating systems are tested. The precipitator is energized manually under air to record “airload” voltage/current data. These can be taken for the total range or at the arc-over limit only. Heating and ventilating systems are activated.

6.2 Startup

The precipitator is energized as soon as gas flow has been started and the temperature of the precipitator's internal parts exceeds the dew point temperature of the gas. High voltage should not be turned on, if there is a chance that a combustible gas mixture is present in the precipitator. Once all fields of the precipitator are energized, the precipitator is put on automatic (cyclic) control for high voltage, rapping, heating and dust handling systems (Table III).

TABLE III: PRECIPITATOR START-UP Checklist

1. Check line voltage for proper phase and magnitude.
2. Inspect transformer-rectifier tanks for signs of oil leaks or physical damage. Check oil tank gauge. Refill if necessary (follow manufacturer's instructions).
3. Check hopper discharge valves and dust handling equipment.
4. Inspect exhaust fan.
5. Follow key-interlock procedures for opening precipitator access doors. Inspect interior of precipitator. Remove any foreign materials (tools, rags, cleaning materials, etc.) from inside the unit.
6. Disconnect high-voltage conductor at support insulator and check resistance between discharge system and ground. Reading should be 100 megohms or greater.
7. Inspect all rapper drives for proper position (follow manufacturer's instructions)
8. Check rotation and alignment of all gear motors and drives that have been serviced.
9. Inspect access doors for operation and alignment. Lock them. Return door keys to their proper location in key-interlock transfer blocks.
10. Check condition of all explosion-relief devices (if applicable).
11. Inspect precipitator control cabinets for evidence of loose connections.
12. Complete procedure outlined in the key-interlock instructions to return all keys to operating position.
13. Preheat support insulators at least 2 hours before energizing the precipitator. Start insulator vent system (if applicable).
14. Activate dust-discharge and dust-handling systems.
15. Start collecting surface and discharge-electrode rapping systems. Operation should be continuous during start-up.
16. Activate gas distribution plate rapping system (if applicable).
17. Turn on high-voltage current as soon as gas flow has been started to the precipitator (by activating exhaust fan, dampers, or slide gates) and the temperature of the precipitator's internal parts exceeds dewpoint of the gas. (High voltage, however, should not be activated if there is a possibility of combustible gases being present in the precipitator)
18. Set precipitator operating control on "automatic".
19. Turn off insulator heaters or set on "automatic"
20. Turn off continuous rapping and set on "automatic".

6.3 Shutdown

All auxiliary heating systems should be put on continuous operation and all rapping systems on "manual" (continuous operation) to prevent corrosion and clean the precipitator as thoroughly as possible. This should continue for several hours after shutdown. The precipitator should be de-energized as soon as the gas flow stops. If the downtime schedule allows for an internal inspection, the doors should be opened following the key interlock procedures. Care should be taken that all high voltage systems are securely grounded before the precipitator is entered. For longer shutdowns, the precipitator should be isolated from the flue system (Table IV).

TABLE IV: PRECIPITATOR SHORT-TERM SHUT-DOWN CHECKLIST

1. Turn on insulator heating system and de-energize high-voltage system.
2. Keep rapping systems for collecting-surface plates, discharge wires, and gas-distribution plates activated unless precipitator is to be entered. (If entry is planned, follow key-interlock system procedures to open precipitator access doors.
3. Keep dust discharge system operating continuously.
4. Operate exhaust fan at reduced flow rate.

TABLE IV: PRECIPITATOR SHUT-DOWN CHECKLIST

1. Activate insulator heating system. Leave on for at least 6 to 8 hours after precipitator is de-energized (do not turn on heating system if maintenance or inspection work is to be done in insulator compartments)
2. Keep rapping systems for collecting surface plates, discharge wires, and gas-distribution plates on for several hours to help clean precipitator as thoroughly as possible.
3. Turn off exhaust fan.
4. Follow key-interlock system procedures to open precipitator access doors.
5. Ground all high-voltage components securely. Warning signs should be used on all switches (follow manufacturer's instructions).
6. Clean precipitator manually.
7. Discharge all dust from hopper if downtime is to be extensive.
8. Seal flues to other precipitators, stack, or any crossover flues to prevent gases from other sources from entering precipitator (such gases can condense and cause extensive corrosion).

7. Performance Monitoring & Evaluation

Performance monitoring is a key factor in establishing good operation and maintenance procedures for an ESP. It includes measurement of key operating parameters by both continuous and intermittent methods, comparison of these parameters with baseline and/or design values, and the establishment of record keeping practices. These monitoring data are useful in performance evaluation and problem diagnosis. In this section, the key operating data and procedures used in performance monitoring are discussed.

7.1 Key Operating Parameters and their Measurement

Several operating parameters are indicative of a likely change in performance. Some of these parameters are easily measured and monitored on a continuous basis, whereas others must be measured only periodically because of the expense and/or difficulty in measurement. Most of these parameters, however, directly affect ESP performance. The following typical parameters are discussed here: gas volume and gas velocity through the ESP; temperature, moisture, and chemical composition of the gas; particle size distribution and concentration; resistivity of the particulate; and power input. Many of these factors are interrelated.

7.1.A. Gas Volume and Velocity

According to predictive equations and models, a decrease in gas volume results in an increase in collection efficiency and vice versa. Although the improvement or deterioration in performance is not nearly as great as the Deutsch-Anderson equation predicts, the equation is qualitatively correct. A decrease in gas volume results in an increase of the SCA (ft of plate area/1000 acfm), a decrease in gas velocity through the ESP, an increase in the treatment time (during which the particulate is subjected to the electric field charging and collecting mechanisms), and hence, improved performance. A decrease in velocity may also reduce rapping reentrainment and enhance the collection of the fine particles in the 0.1 to 1.0 um range, which are exceptionally difficult for most ESP's to collect.

Gas flow distribution is a very important aspect of gas flow through the ESP . Ideally, the gas flow distribution should be uniform throughout the ESP (top to bottom, side to side). Actually, however, gas flow through the ESP is not evenly distributed, and ESP manufacturers settle for what they consider an acceptable variation. (Standards recommend by the Industrial Gas Cleaning Institute have been set for gas flow distribution. Based on a velocity sampling routine, 85 percent of the points should be within 15 percent of the average velocity and 99 percent should be within 1.4 times the average velocity.) Generally, uneven gas flow through the ESP results in lost performance because the reduction in collection efficiency in areas of high gas flow is not compensated for by the improved performance in areas of lower flow. Gas distribution can also affect gas sneakage through the ESP. The use of gas distribution devices such as perforated plates and turning vanes and good ductwork design help to provide good gas distribution.

7.1.B. Gas Temperature

Monitoring the temperature of the gas stream can provide useful information about the performance of an ESP and can provide useful clues for diagnosing both ESP performance and process operating conditions. The major concern in temperature measurement is to avoid sampling at a stratified point where the measured temperature is not representative of the bulk gas flow. Thermocouples with digital, analog, or strip chart display are typical.

The effect of temperature is mot important as it relates to the resistivity of the particulate and as an indictor of excessive inleakage into the gas stream. In moderately sized ESP's, changes in dust resistivity can produce large changes in performance (as evidenced by power input to the ESP and opacity readings). In some cases, when the resistivity versus temperature curve is steep, a change of only 10° to 15° F may substantially change ESP performance because it causes a shift in resistivity. This is particularly true where high resistivity is a problem. Lowering the temperature slightly to increase condensation or adsorption of surface conductivity-enhancing materials is usually one available option, if neither corrosion nor sticky particles pose a problem.

Temperature can also affect gas properties to such an extent that they will change the relative levels of voltage and current and the density and viscosity of the gas stream, which affect particle migration parameters. These effects, however, may go unnoticed on many precipitators, as resistivity effects may overshadow them.

Lastly, comparison of inlet and outlet temperatures may be useful in the diagnosis of excessive inleakage into the ESP. Even the best constructed and insulated ESP will experience some temperature drop, which can range from 1° to 2°F on smaller ESP's or up to 25°F on very large ESP's. In any case, some acceptable difference or maximum differential should be set, and when exceeded, this should be an indicator of improper operation or a maintenance problem that must be corrected.

7.1.C. Chemical Composition and Moisture

The chemical composition of both the particulate entering the ESP and the flue gas can affect ESP performance, although in somewhat different ways. In many process applications, either the gas composition or key indicators of gas composition are usually available on a continuous or real-time basis. Chemical composition of the particulate matter, however, is oft not available except on an intermittent, grab-sample basis.

The operation of an ESP depends on electronegative gases (such as oxygen, water vapor, carbon dioxide, and sulfur dioxide/trioxide) to generate an effective corona and to transport the electrons from the discharge electrode to the collection plate. The presence of one or more of these gases is necessary to enhance the ESP performance, and the relative level in the gas stream is not always important to ESP operation. Levels of C02 or 02, however, are often monitored on combustion sources as a measure of excess air and combustion efficiency and not as an indicator of the potential ESP operation. In most processes, these electronegative gases are available and are not direct concern to operators.

The presence of water vapor and/or acid gases may prove useful as resistivity modifiers or conditioners, and they may be necessary for proper ESP performance. On the other hand, they may cause a sticky particulate that is difficult to remove.

The chemical composition of the particulate matter also influences ESP performance. Specifically, it greatly influences the range of resistivity with which the ESP will have to operate. The presence of certain compounds such as alkalies, calcium, or other components can be used to predict resistivity problems. In addition, chemical composition can change with particle size, which may change ESP performance at the inlet, mid, and outlet sections and further complicate prediction of ESP performance on a day-to-day basis.

From a practical standpoint, the chemical composition of the dust and gas stream is a dynamic quantity, and any monitoring scheme may only point out an optimum range and the variability. Monitoring the level of certain compounds may prove useful in some instances; for example, in the combustion of coal, sulfur content, combustibles content, and chemical composition of the ash may provide supporting evidence when problems occur. In many instances, however, chemical composition is either not monitored or it is monitored for other purposes.

7.1.D. Particle Concentration and Size Distribution

Electrostatic precipitators can be designed for a wide range of mass loadings to provide satisfactory performance when combined with other operating and design parameters. They have been designed to collect loadings from several tenths of a grain per actual cubic feet of gas to values exceeding 100 gr/acf. Within limitations, changes in the mass loading do not seriously affect an ESP's performance, although some changes in outlet concentration can occur. Other factors (e.g., design values of SCA, superficial velocity, and electrical sectionalization and such physical properties as resistivity and particle size distribution) are usually more important to ESP performance when mass loading changes occur.

In the particle size ranges where field charging dominates (above 1 um) and diffusion charging dominates (below 0.1 um), the ESP usually performs reasonably well. It is in this region between 0.1 and 1.0 um, however, that most ESP's have difficulty collecting particulate because neither charging mechanism dominates. The minimum ESP collection efficiency is usually on particles between 0.4 and 0.8 um in diameter. Thus, if a change in loading is also accompanied by a change in particle size distribution, the magnitude of these combined changes must be evaluated to predict ESP performance.

7.1.E. Particulate Resistivity

The particulate resistivity is important to the control of the electrical characteristics of the ESP. Whereas resistivity has little to do with how much charge a particle will accept (that is related to particle size), it is a controlling factor in how much voltage and current are applied in each field of the ESP. The voltage and current levels determine the migration rate of charged particles and the charging rate of the plate. When resistivity is outside of a very narrow range, ESP performance deteriorates. The optimum resistivity range is typically 10 to 10 ohm-cm. The resistivity of a given dust is usually controlled by its chemical composition, the composition of the gas stream (particularly the presence of conditioning agents such as water vapor, S03 HCl, etc.), and the gas stream temperature. Resistivity is generally not a function of particle size although some slight effects may be apparent between large and small particles due to compaction on the plate. The resistivity of large and small particles can be substantially different, however, if their compositions are significantly different as a result of process operating characteristics. The resistivity of a dust is not a static quantity; it varies with process conditions and feed characteristics. Designers of an ESP can only hope that the resistivity will stay within a relatively narrow range over the life of the unit.

7.1.F. Power Input

The power input to the ESP can be a useful parameter in monitoring ESP performance. The value of power input for each field and for the total ESP indicates how much work is being done to collect the particulate. In most situations, the use of power input as a monitoring parameter can help in the evaluation of ESP performance, but some caution must be exercised.

The T-R's of most modern ESP's are equipped with primary voltage and current meters on the low-voltage (a.c.) side of the transformer and secondary voltage and current meters on the high-voltage rectified (d.c.) side of the transformer. The terms primary and secondary refer to the side of the transformer that is being monitored; the input side is the primary side of the transformer. Older models may have only primary meters and, perhaps, secondary current meters. When both voltage and current meters are available on the T- R control cabinet, the power input can be estimated. Each T-R meter reading must be recorded.

The power inputs calculated for each T-R set and for the ESP do not represent the true power entering the T-R or the effective power entering the ESP; however, they are sufficiently accurate for the purpose of monitoring and evaluating ESP performance. These values indicate just how well each of the sections is working when compared with the actual voltage and current characteristics. The ratio of secondary power (obtained from the product of the secondary meter readings) to the primary power input will usually range from 0.5 to 0.9; the overall average for most ESP's is between 0.70 and 0.75. In general, as the operating current approaches the rated current of the T-R it appears to be more efficient in its utilization of power. This is due to a number of factors, including SCR conduction time, resistance of the dust layer, and capacitance of the ESP. The actual voltage and current readings that are used to calculate power will be controlled by the gas composition, dust composition, gas temperature, and physical arrangement within the ESP. Thus, as one moves from inlet fields towards outlet fields, the apparent secondary power/primary power ratio increases in most ESP's because the ESPs tend to operate to their rated current output. When ESP's only have primary voltage and current meters, the power input may be estimated by obtaining the multiplication product.

7.2 Performance Evaluation

Most of the performance changes that occur in ESP's are reflected in the electrical characteristics that are monitored and controlled by the T-R set control cabinets. These changes may be caused by a failure of some internal ESP component or by a change in process operation. Because some changes are very subtle (e.g., a change in gas temperature or excess air level, a change in primary/secondary air ratios in a recovery boiler, or a shift in the feed material characteristics), monitoring and recording the pertinent operating parameters are important aspects of a performance evaluation.

Two considerations are necessary in any performance audit or evaluation of an operating ESP. The first concerns the design factors that are built into the ESP. These include such parameters as the specific collection area (SCA), number of fields, number of T- R's, electrical sectionalization, T-R set capacity, design superficial velocity and treatment time, aspect ratio, and particulate characteristics. This background information permits the auditor or evaluator to determine what the ESP was designed to do and whether operating parameters have changed significantly from design. The second consideration concerns the use of baseline data to establish normal or good operating conditions. These baseline data could consist of values recorded during an emissions test or could be a compilation of operating records to establish normal operating conditions.

No single parameter should be used to evaluate performance; a combination of factors is more likely be reliable. Although some parameters are more important and have greater effect than others, it is usually the combination of these parameters that determines performance of the ESP.

Depending on the situation, at least one person should be responsible for overseeing the operation of the ESP's, for reducing the data to a usable form, performing the evaluations, identifying potential problems, and helping to schedule maintenance. Other personnel may gather data, but one person should understand the significance of the gathered data.

How often and how much data should be gathered is a site-specific decision that will depend on equipment size, design factors, and personnel availability. The purpose of these data is to provide sufficient information for an effective evaluation of performance. Extraneous data of limited value should not be collected unless a specific problem is expected or encountered. When a program of record keeping is just being established, however, it is better to err on the side of having more data than needed at the beginning.

Unnecessary duplication of record keeping should be avoided. This is particularly true of process information involving final quality data that may already be retained by plant personnel. These process records should be available to the personnel responsible for monitoring ESP performance if more detailed data are needed beyond that recorded for the ESP performance evaluation.

The primary indicators of performance are the electrical operating conditions monitored at the T-R control cabinet. These conditions are reflected in the primary voltage, primary current, secondary voltage, and secondary current. Even if all these are not monitored (on older ESP's secondary voltage often is not monitored, and on some newer ones primary voltage and current are not monitored), the values provided should be recorded.

The level of effort required for this task depends on the size of the ESP and on the number of parameters monitored. For relatively small ESP's equipped with two to five T-R sets, very little time is required to record the data. The time required for the larger and more sectionalized ESP's, however, can be substantial.

The T-R data may be recorded in tabular form with the appropriate data for each T-R set. (Figure 23)

Figure 23: PRECIPITATOR OPERATING DATA (Recording Form)

Customer: ______________________ Time: ______________________
Date: ______________________ FieldRep.: ______________________

Chamber/ Field	DC Volts KV	DC Current A or mA	Current Density			Notes:
			µA/ft^2	mA/m^2	nA/cm^2	

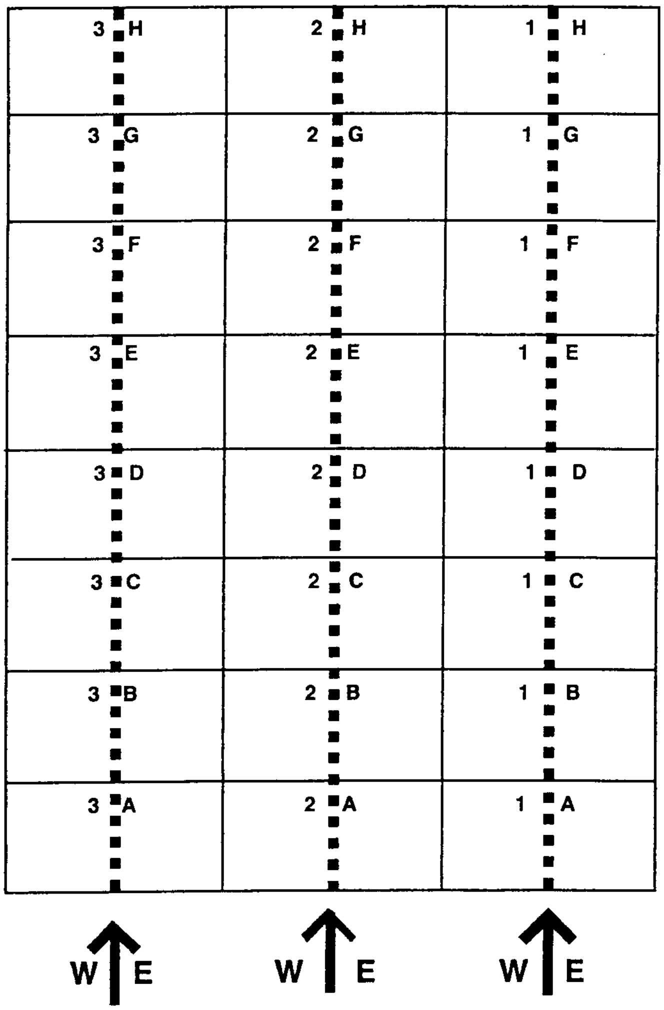
Unit Load - MW
Opacity - %
Inlet Temp.° F
Outlet Temp. °F
O_2 - CO_2% Wet/Dry
Fuel Rate - lbs/hr
Weather
Barometric - Hg
Moisture - %
Gas Flow - acfm
Stream Flow - bs/hr

Sketch of Site:

Again, for ESP's with a small number of T-R sets, this form makes it relatively easy to assemble the data and to track inlet, center, and outlet field performance. Plant personnel will be looking for certain patterns that are indicators of ESP performance levels. For larger ESP'S the tabular form speeds up data gathering, but it does not immediately provide a visual pattern of ESP performance.

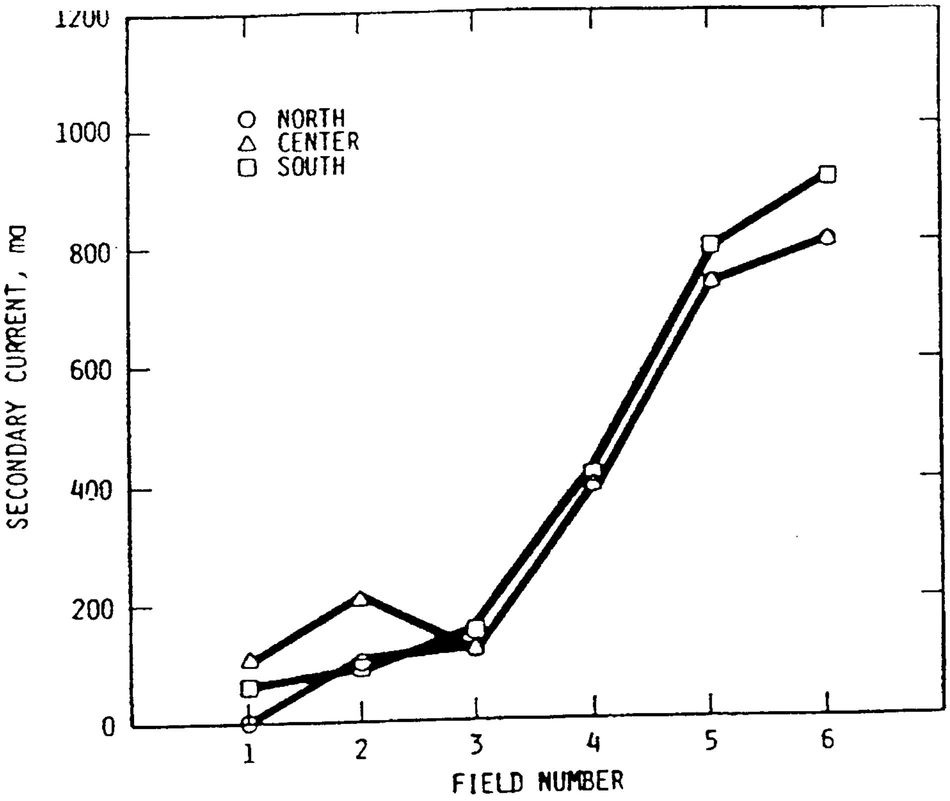
When the tabular form is less than satisfactory, a more graphical approach can be taken. Several graphical approaches are available for obtaining these data in a more useful form. The simplest of these is to draw the ESP plot plan with the relative position of the plate area of each T-R blocked out and to place the electrical data for each T-R in the appropriate box (see Figure 24) This is useful for evaluating the performance of large ESP's and those having fields of different dimensions. When the data gathering is completed, a look at the values for each field will quickly indicate if the desired pattern is there. This graphical representation will also show how many fields are out of service and how severe the problem may be.

Figure 24: Typical Plot Plan Layout for Recording ESP Operating Data



Another graphical method is to plot the electrical data on a graph for each field from inlet to outlet (one for each chamber or grouping of T-R's, if necessary). This also allows a visual evaluation of the data for characteristic patterns (see Figure 25). Usually, all electrical parameters do not have to be plotted, as secondary current and voltage are good first indicators.

Figure 25: Graphical Plot of Precipitator Currents



Another graphical method that can be used to evaluate long-term changes in ESP performance involves plotting the values of interest on a time chart (time on x-axis, voltage/ current on y-axis). Two examples of this technique are shown in Figure 26 & 27. This chart allows maintenance personnel to note any changes that are occurring and the rate of change.

Other data that should be collected from the T-R cabinets include spark rate, evaluation of abnormal or severe sparking conditions, controller status (auto or manual), and identification of bus sections out of service. This additional information helps in the evaluation of ESP performance.

Figure 26: Graphical Display of Precipitator Voltage and Current

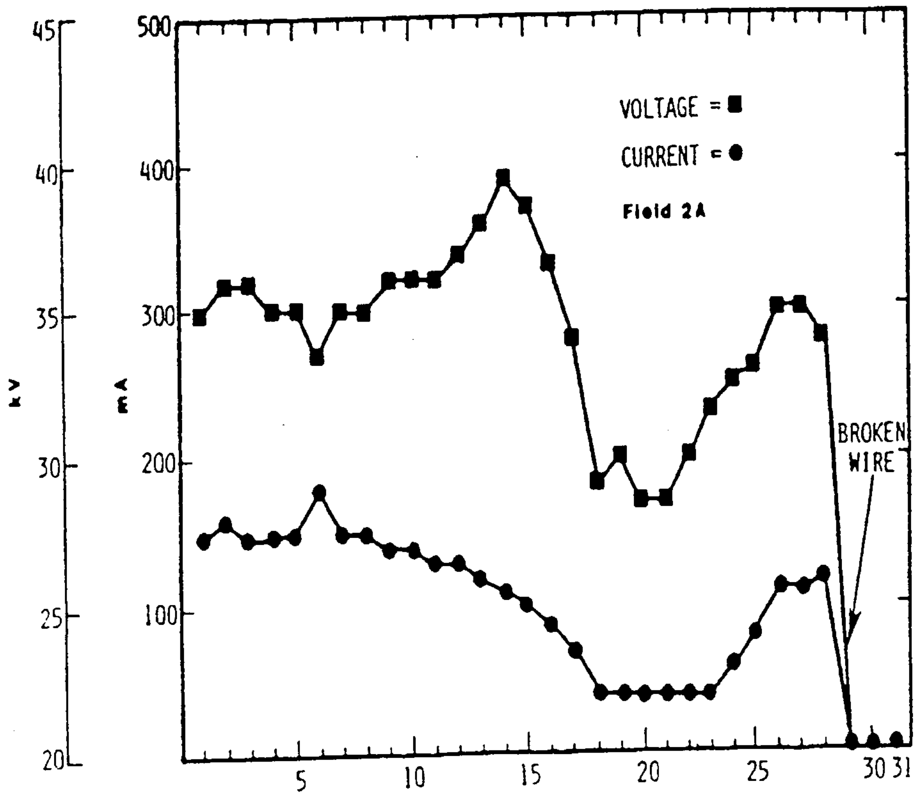
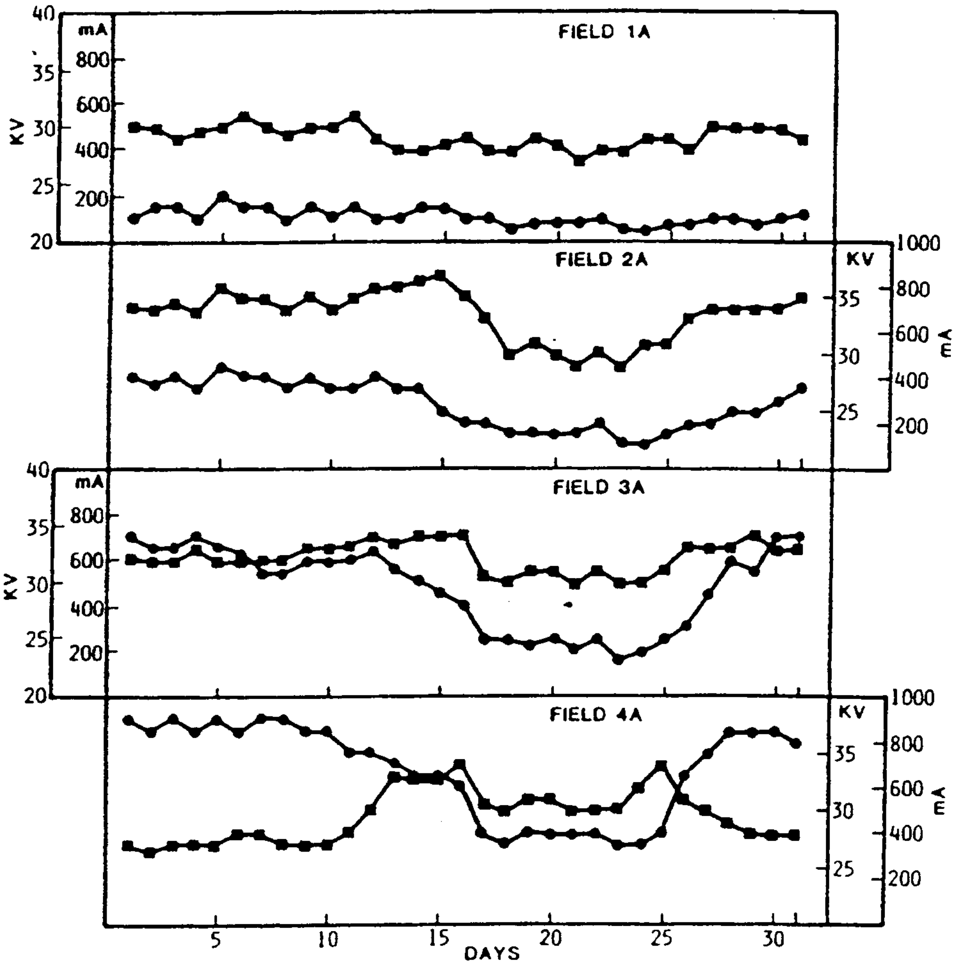
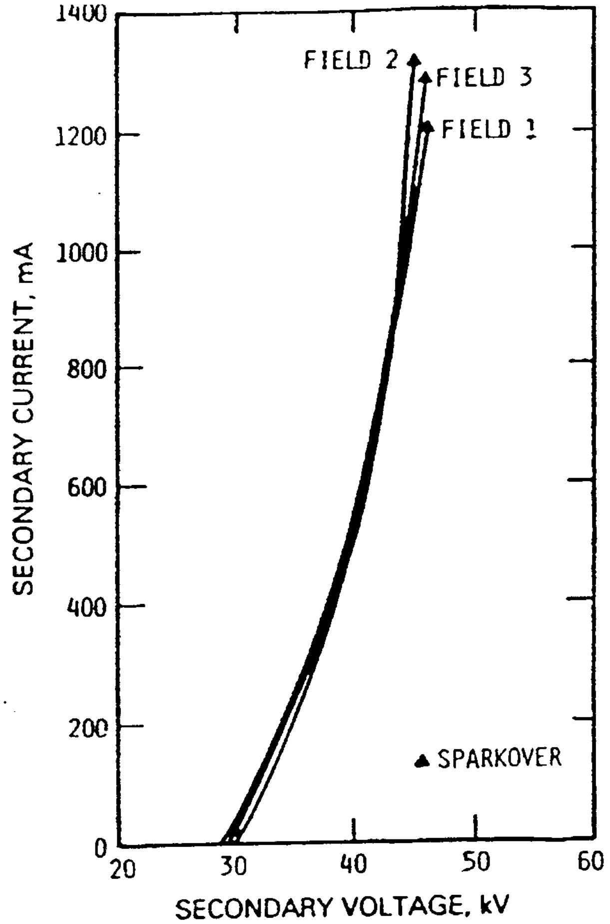


Figure 27: Graphical Display of Precipitator Voltage and Current Over Time



In addition to the routine panel meter readings, other electrical tests of interest to personnel responsible for evaluating and maintaining ESP's include the air load and gas load V-I (voltage-current) tests, which may be conducted on virtually all ESP's. Air load tests are generally conducted on cool, inoperative ESP's through which no gas is flowing. This test should be conducted when the ESP is new, after the first shutdown, and every time off-line maintenance is performed on the ESP. These airload V-I curves serve as the basis for comparison in the evaluation of ESP maintenance and performance. A typical air load curve is shown in Figure 28 .

Figure 28: Typical Air Load Test V-I Curve



The user of the air-load curves enables plant personnel to identify which field(s) may be experiencing difficulty. Comparison with an air-load test run just before a unit is serviced will confirm whether the maintenance work corrected the problem(s). A check should be made to be sure all tools, soda cans, rags, raincoats, and magazines are removed from the ESP prior to its startup.

The gas load V-I curve, on the other hand, is generated during the normal operation of the process while the ESP is energized. The procedure for generating the V-I curve is the same except that gas-load V-I curves are always generated from the outlet fields first and move toward the inlet. This prevents the upstream flow that is being checked from disturbing the V-I curve of the downstream field readings. Although such disturbances would be short-lived (usually 2 minutes, but sometimes up to 20 minutes), working from outlet to inlet also speeds up the process.

The curves generated under gas load will be similar to air-load curves. They will generally be shifted to the left under gas load conditions, however, and the shape of the curve will be different for each field depending on the presence of particulate in the gas stream (See Figures 29 and 30).

Figure 29: Variation of V-I Curves with Collecting Plate Contamination

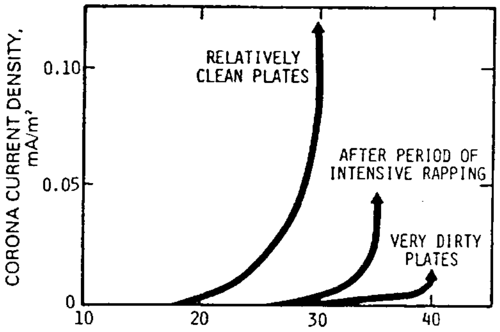
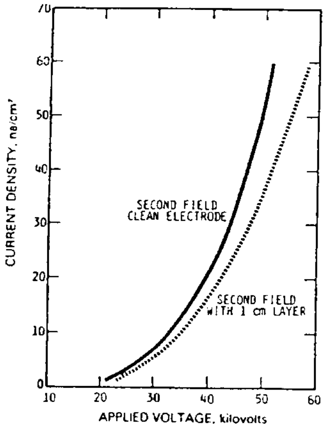


Figure 30: Effect of Dust Layer Thickness on V-I Curve



The pattern in the V-I curves under gas load conditions is similar to what is shown in Figures 31 & 32. As shown, the gas-load curve is to the left of the air-load curve. Both curves shift to the left from inlet to outlet (characteristic of most ESP's operating under moderate resistivity). The end point of each curve is the sparking voltage/current level, or maximum attainable by the T-R. These points represent the characteristic rise in current from inlet to outlet that is normally seen on the ESP panel meters. Problems characterized by the air load curves will normally also be reflected in the gas-load curve, but some problems may show up in one set of curves and not in the other (e.g., high resistivity, some misalignment problems).

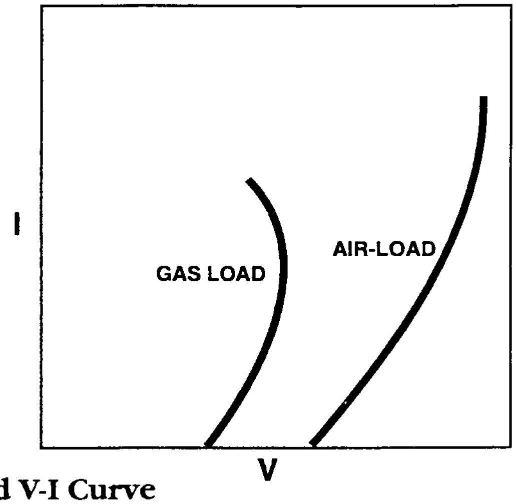


Figure 31: Comparison of Air Load and Gas Load V-I Curve

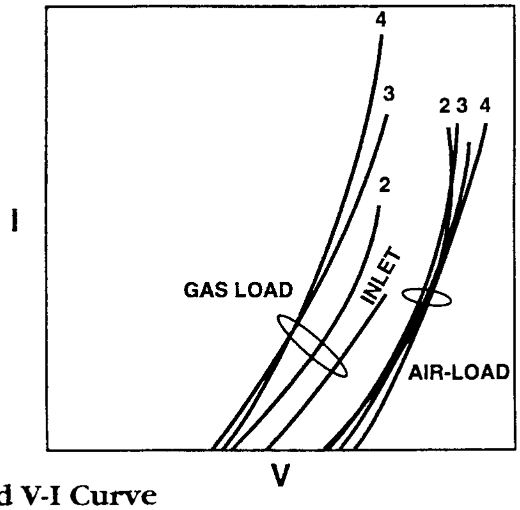


Figure 32: Comparison of Air Load and Gas Load V-I Curve

Other possible data that could aid in the evaluation of trends and long-term performance include a plot of wire failures within the ESP and their frequency, frequency of hopper pluggage, and a plot of the percent of the ESP deenergized on a daily basis. This last item can be used in combination with opacity and electrical data to define when maintenance work is needed and whether it is addressing the problems encountered, and to aid in the scheduling of routine and preventive maintenance.

It is evident that obtaining good operating data and maintaining good records help in the maintenance of ESP performance by providing a historical data base that can be used to evaluate daily operating performance. Record keeping alone, however, will not guarantee satisfactory long-term performance. Analysis of the data and an understanding of the fundamental design features and limitations and the operating characteristics of the ESP are necessary to correct minor problems before they become major.

7.3 Problem Diagnosis

Many ESP operating problems are reflected in the electrical operating characteristics. In a typical, well-designed, operated, and maintained ESP (without resistivity problems), a pattern of increasing current and decreased sparking from the inlet to the outlet fields would be expected. The operating voltage may be somewhat low because of sparking at the inlet and increase in the second and third fields. The voltage may begin to drop as the gas approaches the outlet because the gas is relatively clean. Although this is not a problem in every ESP, the tendency in most ESP' s is for the current to increase from inlet to outlet. It is important to be familiar with the operating characteristics of the ESP and to know what is typical. The record-keeping discussed earlier helps one to become more knowledgeable.

One of the difficulties in assessing ESP performance is that many different problems produce the same electrical characteristics on the panel meters. For this reason, plant personnel obtain additional data to reduce the number of possible causes to one or two. In addition, synergism often causes the original problem or failure to lead to additional problems that can cascade into even more problems. When this occurs, it is difficult to identify the original cause of a problem. Nevertheless, it is usually important to identify and correct all casual factors rather than to treat the symptom. Again, the key to diagnostic troubleshooting is to know the precipitator's characteristics; to understand what the meter reading mean; and to use all the process, opacity, and electrical data to assist in the evaluation. An internal inspection may even be necessary to confirm or eliminate possible sources of problems.

Most major performance problems can be categorized into the following areas: resistivity, hopper pluggage, air inleakage, dust buildup, wire breakage, rapper failure, inadequate power supplies and/or plate area, changes in particle size, and misalignment of ESP components. Some of these problems are related to design limitations, operational changes, maintenance procedures, or a combination thereof.

7.3.A. Problems Related to Resistivity

The resistivity of the dust on the collection plate affects the acceptable current density through the dust layer, the ability to remove the dust from the plates, and indirectly, the corona charging process. Much attention has been given to high resistivity conditions in utility flyash applications. Because the optimum resistivity range for ESP operation is relatively narrow, however, both high and low resistivity cause problems. When a unit is designed with modest plate area, sectionalization, and power input capabilities, poor ESP performance can result from excursions outside the optimum resistivity grange.

7.3.A.a. High Resistivity

The most common resistivity problem is that caused by high dust resistivity. Because of their inability to release or transfer electrical charge, the particles acquire charge from the corona charging process and migrate to the collection plate. Once at the collection plate, the particles neither give up very much of their acquired charge nor easily pass the corona current to the grounded collection plates. As the dust layer buildup continues, the resistance to current flow increases, and the controller responds by "opening up" the SCR more to increase the voltage level. This is demonstrated in the V-I curve presented in Figure 33. Although this would occur with most all particulates, the detrimental effect on ESP performance is more pronounced when particle resistivity is high.

The voltage drop across the dust layer may be substantial. The dust layer voltage drop (which depends on the resistivity and thickness of the dust layer) can be approximated by Ohm's law. As the current increases, the voltage drop also increases. Under high resistivity conditions, however, very high voltage drops may occur at low current density; when the voltage drop exceeds 15 to 20 kV/cm, the dust layer will break down electrically. As the resistivity climbs, the current level at which this breakdown occurs decreases. It is this breakdown of the dust layer that diminishes the ESP performance.

As the resistivity climbs well into the 1013 ohm-cm range, the sparking may be sharply reduced or become nonexistent because the dust layer voltage exceeds the breakdown threshold at such low current density that insufficient voltage is applied to the wire to propagate a spark across the inter-electrode space. Also, the breakdown of the dust layer may be widespread across the plate. This condition, known as "back- corona," is characterized by a discharge of positive ions from the plates that may reduce the charging of particles and even reduce the voltage below the level of negative corona initiation.

High resistivity also tends to promote rapping problems as the electrical properties of the dust tend to make it very tenacious. High voltage drop through the dust layer and the retention of electrical charge by the particles make the dust difficult to remove because of its strong attraction to the plate. In addition to the reduced migration and collection rate associated with high resistivity dust, greater rapping forces usual required to dislodge the dust may also aggravate or cause a rapping reentrainment problem. Important items to remember are 1) difficulty in removing the high resistivity dust is related to the electrical characteristics, not to the sticky or cohesive nature of the dust; and 2) the ESP must be able to withstand sustaining damage to insulators or plate support systems. Figure 34 shows an example V-I curve for an ESP field with insulator tracking (i.e.., current leakage) problems.

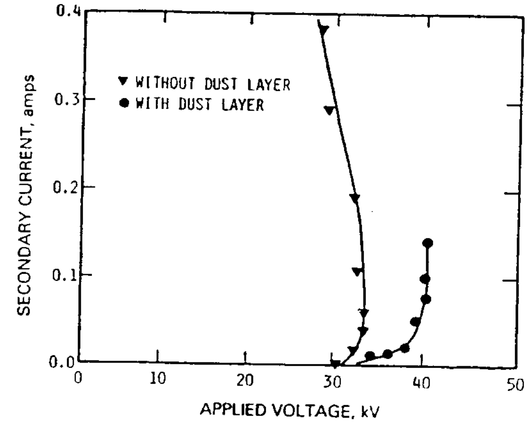


Figure 33: V-I Characteristics of Inlet Section, ESP Containing High Resistivity Ash

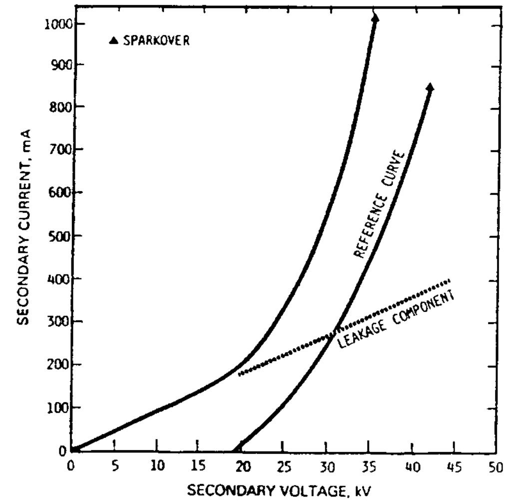


Figure 34: Air Load Curve for ESP Field with Insulator Tracking

7.3.A.b. Low Resistivity

Low dust resistivity can be just as detrimental to the performance of an ESP as high resistivity. Low resistivity refers to the inability of particles to retain a charge once they have been collected on the plate. As in the normal-and high resistivity cases, the ability of the particulate matter to obtain a charge is not affected by its resistivity; particle charging occurs by the previously discussed charging mechanisms, which are dependent on particle size. Once the particles are at the collection plate, however, they release much of their acquired charge they are capable of passing the corona current quite easily. Thus attractive and repulsive electrical forces that are normally at work at higher resistivities are lacking, and the binding forces ("holding power") to the plate are considerably lessened. Particle reentrainment is a substantial problem at low resistivity, and ESP performance appears to be very sensitive to contributors of reentrainment, such a poor rapping or poor gas distribution.

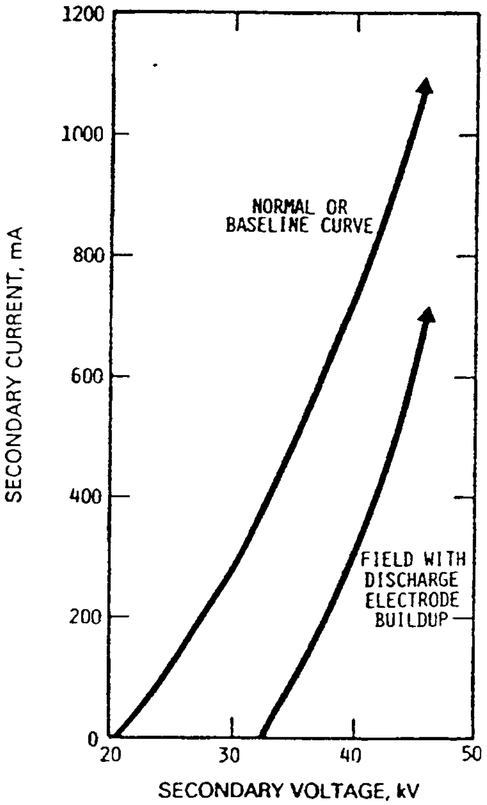
The voltage drop across the dust layer on the plate is usually small. The lower resistance to current flow than in the optimum-and high-resistivity ranges means lower operating voltages are required to obtain substantial current flow. Thus, operating voltages and currents are typically close to clean plate conditions, even when there is some dust accumulation on the plate. A typical low-resistivity condition, then, is characterized by low operating voltages and high current flow, which would be reflected in the T-R panel meter readings. These electrical conditions may look very similar to those of high resistivity with well developed back-corona. In any case, the result is usually the same-reduced ESP performance.

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

7.3.B. Excessive Dust Accumulations on Electrodes

Where no ash resistivity problem exists, the cause for excessive dust accumulation in an ESP is often external. When buildup material on the discharge electrodes and collecting electrodes or plates is difficult to distinguish in an operating ESP, differences in the V-I curves can often point up the nature of the problem (see Figure 35).

Figure 35: V-I Curve for a Field with Excessive Discharge Wire Buildup



Buildup of material on the discharge electrodes (whether straight-wired, barbed-wired, or rigid) often means an increase in voltage to maintain a given operating current. The effect of dust buildup on the discharge electrodes is usually equivalent to changing the effective wire size diameter, and since the corona starting voltage is strongly a function of wire diameter, the corona starting voltage tends to increase and the whole V-I curve tends to shift to the right. Sparking tends to occur at about the same voltage unless resistivity is high. This effect on corona starting voltage is usually more pronounced when straight wires are uniformly coated with a heavy dust, and less pronounced on barbed wires and rigid electrodes or when the dust layer is not uniform.

Under normal operating conditions, most of the dust would be collected at the plate and relatively little would collect on the wires. The dust that collects on the wires is usually the dust that enters the corona discharge area with the proper trajectory to attach to the wire. The material collected on the plate is usually allowed to buildup for some specified length of time to take advantage of certain cohesive forces between particles and then dislodged by activation of a rapper. This dust buildup usually changes the electrical characteristics of the field and causes a shift in voltage and current over the period of the buildup.

The usual cause for buildup on the collection plates or discharge wires is failure of the rapping system or an inadequate rapping system. The rapping system must provide sufficient force to dislodge the dust without damaging the ESP or causing excessive reentrainment. The failure of one or two isolated rappers does not usually degrade ESP performance significantly. The failure of an entire rapper control system or all the rappers in one field, however, can cause a noticeable decrease in ESP performance, particularly with high- resistivity dust.

Excessive dust buildup also may result from sticky dusts or dew point conditions. In some cases, the dusts may be removed by increasing the temperature, but in many cases, the ESP must be entered and washed out.

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

7.3.C. Wire Breakage

Some ESP's operate for 10 to 15 years without experiencing a single wire breakage, whereas others experience severe problems causing one or more sections to be out of service nearly every day of operation. Much time and effort have been expended to determine the causes of wire breakage. One of the advantages of a rigid-frame or rigid-electrode ESP is that this type uses shorter wires or no wires at all. Although most of the new ESP's are of the rigid-frame and rigid- electrode type (and some weighted-wire systems have also been retrofitted to rigid electrode), the most common ESP in service today is still the weighted-wire; therefore, the nature, severity, and locations of wire failures cannot be overlooked.

Wires usually fail in one of three areas: at the top of the wire, at the bottom of the wire, and wherever misalignment or slack wires reduce the clearance between the wire and plate. Wire failure may be due to electrical erosion, mechanical erosion, corrosion, or some combination of these. When wire failures occur, they usually short-out the field where they are located, and in some cases, may short-out an adjacent field. Thus, the failure of one wire can cause the loss of collection efficiencies in an entire field or bus section. In some smaller ESP applications, this can represent one-third to one-half of the charging/collecting area and thus substantially limit ESP performance.

Wire failure should not be a severe maintenance problem or operating limitation in a well-designed ESP. Excessive wire failures are usually a symptom of a more fundamental problem. Plant personnel should maintain records of wire failure locations. Although ESP performance will generally not suffer with up to approximately 10 percent of the wires removed, these records should be maintained to help avoid a condition in which entire gas lanes may be deenergized. Improved sectionalization helps to minimize the effect of a broken wire on ESP performance, but performance usually begins to suffer when large percentages of the ESP are deenergized.

7.3.D. Hopper Pluggage

Perhaps no other problem (except fire or explosion has the potential for degrading ESP performance as much as hopper pluggage. Hopper pluggage can permanently damage an ESP and severely affect both short-term and long-term performance. Hopper pluggage is difficult to diagnose because its effect is not immediately apparent on the T-R panel meters. Depending on its location, a hopper can usually be filled in 4 to 24 hours. In many cases, the effect of pluggage does not show up on the electrical readings until the hopper is nearly full.

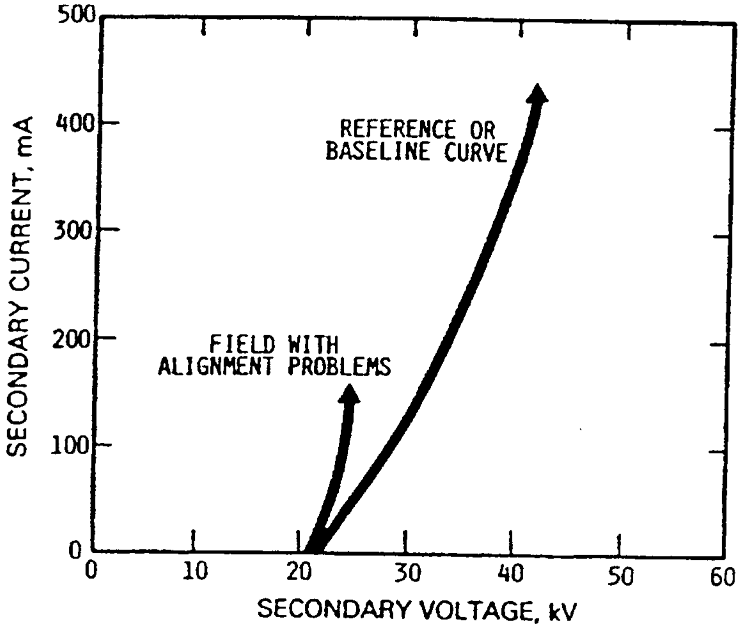
The electrical reaction to most plugged hoppers is the same as that for internal misalignment, a loose wire in the ESP, or excessive dust buildup on the plates. Typical symptoms include heavy or "bursty" sparking in the field(s) over the plugged hopper and reduced voltage and current in response to the reduced clearance and higher spark rate. In weighted-wire designs, the dust may raise the weight and cause slack wires and increased arcing within the ESP. This drain of power away from corona generation renders the field performance virtually useless. The flow of current also can cause the formation of a dust clinker resulting from the heating of the dust between the wire and plate.

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

7.3.E . Misalignment

As mentioned several times in the previous sections, misalignment is both a contributor to and a result of component failures. In general, most ESP ' s are not affected by a misalignment of less than about 3/16 in. Indeed, some tolerance must be provided for expansion and contraction of the components. Beyond this limit, however, misalignment can become a limiting factor in ESP performance and is usually visually evident during an internal inspection of the ESP. Whether caused by warped plates, misaligned or skewed discharge guide frames, insulator failure, or failure to maintain ESP "box-squareness," misalignment reduces the operating voltage and current required for sparking. The V-I curve would indicate a somewhat lower voltage to achieve a low current level with the sparking voltage and current greatly reduced (See Figure 36). Since the maximum operating voltage/current levels are dependent on the path of least resistance in a field, any point of close tolerance will control these levels.

Figure 36: Air Load V-I Curve Pattern Generated by Alignment Problems



7.3.F. Unusually Fine Particle Size

Unusually fine particles present a problem if 1) the ESP was not designed to handle them, or 2) a process change or modification shifts the particle size distribution into the range where ESP performance is poorest. A shift in particle size distribution tends to alter electrical characteristics and increase the number of particles emitted in the light-scattering size ranges (opacity).

As was discussed in Section 2, there are two basic charging mechanisms: field charging and diffusion charging. Although field charging tends to dominate in the ESP and acts on particles greater than 1 micrometer in diameter, it cannot charge and capture smaller particles. Diffusion charging, on the other hand, works well for particles smaller than 0.1 micrometer in diameter. On particles between 0.1 and 1.0 micrometer in diameter, and particularly in the range of 0.2 to 0.5 micrometer, performance of the ESP diminishes considerably. Because neither charging mechanism is very effective, particles in this range are more difficult to charge; and once charged, they are easily bumped around by the gas stream, which makes them difficult to collect. The collection efficiency of an ESP can drop from as high as 99.9+ percent on particles sized above 1.0 micrometer and below 0.1 micrometer, to only 85 to 90 percent on particles in the 0.2- to 0.5- micrometer diameter range, depending upon the type of source being controlled. If a significant quantity of particles fall into this range, the ESP design must be altered to accommodate the fine particles.

Inleakage is often overlooked as an operating problem. In some instances, it can be beneficial to ESP performance, but in most cases its effect is detrimental. Some of the causes of inleakage, which may occur at the process itself or at the ESP, are leaking access doors, leaking ductwork, and even open sample ports.

Inleakage usually cools the gas stream, and it can also introduce additional moisture. The result is often localized corrosion of the ESP shell, plates, and wires. The temperature differential also could cause electrical disturbances (sparking) in the field. Finally, the introduction of ambient air can affect the gas distribution near the point of entry. The primary entrance paths are through the access doors. Inleakage through hopper doors may reentrain and excessively cool the dust in the hopper, which can cause both reentrainment in the gas stream and hopper pluggage. Inleakage through the access door is normally accompanied by an audible inrush of air.

8.0 O&M Procedures

Operating practices can significantly affect daily and long-term ESP performance. These practices and procedures should be straightforward and cover most of the situations expected to be encountered, and personnel should be trained so that these practices become routine.

8.1 Preventive Maintenance

The goal of preventive maintenance is to maintain the long-term performance of the ESP and to reduce or minimize the failure of various components that affect ESP performance. An important aspect of preventative maintenance is routine inspection of the ESP, both internally and externally. These inspections include daily or shift inspections, weekly inspections, monthly or quarterly inspections, and outage inspections (the only time internal inspections can be performed). Depending on the unit's operating history and the manufacturer's recommendations, internal inspections can be performed quarterly, semiannually, or annually. As the time interval increases, the amount of action required usually increases. Daily and weekly inspections may require checks of operating parameters and general operating conditions, whereas monthly or quarterly inspections require specific actions regardless of performance of the ESP.

8.1.A. Daily Inspections and Maintenance

Most often the daily inspection or shift inspection will be conducted as part of a parameter monitoring and record keeping plan. The purpose of this routine and frequent inspection is to identify the existence of any operating problems before they develop into more serious and possibly more damaging failures. It is extremely important to have all ancillary equipment equipped with alarms, and plant personnel should respond to these alarms immediately. Some problems can and have led to long-term degradation of ESP performance because they failed to be diagnosed or no action was taken to correct them. Table V summarizes the data that the operator or ESP coordinator should record daily.

TABLE V: DAILY INSPECTION CHECKLIST

- Corona power levels (i.e., primary current, primary voltage, secondary current, secondary voltage) by field and chamber. (twice a shift)
- Process operating conditions [i.e., firing rates, steam (lb/h), flue gas temperature, flue gas oxygen, etc.]. The normal operator's log may serve this purpose. (hourly)
- Rapper conditions (i.e., rappers out rapper sequence, rapper intensity, rapping frequency by field and chamber. (once a day)
- Dust discharge system (conveyors, air locks, valves for proper operation, hopper levels, wet-bottom liquor levels.
- Opacity (i.e., absolute value of current 6-minute average and range or magnitude of rapper spiking) for each chamber duct if feasible. (2-hour intervals)
- Abnormal operating conditions (i.e., bus duct arcing, T-R set control problems, T-R set trips excessive sparking). (twice a shift)
- Audible air inleakage (i.e., location and severity). (once a day)

8.1.B. Weekly Inspections and Maintenance

The best way to start a weekly inspection is with a brief review of the daily or shift inspection data. This review should attempt to identify any apparent trends in the key operating parameters and to determine whether a change is needed in some operating practice or maintenance procedure. In addition, this review should confirm that all requested or required maintenance has been completed satisfactorily or has been scheduled in a timely manner. Lastly, a week is generally sufficient time for a change in operation (e.g., rapping intensity and timing, some process changes, gas-conditioning systems operation) to surface in ESP performance, even though longer periods may be necessary to establish the trend. Table VI summarizes the items that the operator or ESP coordinator should record weekly.

TABLE VI: WEEKLY INSPECTION CHECKLIST

- Trends analysis (plot gas load V-I curves for each field and chamber and other key parameters to check for changes in values as compared with baseline).
- Check and clean or replace T-R set cabinet air filters and insulator purge air and heating system filters.
- Audible air inleakage (i.e., location and severity).
- Abnormal-conditions (i.e., bus duct arcing, penthouse and shell heat systems, insulator heaters, T-R set oil levels, and temperature).
- Flue gas conditions exiting the ESP (i.e., temperature and oxygen content).
- More extensive rapper checks (also optimize rapper operation if needed).

8.1.C. Monthly to Quarterly Inspections and Maintenance

Whether a monthly or quarterly inspection is required depends on the manufacturer's recommendations and on selected site-specific criteria; however, all of the recommended procedures should be followed at least quarterly. Table VII summarizes the items that the operator or ESP coordinator should record quarterly.

TABLE VII: QUARTERLY INSPECTION CHECKLIST

- Internal inspection of shell for corrosion (i.e., doors, hatches, insulator housings, wet-bottom liquor level, dry bottom, roof area).
- Effectiveness of rapping (i.e., buildup of dust on discharge electrodes and plates).
- Gas distribution (i.e., buildup of dust on distribution plates and turning vanes).
- Dust accumulation (i.e., buildup of dust on shell and support members that could result in grounds or promote advanced corrosion).
- Major misalignment of plates (i.e., visual check of plate alignment).
- Rapper, vibrator, and T-R control cabinets (motors, lubrication, etc.).
- Rapper distribution switch contacts (i.e., wear arcing, etc.) that are now used infrequently.
- Vibrator cam contacts (i.e., wear, arcing, etc.) that are no longer used.
- Rapper assembly (i.e., loose bolts, ground wires, water in air lines, solenoids, etc.).
- Vibrator and rapper seals (i.e., air inleakage, wear, deterioration).
- T-R set controllers (i.e., low-voltage trip point, over-current trip point, spark rate, etc.).
- Vibrator air pressure settings.

8.1.D. Annual Inspection (Outage) and Maintenance

The process and its ESP generally should be shut down at least once a year for a more complete inspection, including a check of internal conditions. The design of some ESPs is such that they may be isolated or bypassed without a process shutdown. In other situations, however, outages may occur on a more frequent basis. In all cases, however, adherence to established safety and confined-area entry procedures cannot be overemphasized. Safety interlocks should never be bypassed to enter the ESP.

Before anyone enters an ESP, an airload check of each field is recommended. This serves as a record for comparison when the ESP maintenance is complete and all scheduled maintenance has been performed. When these airload tests have been completed, the inspection is ready to begin (Note: gas-load tests may be used just prior to shutdown). During the inspection more attention may be focused on certain selected areas where readings are abnormal or unusual.

Table VIII summarizes the items that the operator or ESP coordinator should check during the annual outage inspection.At the completion of the outage, all personnel, tools, and other materials used inside the ESP should be accounted for. A final safety check should be completed for each section of the ESP to determine that all personnel have exited before the ESP is closed up. An airload test of each field should then be performed. This final airload test will indicate whether the scheduled maintenance was in fact completed. The airload test will also detect any mistakes or forgotten items and will serve as a record or certification of readiness for operation. This airload test should also become part of the permanent records kept by the plant maintenance personnel.

TABLE VIII: ANNUAL INSPECTION CHECKLIST

- Transformer Enclosure
    - HV line, insulators, bushings, and terminals
    - Electrical connections
    - Broken surge arrestors

(continued Next Page)

TABLE VIII: ANNUAL INSPECTION CHECKLIST
(Continued from Previous Page)

- High-Voltage Bus Duct
  - Corrosion of duct
  - Wall and post insulators
  - Electrical connections
- Penthouse, Rappers, Vibrators
  - Upper rapper rod alignment
  - Rapper rod insulators
  - Ash accumulation
  - Insulator clamps
  - Lower rapper rod alignment
  - Support insulator heaters
  - Dust in penthouse area
  - Corrosion in penthouse area
  - Water inleakage
  - HV connections
  - HV support insulators
  - Rapper rod insulator alignment
- Collecting Surface Anvil Beam
  - Hanger rods
  - Ash buildup-
  - Weld between anvil beam and lower rapper rod
- Upper Discharge Electrode Frame Assembly
  - Welds between hanger pipe and hanger frame
  - Discharge frame support bolts
  - Support beam welds
  - Upper frame levelness and alignment to gas stream

(continued next page)

TABLE VIII: ANNUAL INSPECTION CHECKLIST

(Continued from Previous Page)

- Lower Discharge Electrode Frame Assembly

    Weight guide rings
    Levelness of frame
    Distortion of the frame

- Stabilization Insulators

    Dust buildup and electrical tracking
    Broken insulators

- Collecting Electrodes

    Dust deposits; location and amount.
    Plate alignment
    Plate plumbness
    Plate warpage

- Discharge Electrode Assembly

    Location of dust buildup and amount
    Broken wires
    Wire alignment
    Weight alignment and movement

- Hoppers

    Dust buildup
    Level detectors
    Heaters
    Vibrators
    Chain wear, tightness, and alignment
    Dust buildup in corners and walls

(Continued Next Page)

TABLE VIII: ANNUAL INSPECTION CHECKLIST
(Continued from Previous Page)

- Dust Discharge System

    Condition of valves, air locks, conveyors

- General

    Corrosion
    Interlocks
    Ground system
    Turning vanes, distribution plates, and ductwork

9. TROUBLE SHOOTING

Trouble shooting a precipitator starts normally with an unacceptable stack discharge plume. This condition necessitates a good look at the precipitator and the process it serves.

Most precipitator problems are either process related, design, or equipment related. (Table IX).

The first, and most of time best indication of the state of the precipitator is to look at the electrical controls and to try to interpret the meter readings in the control cabinets. Normally, it is best to compare the readings with those taken prior to the emergency conditions; i.e., during normal operation of the precipitator and to define operational problems based on this comparison.

TABLE IX: TYPICAL ESP FAILURE MODES

1) Fundamental Problems -

This category includes gas stream characteristics such as high resistivity; unusually fine particle size, which can be accounted for in the design of the ESP; and overall design inadequacies (poor gas flow distribution, inadequate plate area, inadequate or unstable energization equipment not matched to process characteristics, improper rappers for the process particulate beina collected). Because these problems will cause O&M difficulties throughout the life of the ESP, they are essentially independent of a good O&M program. As discussed in Section 2.2, care must be taken during the design and specification of each component of the ESP if the plant O&M personnel are expected to keep the ESP operating within prescribed air pollution control limits. In other words, if the ESP is poorly designed, a proper O&M program may only serve to keep the ESP operating marginally within compliance or at some minimum level above the compliance limit. In these instances, the design-related problem must be corrected before the O&M program can be truly effective.

2) Mechanical Problems -

These problems include electrode alignment (i.e., warped plates, close clearances, twisted frames), wire breakage, cracked plates, air inleakage, cracked insulators, dust deposits, and plugged hoppers. Problems such as these will generally be discernible through a review of V-I curves or in the course of routine external or internal inspections. Improper design or construction may contribute to these problems, and efforts should be made to find the cause of the problem instead of blindly replacing the component.

3) Operational Problems -

This category of problems includes process upsets that degrade ESP performance, inadequate power input or failure of T-R sets, electrical sections out of service, improper operation or failure of rappers, and dust removal valve failures. These problems also can be influenced by poor design, and the resulting degradation in performance can be immediate or occur over a period of time (e.g., when rappers fail and dust deposits build up on wires or plates).

9.1 Process-Related Problems

These should be explored after incidents of excessive arcing, dust build-up, back-corona or corrosion have been observed. Causes could be changes in flow rate, temperature, chemical analysis of the gas; or loading, particle size, chemical analysis of the dust (Table X).

TABLE X: TROUBLE SHOOTING CHECKLIST - PROCESS PROBLEMS

- Change in gas flow rate
- Change in gas characteristics
- Change in dust characteristics
- Gas velocity distribution
- Gas temperature distribution
- Dust distribution
- Corrosion

9.2 Design/Equipment-Related Problems

Typical problems relate to gas velocity distribution, dust distribution, temperature gradients, dust buildup, sneakage, air inleakage, hopper pluggage, reentrainment, mechanical, structural or electrical equipment failures, insulator failures, electrode alignment; or inadequate rapping frequency, duration, or intensity (Tables XI And XII). Specific malfunctions can be analyzed and treated accordingly. Trouble shooting charts are normally provided by the precipitator manufacturer. It is best to use these charts since they are tailored to the specific precipitator design and application.

A summary of problems associated with ESP's (Table XIII and a trouble shooting chart for ESP's (Table XIV) are appended.

TABLE XI: TROUBLE SHOOTING CHECKLIST - DESIGN PROBLEMS

- Gas velocity distribution
- Gas temperature distribution
- Dust distribution
- Dust buildup/pluggage
- Air inleakage
- Gas sneakage
- Equipment failures
- Close electrical clearances
- Electrode misalignment
- Inadequate rapping frequency, intensity, duration
- Corrosion

TABLE XII: TROUBLE SHOOTING CHECKLIST - EQUIPMENT PROBLEMS

- Equipment failures
- Air inleakage
- Electrode misalignment
- Corrosion
- Erosion

TABLE XIII: SUMMARY OF ESP PROBLEMS (Back of Book)

TABLE XIV: ESP TROUBLESHOOTING (Back of Book)

(See Appendix at back of book for Tables XIII and XIV)

9.3 Malfunction Plan

In spite of all preparation to maintain the performance of the precipitator, it can be expected that a breakdown will occur at the most unlikely and most inconvenient time. In this case, a plan should be available to deal with the emergency situation. This plant should identify the individual or individuals responsible for corrective action, the procedures to be followed, and the availability of detail information on equipment and process, on labor and materials, tools, and possible alternative actions (Table XV). The emergency procedure should allow for corrective actions to achieve compliance with the emission regulations as expeditiously as possible.

TABLE XV: MALFUNCTION PLAN

- Identify person responsible for corrective action
- Shutdown procedures
- Notification of management/authorities
- Safety procedures
- Identify course of action
- Availability of process and design information
- Availability of spare parts
- Availability of special tools
- Availability of manpower
- Re-start procedures
- Code compliance check

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TABLE XIV: TROUBLESHOOTING CHART FOR ESPs

SYMPTOM:	PROBABLE CAUSE:	REMEDY:
1. No primary voltage No primary current No ESP current	DC overload condition	Check overload relay setting Check wiring and components
Vent fan on	Misadjustment of current limit control	Check adjustment of current Limit control setting
	Overdrive of rectifiers	Check signal from firing circuit mode
2. No primary current No ESP current Vent fan off Alarm energized	Fuse blown or circuit breaker tripped Loss of supply power	Replace fuse or reset circuit breaker Check supply to control unit
3. Control unit trips out an overcurrent when sparking occurs at high currents	Circuit breaker defective or incorrectly sized	Check circuit breaker
	Overload circuit incorrectly set	Reset overload circuit
4. High primary current No ESP current	Short circuit condition in primary system	Check primary power wiring
	Too high ESP voltage for prevailing operating conditions	Lower the ESP voltage
	High-voltage circuit shorted by dust buildup between emitting & collecting electrodes	Remove dust buildup
	Slack or broken emitting electrode wire shooting the high "V" circuit	Deenergize ESP & remove or replace broken or slack wire
	Circuit Component Failure	Check transformer-rectifier & ESP: ground T-R high "V" connector to ESP
	Trouble in ESP 1) Dust buildup in hopper; check meters: - ammeter very high - KV meter very low - Milliamperes very high	Clean off dust buildup
	2) Metallic debris left in unit during shutdown for maintenance	Deenergize ESP and remove debris
	3) Unhooked collecting plate touching emitting frame	Repair
	4) Broken support insulator	Repair
	5) Excessive dust buildup on hopper beams or cross member	Clean

Continues next page

TABLE XIV: TROUBLESHOOTING CHART FOR ESPs

	PROBABLE CAUSE:	REMEDY:
	5) excessive dust buildup on hopper beams or cross member	Clean
5. Low primary voltage High secondary current	Short circuit in secondary circuit or precipitator	Check wiring and components in high voltage circuit; Check ESP for: Interior dust buildup Full hoppers Broken wires Ground switch left on Ground jumper left on Foreign material on high voltage frame or wires Broken insulators
6. Abnormally low ESP current and primary voltage with no sparking	Misadjustment of current and/or voltage limit controls	Check settings of current and voltage limit controls
	Misadjustment of firing circuit control	Turn to maximum and check setting of current and voltage limit controls
	Heavy coating on emitting electrode wires	Check emitting frame vibration and emitting vibration shaft insulator
	Stream of cold air entering ESP from defective door gasket duct opening, inlet gas system rupture - condensation	Repair
	Wet dust clinging to wires causes extremely low milliammeter readings	Eliminate source of condensation
	Severe arcing in the ESP without tripping out the unit	Eliminate cause of arcing
7, Spark meter reads high-off scale	Continuous conduction of spark counting circuit	Deenergize, allow integrating capacitor to discharge and re-energize
Low primary voltage and current No spark rate indication	Spark counter counting 60 cycles peak	Readjust controls
8, Spark meter reads high Primary voltage and current very unstable	Misadjustment Loss of limiting control	Readjust Replace control
9. No spark rate indication voltmeter and ammeter unstable indicating sparking	Failure of spark meter Failure of integrating capacitor Spark counter sensitivity too low	Replace spark meter Replace capacitor Readjust sensitivity
10. No response to voltage limit adjustment Does respond to current adjustment	Controlling on current limit or spark rate	None needed if unit is operating at maximum current or spark rate Reset current and spark rate adjustment if neither is at maximum
11. No response to voltage limit adjustment Does respond to other adjustment	Controlling on voltage or current	None needed if unit is operating at maximum voltage or current Reset voltage and current adjustment if either is at maximum

TABLE XIII: SUMMARY OF PROBLEMS ASSOCIATED WITH ESPs (REFERENCE 5)

Malfunction	Cause	Effect on ESP Efficiency[1]	Corrective Action	Preventative Measures
1. Poor electrode alignment	1) Poor design 2) Ash buildup on frame, hoppers 3) poor gas flow	Can drastically affect performance and lower efficiency	Realign electrodes Correct gas flow	Check hoppers frequently for proper operation
2. Broken electrodes	1) Wire not rapped clean, causes an arc which embrittles and burns through the wire 2) Clinkered wire. Causes: a) poor flow area, distribution through unit is uneven; b) excess free carbon due to excess air above combustion requirements or fan capacity insufficient for demand required c) wires not properly centered d) ash buildup resulting in bent frame, same as c); e) clinker bridges the plates and wire shorts out; f) ash buildup, pushes bottle weight up causing sag in the wire; g) "J" hooks have improper clearances to the hanging wire h) bottle weight hangs up during cooling causing a buckled wire i) ash buildup on bottle weight to the frame forms a clinker and burns off the wire.	Reduction in efficiency due to reduced power output, bus section unavailability	Replace electrode	Boiler problems; check space between recording steam and air flow pens, pressure gauges; fouled screen tubes Inspect hoppers; check electrodes frequently for wear; inspect rappers frequently
3. Distorted or skewed electrode plates	1) Ash buildup in hoppers 2) Gas flow irregularities 3) High temperatures	Reduced efficiency	Repair or replace plates Correct gas flow	Check hoppers frequently for proper operation; check electrode plates during outages
4. Vibrating or swinging electrodes	1) Uneven gas flow 2) Broken electrodes	Decrease in efficiency due to reduced power input	Repair electrode	Check electrodes frequently for wear
5. Inadequate level of power input (voltage too low)	1) High dust resistivity 2) Excessive ash on electrodes 3) Unusually fine particle size 4) Inadequate power supply 5) Inadequate sectionalization 6) Improper rectifier and control operation 7) Misalignment of electrodes	Reduction in efficiency	Clean electrodes; gas conditioning or alterations in temperatures to reduce resistivity; increase sectionalization	Check range of voltages frequently to make sure they are correct; check in-situ resistivity measurements

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[1] *The effect of precipitator problems can only be discussed on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems*

TABLE XIII: SUMMARY OF PROBLEMS ASSOCIATED WITH ESPs (REFERENCE 5)

Malfunction	Cause	Effect on ESP Efficiency[1]	Corrective Action	Preventative Measures
6. Back Corona	1) Ash accumulated on electrodes causes excessive sparking requiring reduction in voltage charge	Reduction in efficiency	Clean electrodes; gas conditioning or alterations in temperatures to reduce resistivity; increase sectionalization	Check range of voltages frequently to make sure they are correct; check in-situ resistivity measurements
7. Broken or cracked insulator or flower pot bushing leakage	1) Ash buildup during operation causes leakage to ground 2) Moisture gathered during shutdown or low load operation	Reduction in efficiency	Clean or replace insulators and bushings	Check frequently; clean and dry as needed; check for pressurization at top housing
8.Air inleakage through hoppers	1) From dust conveyor	Lower efficiency- - dust reentrained through ESP	Seal leaks	Identify early by increase in ash concentration at bottom of exit to ESP
9. Air inleakage through ESP shell	1) Flange expansion	Same as above, also causes intense sparking		
10. Gas bypass around ESP: - dead passage above plates - around high tension frame	1) Poor design - improper isolation of active portion of ESP	Only a few percent drop in efficiency unless severe	Baffling to direct gas into active ESP section	Identify early by measurement of gas flow in suspected areas
11. Corrosion	1) Temperature goes beyond dew point	Negligible until precipitator interior plugs or plates are eaten away; air leaks may develop causing significant drop in performance	Maintain flue gas temperature above dew point	Energize precipitator after boiler system has been on line for ample period to raise flue gas temperature above dew point

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TABLE XIII: SUMMARY OF PROBLEMS ASSOCIATED WITH ESPs (REFERENCE 5)

Malfunction	Cause	Effect on ESP Efficiency[1]	Corrective Action	Preventative Measures
12. Hopper Pluggage	1) Wires, plates, insulators fouled because of low temperature 2) Inadequate hopper insulation 3) Improper maintenance 4) Boiler leaks causing excessive moisture 5) Ash conveying system malfunction - gasket inleakage - blower malfunction - solenoid valve 6) Misadjustment of hopper vibrators 7) Material dropped into hopper from bottle weights 8) Solenoid, timer malfunction 9) Suction blower filter not changed	Reduction in efficiency	Provide proper flow of ash	Frequent checks for adequate operation of hoppers. Provide heater thermal insulation to avoid moisture condensation
13) Inadequate rapping, vibrators fail	1) Ash buildup 2) Poor design 3) Rappers misadjusted	Resulting buildup on electrodes may reduce efficiency	Adjust rappers with optical dust measuring instrument in ESP gas stream	Frequent checks for adequate operation of rappers
14) Too intense rapping	1) Poor design 2) Rappers misadjusted 3) Improper rapping force	Reentrians ash, reduces efficiency	Adjust rappers with optical dust measuring instrument in ESP gas stream	Frequent checks for adequate operation of rappers Reduce vibrating or impact force
15) Control failures	1) Power failure in primary system 2) Transformer or rectifier failure a. insulation breakdown in transformer b. arcing in transformer between high voltage switch contacts c. leaks or shorts in high voltage structure d. insulating field contamination	Reduced efficiency	Find source of failure and repair or replace	Pay close attention to daily reading of control room instrumentation to spot deviations from normal readings
16) Sparking	1) Inspection door ajar 2) Boiler leaks 3) Plugging of hoppers 4) Dirty insulators	Reduced efficiency	Close inspection doors; repair leaks in boiler; unplug hoppers; clean insulators	Regular preventative maintenance will alleviate these problems

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[1] *The effect of precipitator problems can only be discussed on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems*