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INSPECTION PROCEDURES FOR EVALUATION OF ELECTROSTATIC PRECIPITATOR CONTROL SYSTEM PERFORMANCE

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INSPECTION MANUAL FOR EVALUATION OF ELECTROSTATIC PRECIPITATOR PERFORMANCE

by

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SECTION 1

INTRODUCTION

The Division of Stationary Source Enforcement (DSSE) of the U.S. Environmental Protection Agency (EPA) the Enforcement Divisions of the EPA Regional Offices, and various state and local agencies delegated authority to enforce Federal emission standards have the responsibility for enforcing emission standards for regulated stationary source and for ensuring continued compliance with the standards. An important part of the agency's stationary source compliance monitoring and surveillance program is the inspection of sources. The EPA field enforcement staff inspect sources at regular intervals and determine their compliance status by observing major operating parameters of the emission control systems and process parameters affecting emissions.

At the present time, no guidelines exist for determining whether a control system is adequately designed or is being properly operated and maintained. Therefore, DSSE is planning to prepare technical guidelines for inspection and performance evaluation of control systems. These guidelines will provide the inspector with necessary background and information relating to inspection and performance evaluation of a particular control system. At present, the emphasis is on sources already in operation. Another set of guidelines applicable to new sources are being planned that will provide technical information and procedures specifically for the preconstruction engineering review of control equipment design and construction and proposed operational parameters.

This report consists of seven major sections. The first four sections orient the reader to the basics of ESP operation, maintenance, and sizing; the remaining three sections present guidelines for inspection and performance evaluation.

Section 2 presents the basics of ESP's. A brief history of electrostatic precipitators is followed by descriptions of ESP types and components, as well as sizing information. Section 3 deals with ESP instrumentation, the major operational parameters, and operational records.

Operation and maintenance practices are outlined in Section 4. The discussion includes matching of various operating parameters for optimum performance, typical ESP maintenance schedules, maintenance of peripheral accessories, and common ESP malfunctions and their effects on performance.

Section 5 provides a detailed procedure for inspection of ESP's, with an inspection checklist that covers all ESP components and peripheral systems. Frequency and duration of inspections and operating conditions during inspection are discussed.

Section 6 presents procedures for evaluating and predicting ESP performance on the basis of inspection results. A procedure is provided for relating ESP electrical data (corona power) to emission level, based on previous stack emission test data. Brief discussions are made on the use of advanced modeling techniques including a) programmable calculator ESP performance model and, b) EPA/Southern Research Institute computerized ESP performance model. Performance case histories of two ESP installations are included in Section 7 to provide insight into ESP performance evaluation.

The appendices provide supporting information for the performance evaluation of ESP's. Appendix A outlines a typical maintenance schedule for ESP's; Appendix B discusses the common ESP malfunctions; Appendix C presents preinspection and inspection checklists for evaluation of ESP condition and performance.

SECTION 2

OVERVIEW OF ELECTROSTATIC PRECIPITATION

2.1 INTRODUCTION[1,2]

The three basic processes involved in electrostatic precipitation are: (1) the transfer of an electric charge to suspended particles in the gas stream, (2) establishment of an electric field for removing the particles to a suitable collecting electrode, and (3) removal of the particle layers from the precipitator with as little loss to the atmosphere as possible. Figure 2-1 illustrates the basic processes involved in electrostatic precipitation, and Figure 2-2 shows the processes and their interrelationship.

In a single-stage precipitator, high-voltage direct current (d.c.) corona is responsible for producing negative ions, charging the suspended particles, and creating the electric field.

Two basic hardware components of the precipitation process are: (1) the precipitation chamber, in which the particles are electrified and removed from the gas and (2) the high-voltage transformer and rectifier, which function to create the strong electrical field in the chamber.

In practice, the precipitation chamber consists of a shell made of metal, tile or other similar material. Suspended within the shell are grounded steel plates (collecting electrodes) connected to the grounded steel framework of the supporting structure and to an earth-driven ground. Suspended between the plates are metal rods or wires (discharge electrodes), insulated from ground and negatively charged at voltages ranging from 30,000 to 100,000 volts (30 to 100 kV). The large voltage

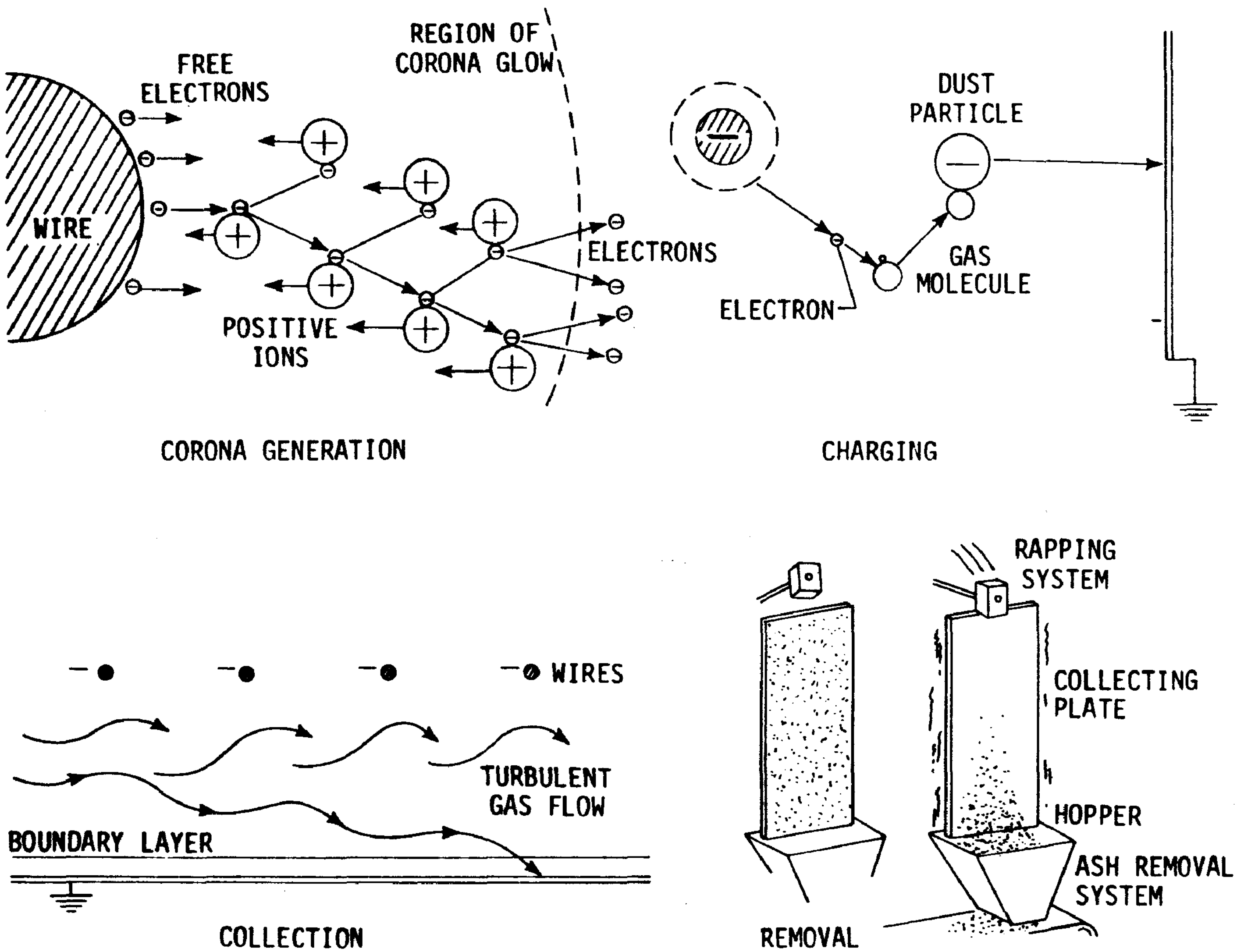

Figure 2-1. Basic processes involved in electrostatic precipitation.[10]

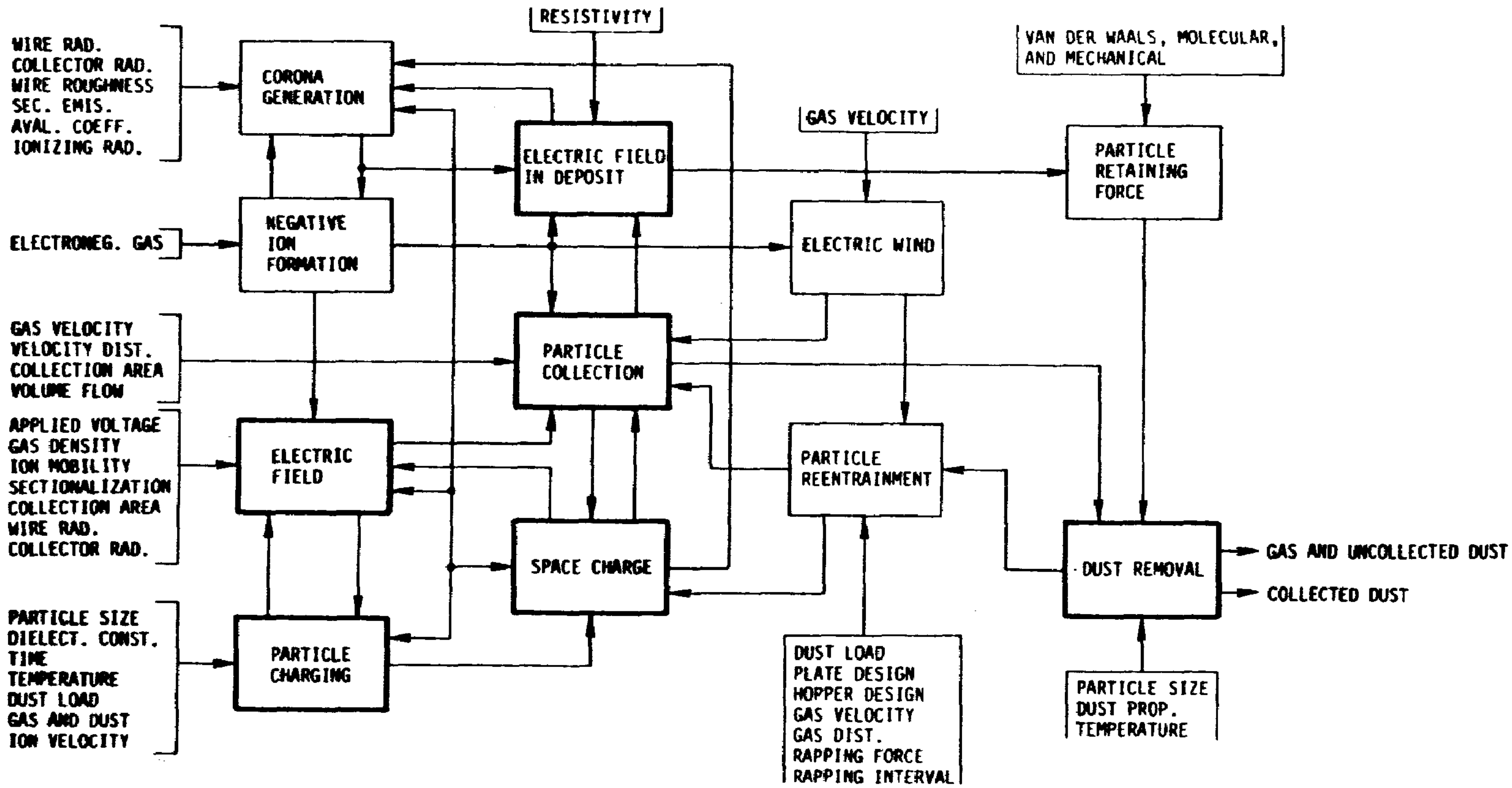

Figure 2-2. Electrostatic precipitator system model.[11]

differential between the wires and the plates sets up a high electrical field. High electric field levels ionize electronegative gas molecules (e.g., O_2, SO_2), which impart negative charges to the suspended particles. Due to the electric field and particulate charge, a powerful force (about 3000 times gravity) acts on the particle in the direction of the collection plates.

The solid dust particles are removed by periodic rapping of the collection plate so that the dust falls in sheets into a receiving hopper. Solid material can also be removed by irrigation of the collection electrode with water or other fluid in what is termed a "wet" precipitator. Liquid particles, such as acid mists or tars, coalesce on the collection plate and drain into a sump at the bottom of the precipitator.

2.2 CHARGING MECHANISMS[1,2]

Particle charging and subsequent collection takes place in the region between the boundary of the corona glow and the collection electrode, where gas particles are subjected to the generation of negative ions from the corona process. Charging is accomplished by field and diffusion mechanisms. The predominant mechanism varies with particle size.

In field charging, ions from the corona are driven onto the electric field. As the ions continue to impinge on a dust particle, the charge on it increases until the local field developed by the charge on the particle causes distortion of the electric field lines such that they no longer intercept the particle. As the particle reaches this saturation charge level, no further charging will take place. This is the predominant mechanism for particles larger than about 0.5 micrometers (μm).

The time required for a particle to reach its saturation charge, varies proportionally to the ion density in the region where charging takes place. Under normal conditions with sustained high-current levels, charging times are only a few milliseconds. Limitation of current because of high resistivity or other factors can lengthen charging times significantly and cause the particles to travel several feet through the precipitator before saturation charge is approached.

The waveform of the secondary voltage can further affect the charging times. The rectified unfiltered voltage has peaks and low occurring at regular intervals, which match with the frequency of the primary voltage. Thus, the electric field varies with time, and the dust particles in the interelectrode region are subjected to time-varying fields. The particle charging is interrupted for that portion of the cycle during which the charge on the particle exceeds that corresponding to the saturation charge for the electric field existing at the time. This further lengthens the charging times and, in the case of high-resistivity dust, degrades precipitator performance.[2]

Diffusion charging is associated with ion attachment resulting from random thermal motion, and is the dominant charging mechanism for particles below about 0.2 μm. As with field charging, diffusion charging is influenced by the magnitude of the electric field, since ion movement is governed by electrical as well as diffusional forces. Neglecting electrical forces, an explanation of diffusion charging is that the thermal motion of molecules causes them to diffuse through a gas and contact the particles. The charging rate decreases as a particle acquires a charge and repels additional gas ions, but charging continues to a certain extent because there is no theoretical saturation or limiting charge other than the limit imposed by the field emission of electrons. This is because the distribution of thermal energy ions will always overcome the repulsion of the dust particle.[2]

The particle size range of about 0.2 to 0.4 μm is a transitional region in which both mechanisms of charging are present but neither is predominant. Fractional efficiency test data for precipitators have shown reduced collection efficiency in this transitional size range, where diffusion and field charging overlap.

2.3 RESISTIVITY

Since dust resistivity can greatly limit preicpitator performance when it is outside the preferred range of 10^8 ohm-cm to 10^{10} ohm-cm, it is a major factor in preicpitator technology. Resistivity plays a major role in the electrical conditions of the collection dust layer, influencing the:

1) electric field stress in the dust layer
2) voltage drop across the dust layer, and
3) electrical force component holding the dust layer to the collection plate.

Resistivity also affects the electrical operating conditions of an ESP, due to its impact on particle charging, and 2) the interdependent relationship between dust layer conditions and the operating voltage and current levels.

Table 2-1 provides a brief description of characteristics associated with the typical levels of dust resistivity. The identified characteristics reflect generalized cases and conditions, indicating that an optimum range exists for resistivities between 10^8 and 10^{10} ohm-cm. As resistivity levels deviate from the preferred range, special design considerations need to be made to compensate for the respective change in precipitation characteristics. Accordingly, for ESP's treating streams with fluctuating resistivity levels, (e.g., different temperature, moisture, fuel quality), special or different ESP operation may be necessary to maintain collection performance.

Fly ash resistivity depends primarily on the chemical composition of the ash, the ambient flue gas temperature, and the amounts of water vapor and SO_3 in the flue gas.[4] High resistivity, which is characteristic of certain low-sulfur coals, causes uncertainly in sizing cold-side ESP's, which generally operate at temperatures of 120° to 175°C (250°-350°F).

At low temperatures [<80°C (<175°F)], current conduction occurs principally along the surface layer of the dust and is

TABLE 2-1. ESP CHARACTERISTICS ASSOCIATED WITH DIFFERENT LEVELS OF RESISTIVITY

Resistivity level ohm-cm	ESP characteristics
$<10^8$	(1) Normal operating voltage and 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), (2).
$>10^{12}$	(1) Reduced operating voltage levels; high operating current levels. (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.

Typical values

Operating voltage : 30-70 kV, dependent on design factors

Operating current density: 5-50 nA/cm^2

Dust layer thickness : 0.5 to 2 cm (1/4-1 in.)

related to the absorption of water vapor and other conditioning agents in the flue gas. For fly ash, resistivity is primarily related in an inverse manner to the amount of SO_3 and moisture in the flue gas. Burning of low-sulfur coal releases smaller amounts of SO_2, which is oxidized to SO_3. A higher resistivity fly ash results, except at temperatures below about 80°C (170°F), where significant amounts of SO_3 are absorbed onto the fly ash particles.

At elevated temperatures [<200°C (<400°F)], conduction takes place primarily through the bulk of the material, and resistivity depends on the chemical composition of the material. For fly ash, resistivity above 200°C (400°F) is generally below the critical value of about 10^{10} ohm-cm, although it has been shown to decrease with increasing amounts of sodium, lithium, and iron.[5]

The range of operation of cold-size fly ash precipitators is 120° to 200°C (250° to 400°F), a range in which conduction takes place by a combination of the surface and bulk mechanisms and resistivity of the ash is highest. Figure 2-3 illustrates the relationship between resistivity, temperature, and responsible conduction mechanisms.

2.4 TYPES OF ELECTROSTATIC PRECIPITATORS

Two types of electrostatic precipitators are used for particulate control: dry and wet electrode precipitators. Within each of these categories precipitators can be further classified by electrode geometry.[3] Most precipitators in use today are the dry type with plate-type collection electrodes and pyramidal hoppers. Gas flow is normally horizontal through the ESP. Figure 2-4 presents an example of this type of precipitator. A less common electrode arrangement is a wire-pipe (cylindrical) ESP.

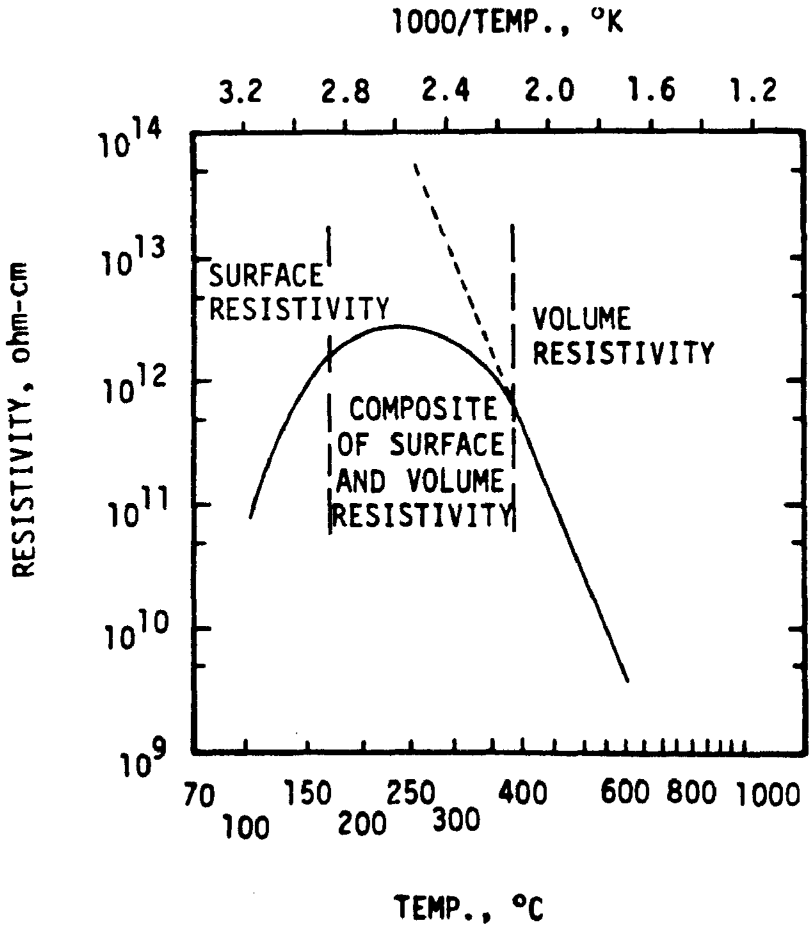

Figure 2-3. Typical temperature-resistivity relationship.[2]

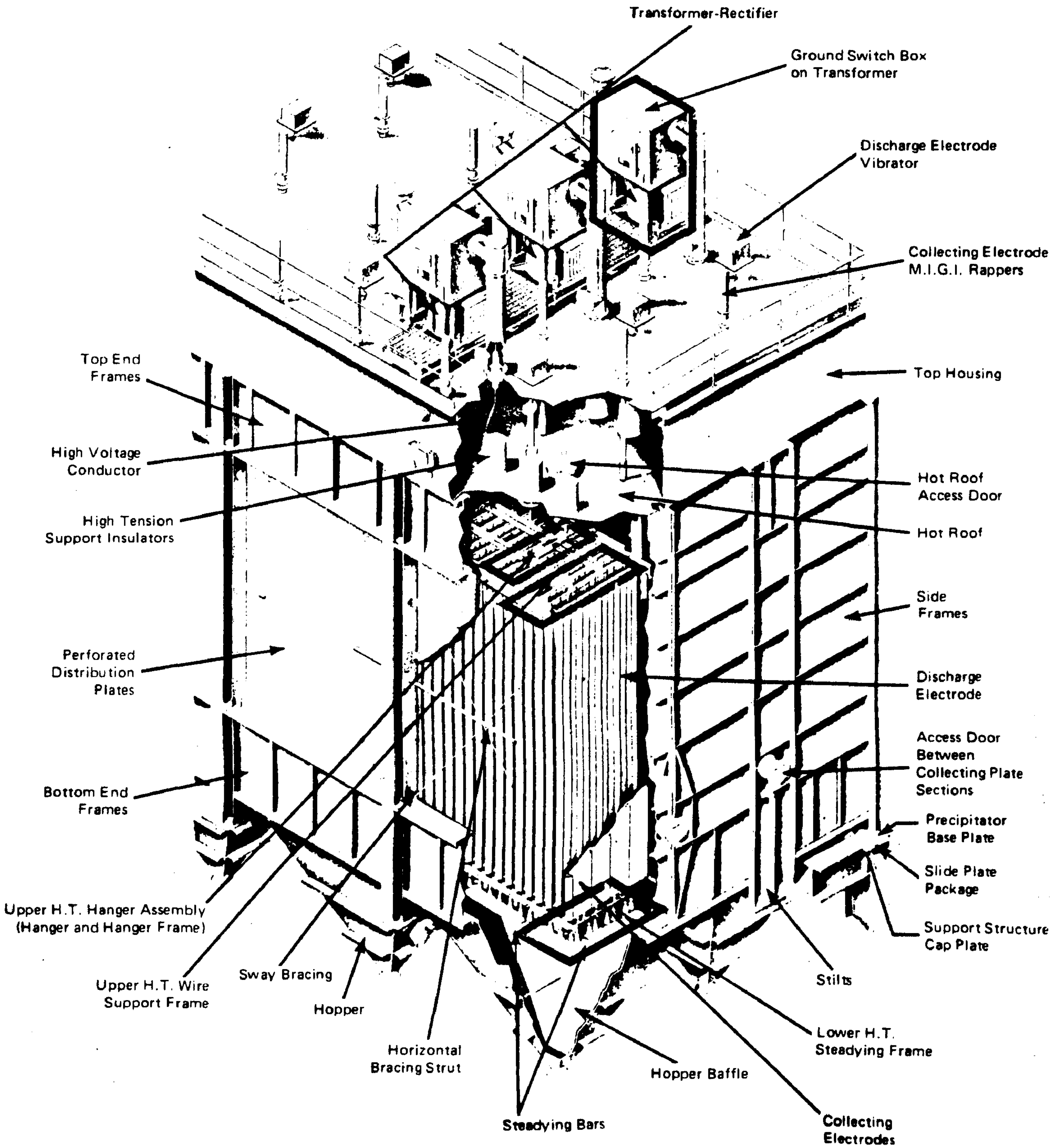

Figure 2-4. Typical electrostatic precipitator with top housing. (Courtesy of Research Cottrell)

2.4.1 Dry Precipitators

Dry precipitators are installed in industries with widely varying condition of gas temperature and pressure, such as electric utility power boilers, cement kilns, and metallurgical furnaces. In the electric utility industry, precipitators are classified as cold or hot, depending on the location of the ESP relative to the air preheater.

The cold-side ESP, located downstream of the air preheater, operated in the range of 100° to 200°C (200° to 400°F). The greatest disadvantage of a cold-side ESP is that its efficiency varies with fuel composition and boiler firing conditions, whereas the efficiency of a hot-side ESP is less dependent of these factors.

Hot-side ESP's are located upstream of the boiler air preheater. The operating temperature range is generally between 300° and 450°C (600° to 800°F). At this temperature, the resistivity of fly ash is significantly lessened and, for certain coal types, collectibility can be greatly increased. Also, because of the ESP location, the heat transfer surfaces of the air preheater are less likely to be fouled by fly ash. There are corresponding reductions in the need for soot blowing of the air preheater and in hopper plugging. One drawback of locating the ESP upstream of the air preheaters is that the soot blown from the air preheater cannot be captured; this may result in occasional increased emissions.

The typical hot-side precipitator operates at lower voltages than a cold-side unit. If designed correctly, it operates at much higher current densities and is characterized by a relatively high-power density and by stable, current-limited operation.

Thermal expansion has been a problem with hot ESP's. After construction at ambient temperatures, the internals are maintained during operation at approximately 350° to 400°C (650° to 750°F), while the externals remain near ambient temperatures.

Adequate provision for differential movement of the precipitator on its support structure, proper insulation, and adherence to design stress values have largely eliminated this problem.

Some ESP manufacturers favor cold-side installations, others stress hot-side units; there is no adequate rule of thumb for choice of either type. The selection is usually based on operability, economics, and particulate characteristics.

For new construction at a coal-fired power plant, if the specific collection area (SCA) required for a cold-side ESP is greater than 100 m^2/m^3/sec (500 ft^2/100 acfm),* a hot-side unit would be the proper choice. If the SCA can be smaller, a cold-side unit could be used.

2.4.2 Wet Precipitators

Wet precipitators are used primarily in the metallurgical industry, usually operating below 75°C (170°F). Until the late 1960's, their use was restricted mostly to acid mist, coke oven off-gas, blast furnace, and detarring applications. Their use in other areas is rapidly increasing as air pollution control codes for those areas are becoming more stringent. The newer applications include sources with sticky and corrosive emissions that must meet these standards. Because of inherent temperature range limitatons, they are not used for boiler installations.

The fundamental difference between a wet and a dry ESP is that a thin film of liquid flows over the collection plates of a wet ESP to wash off the collected particulates. In some cases, the liquid is also sprayed in the gas flow passages to provide cooling, conditioning, or sometimes a scrubbing action. When the liquid spray is used, it is precipitated with the particles, providing a secondary means of wetting the plates. Three different wet ESP configurations are discussed below and illustrated in Figure 2-5.

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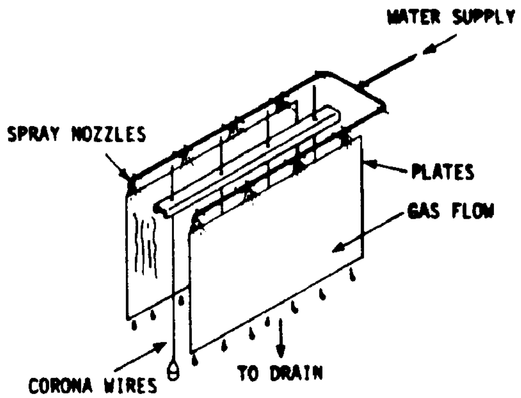
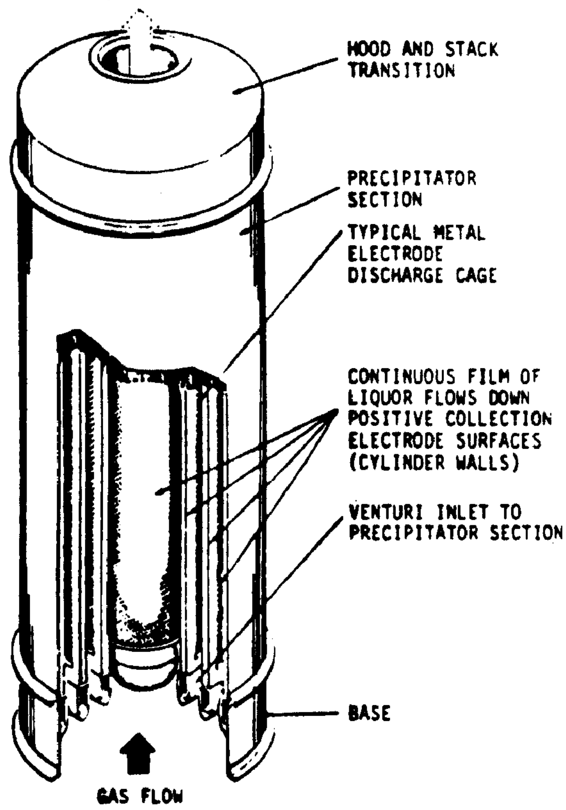
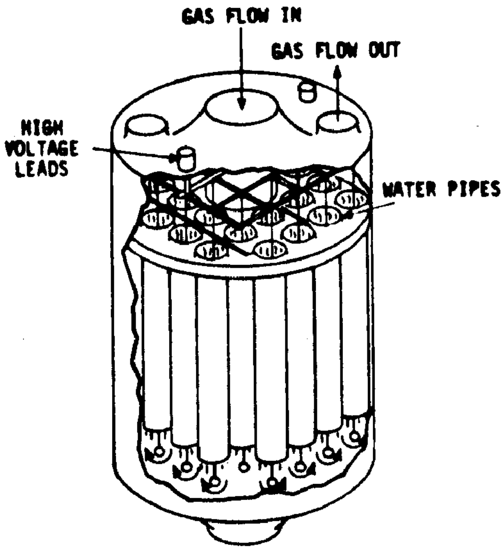
* Metric SCA (m^2/m^3/sec) = 0.197 x British SCA (ft^2/1000 acfm).



A. Plate type (horizontal flow)



B. Concentric plate type



C. Conventional pipe type

Figure 2-5. Three types of wet electrostatic precipitators.

Plate-type (Horizontal Flow)--

The effluent gas stream is usually preconditioned to reduce temperature and achieve saturation. As the gas enters the inlet nozzle, its velocity decreases because of the diverging cross section. At this point, additional sprays may be used to create good mixing of water, dust, and gas as well as to ensure complete saturation before the gas enters the electrostatic field. Baffles are often used to achieve good velocity distribution across the inlet of the precipitator.

Within the charging section, water is sprayed near the top of the plates in the form of finely divided drops, which become electrically charged and are attracted to the plates, coating them evenly. Simultaneously, solid particles are charged; they "migrate" and become attached to the plates. Since the water film is moving downward by gravity on both the collecting and discharge electrodes, the particles are captured in the water film, which is disposed of from the bottom of the precipitator in the form of slurry.

Concentric-plate ESP--

The concentric-plate ESP consists of an integral tangential prescrubbing inlet chamber followed by a vertical wetted-wall concentric-ring ESP chamber. Concentric cylindrical collection electrodes are wetted by fluids dispensed at the top surface of the collection electrode system. The discharge electrode system is made of expanded metal with uniformly distributed corona points on the mesh background. This system is intended to combine the high, nearly uniform, electric field associated with a parallel plate system and the nearly uniform distribution of corona current density associated with closely spaced corona points. Higher gas flows can be handled by adding concentric electrode systems and by increasing the length of each electrode.

Conventional Pipe-type ESP--

This system consists of vertical collecting pipes, each containing a discharge electrode (wire type), which is attached to the upper framework and held taut by a cast-iron weight at the bottom. A lower steadying frame keeps the weights and thus the wires in position.

The upper frame is suspended from the high-voltage insulators housed in the insulator compartments, which are located on top of the precipitator shell (casing). Heating and ventilating systems help to prevent accumulation of moisture and dust in the insulator compartments.

The washing system usually consists of internal nozzles located at the top of the plates. At specified intervals, the tubes are washed thoroughly. During the washing, the louver damper to the exhaust fan is closed to prevent carryover of droplets.

2.5 BASIC ESP COMPONENTS

This section briefly describes major ESP components and presents current nomenclature for a typical ESP configuration.

2.5.1 Precipitator Casing

The precipitator casing is of gas-tight, weatherproof construction. Major casing parts are the inlet and outlet connections, the shell and hoppers, inspection doors, and insulator housing. The casing is fabricated of steel of a type suitable for the application (type of process, heat range, etc.). The shell is reinforced to handle maximum positive or negative pressure, support the weight of the internals, and sustain environmental stresses such as those imposed by wind, snow, and earthquake. The shell and insulator housing form a grounded steel chamber, completely enclosing all the voltage equipment to ensure the safety of personnel.

2.5.2 Dust Removal System

Dust hoppers are required for temporary storage of the collected dust. They should be large enough to hold the dust collected in a 24-hour period. The most common hopper design is pyramidal, converging to a square or round discharge area.

To prevent plugging, hoppers should be kept clean, dry, and if the dust is moisture-laden, warm. Many hoppers do not require vibrators, but it is economical to install mounting devices for future installation of vibrators should operation show that they are necessary. If insulation does not keep the hopper warm enough, additional heating of the hoppers may be required for effective performance.

Frequently, hoppers are baffled at the divisions between two dust-plate sections to prevent gas from bypassing the precipitator.

Access to hoppers should be by external, key-interlocked doors to prevent dangerous dust accumulations on the interior side of the door. Enough "poke hole" ports should be provided to allow for cleaning a blockage at the discharge.

Systems for removal of dusts accumulated in hoppers include containers, dry vacuum, wet vacuum, screw conveyors, and scrape bottom systems.

2.5.3 Collection Electrodes

Collection electrodes are the grounded metal plates upon which the dust collects. Many shapes of flat collecting electrodes are used in ESP's, as shown in Figure 2-6, and some ESP's are designed with cylindrical collection surfaces. All plate configurations are designed to maximize the electric field and to minimize dust reentrainment. All collection plates have a baffle arrangement to minimize gas velocities near the dust surfaces as well as to provide stiffness.[3] Collection plates are commercially available in lengths ranging from 1 to 3 meters (3 to 9 feet) and heights from 3 to 15 meters (9 to 50 feet). Generally, these panels are grouped within the precipitator to form independently rapped collection modules. The total effective length of these plates divided by their effective height is referred to

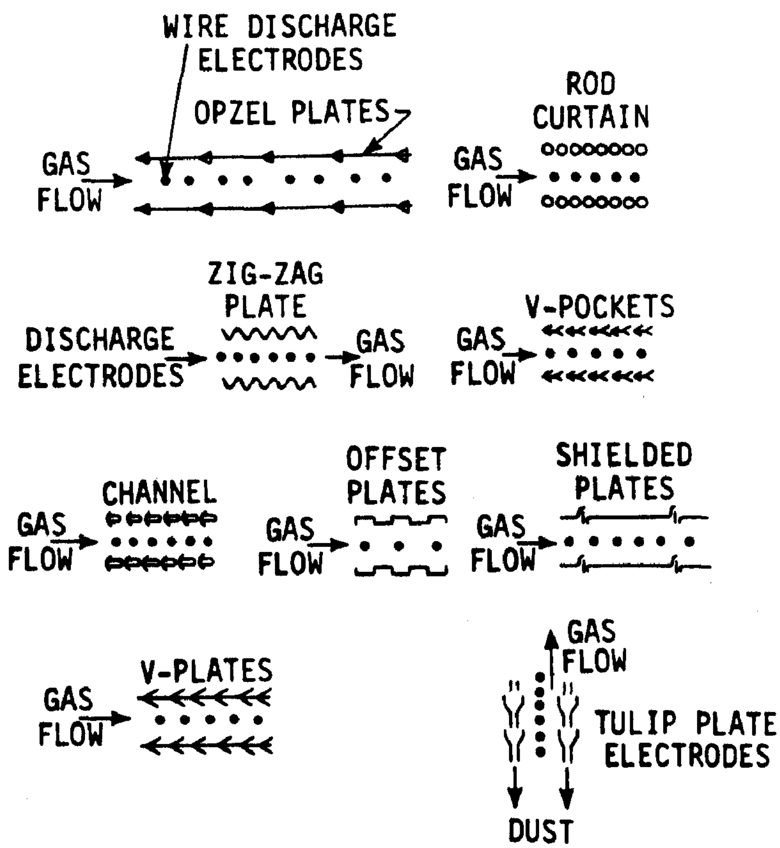


Figure 2-6. Various designs of collection electrodes.[2]

as the aspect ratio. Aspect ratios larger than 1.0 provide longer residence time for the gas and increase collection efficiency, all other factors being equal.

2.5.4 Discharge Electrodes

The discharge electrodes are maintained at high electrical voltage during ESP operation. The high-voltage electrodes ionize the gas and establishes the electric field, which imparts a charge to the particle and causes precipitation.

Discharge electrodes are also referred to as corona electrodes, corona wires, cathodes, and high-voltage electrodes.

Discharge electrodes are metal, the type determined by the composition of the gas stream. The form of the electrodes may be cylindrical or square wire, barbed wire, or stamped or formed strips of metal of various configurations (see Figure 2-7).

Discharge electrodes are mounted in a variety of 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 mats or frames. Regardless of how they are mounted, they must be stabilized against swinging in the gas stream. Examples of the wire weight and rigid wire systems are shown in Figures 2-8 and 2-9.

2.5.5 Electric Power Supplies

The electrical energizing sets consist of high-voltage silicon diode power packs developed specifically for the high loads required for supplying high-voltage direct current to electrostatic precipitators.

The power supply system consists of four 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 without causing arc-over (sparking) between the electrode and the collection surface. The automatic control system maintains optimum voltage value, adjusting to

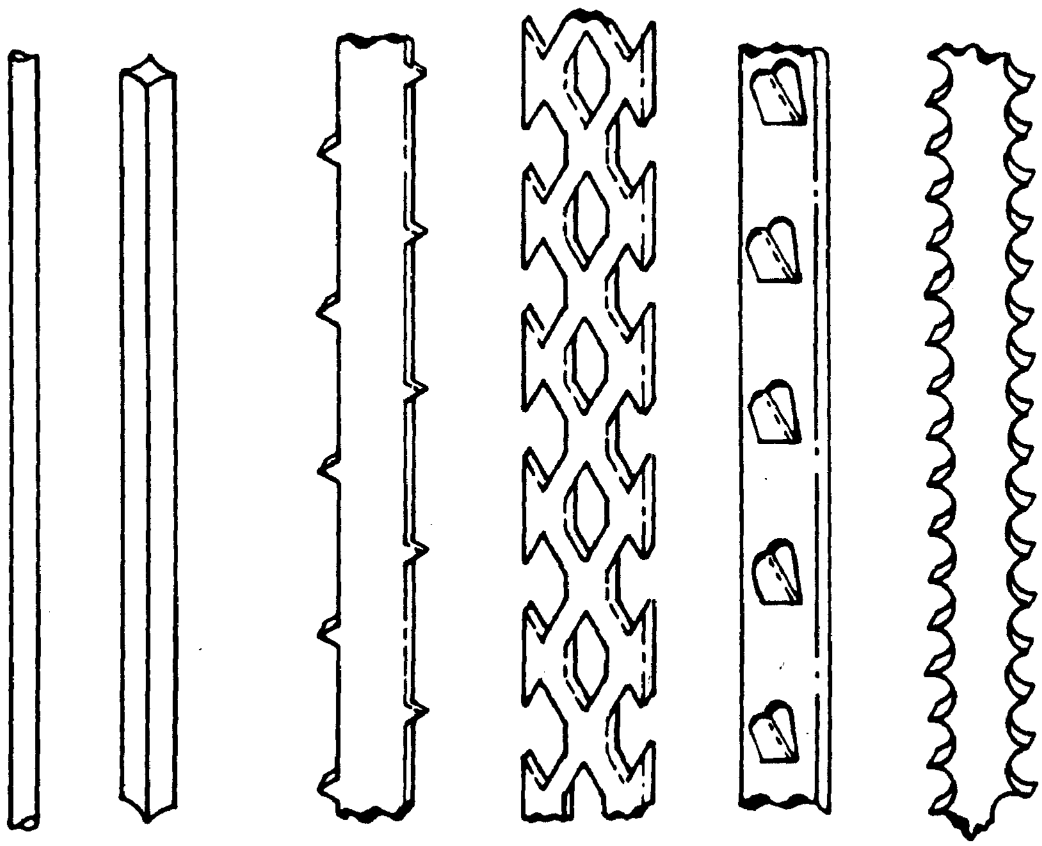


Figure 2-7. Typical forms of discharge or corona electrodes.[3]

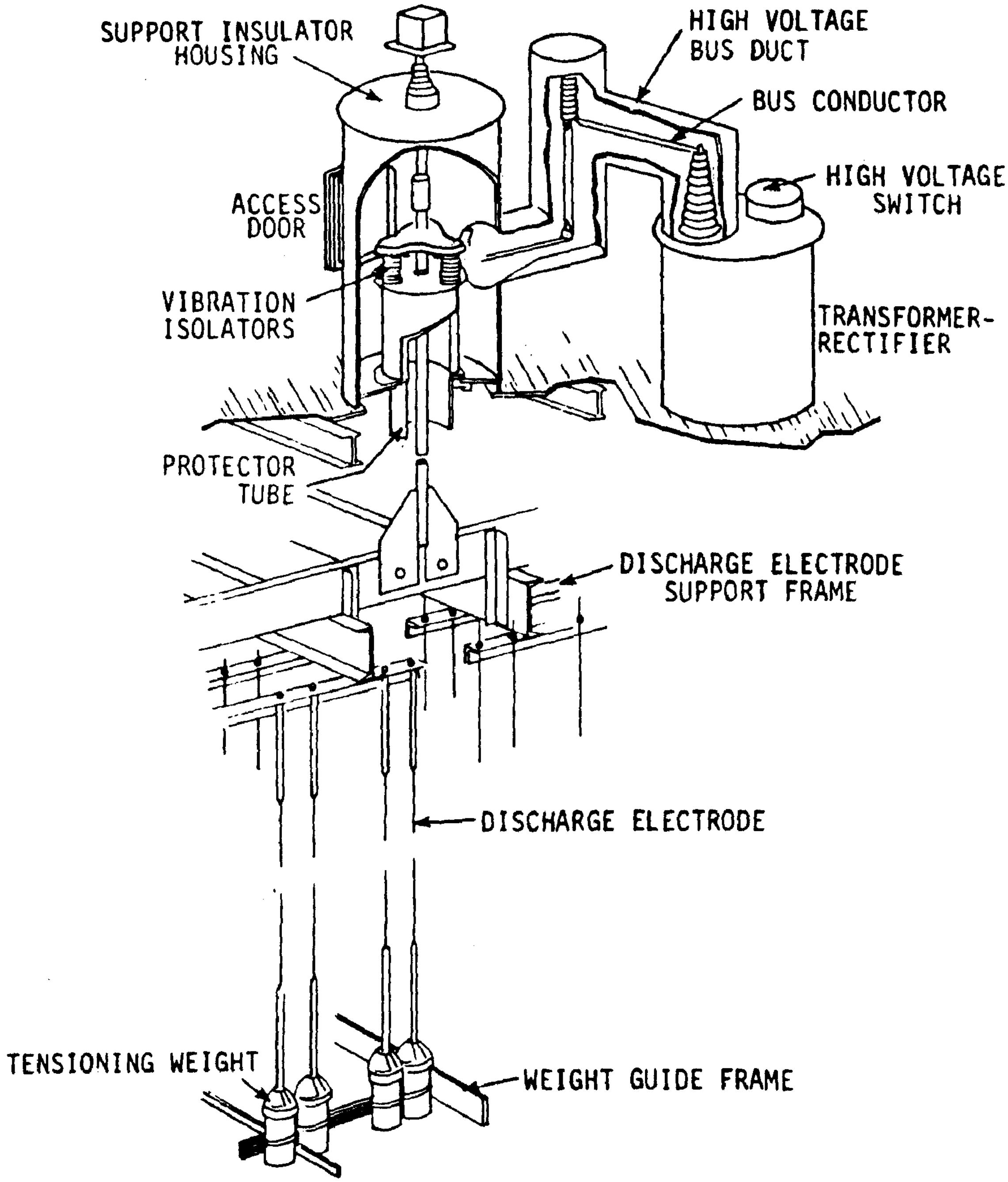


Figure 2-8. Precipitator charging system and wire hanging system.

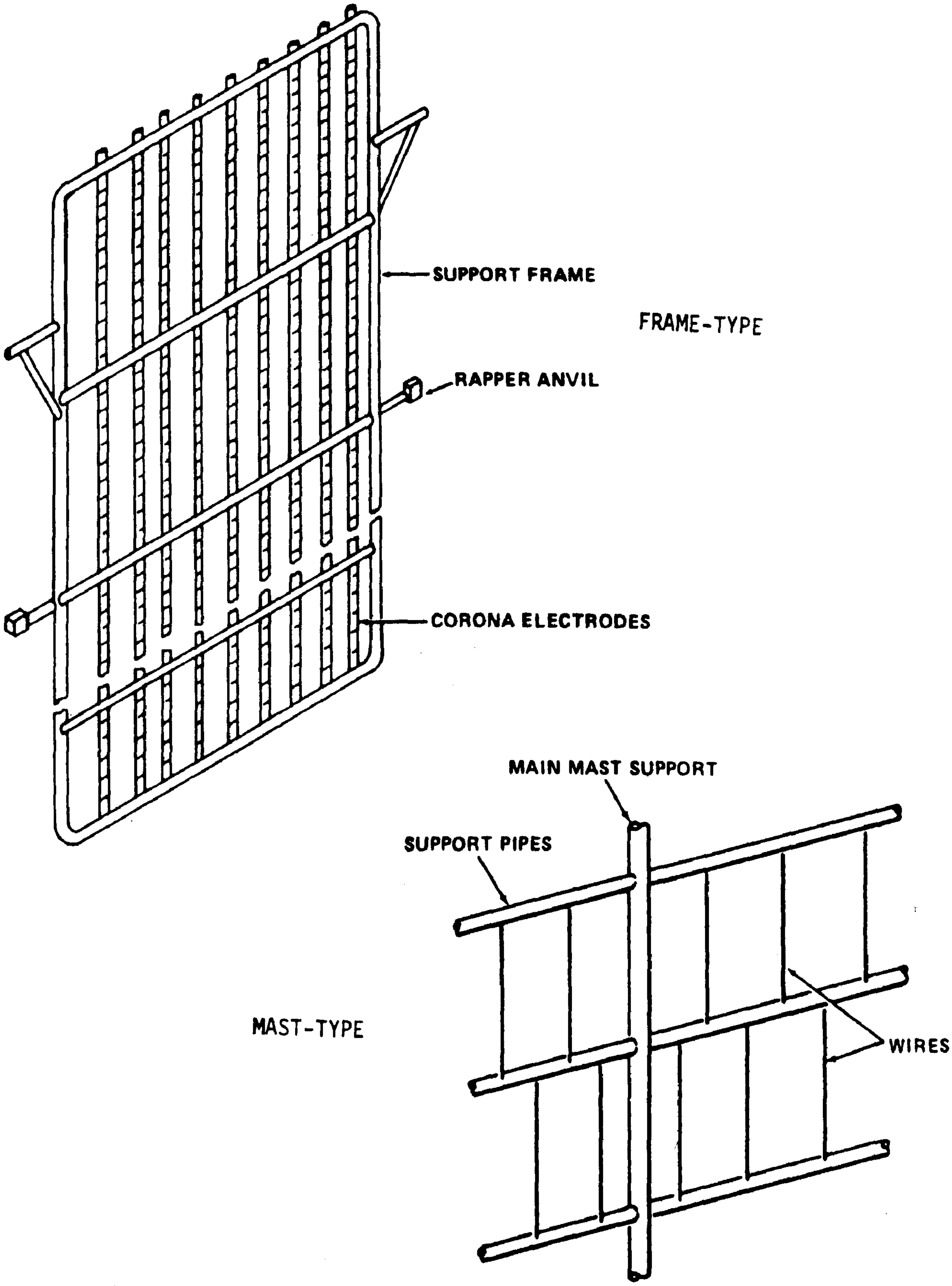


Figure 2-9. Supported electrode structures.[3]

fluctuations in characteristics and concentrations of the dust. A more detailed description of the operation of an automatic control system is given in Section 3.1.

The electrical system of an ESP is arranged in bus sections, each section representing any portion of the ESP that can be energized independently. This is accomplished by subdividing the high-voltage system and arranging the support insulators. Some power system arrangements are shown in Figure 2-10.

The sectionalization of precipitators is very important. First, if the precipitator is sparking, less of the precipitator is disabled during the spark interval if the system is highly sectionalized. Higher average voltage and higher electric field levels are maintained, and precipitator efficiency is not reduced. Also, the smaller electrical sets have higher internal impedances, which facilitate spark quenching and minimize the tendency of a spark to arc. Smaller precipitator sections localize the effects of electrode misalignment and permit higher voltages in the remaining sections. Finally, with adequate sectionalization in very large precipitators, reasonably good collection efficiencies can be maintained if a section must be deenergized because of wire breakage or other electrical trouble. All new ESP's are designed so that if one field shorts out, the overall ESP efficiency will not fall below specifications.

2.5.6 Rappers

Rapping systems are incorporated in an ESP to dislodge dust from the collecting and discharge surfaces; their effectiveness and reliability are essential. Generally available types of rappers are pneumatic or electromagnetic impulse units, electric vibrators, and mechanical hammers.

Rapper systems are designed to be compatible with the internal suspension system and the number of surfaces affected by the rapping shock. Pneumatic rappers supply the most shock and dislodge tenacious dusts most readily. It is important in any

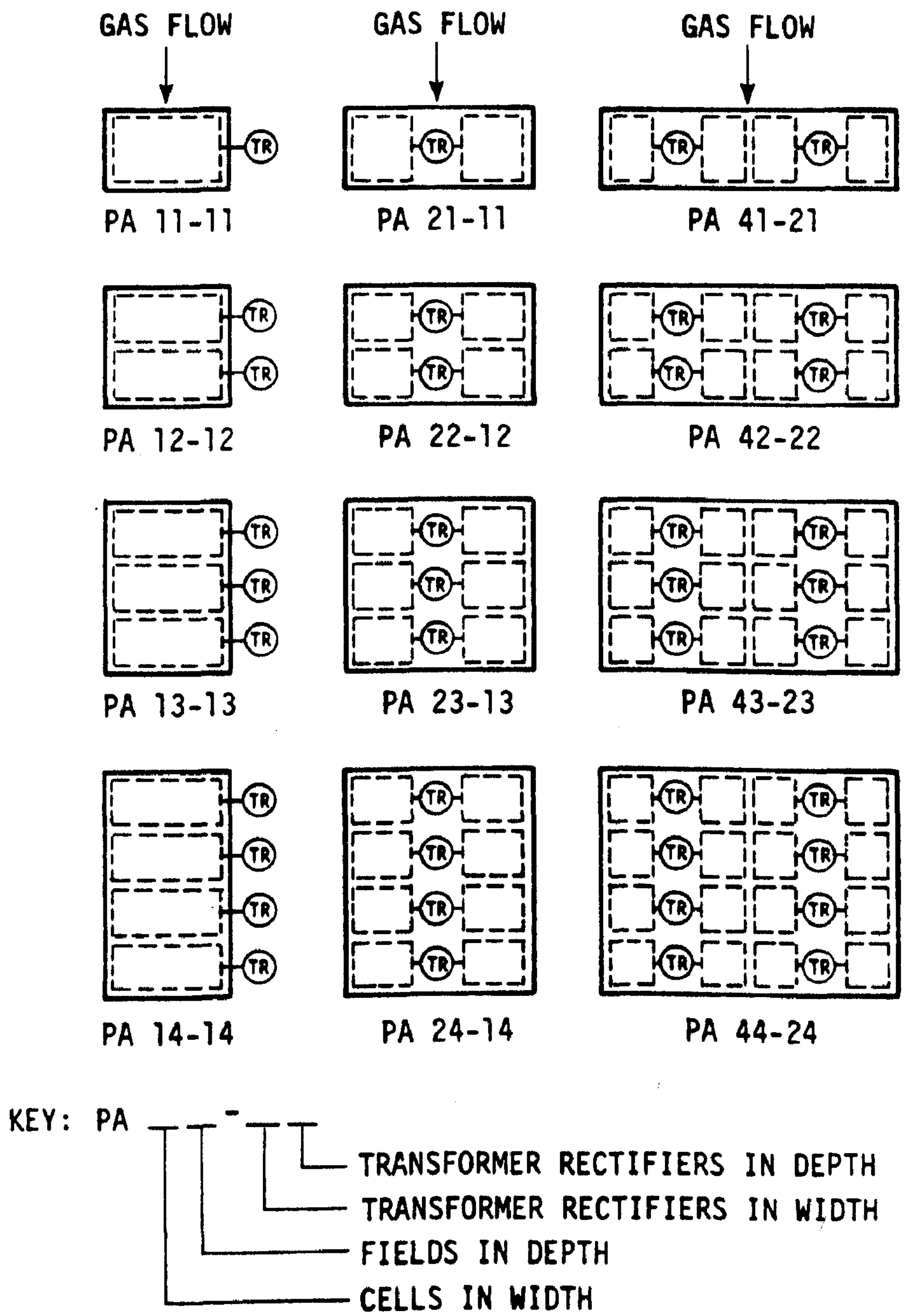


Figure 2-10. Various combinations of electrical sectionalization in an ESP.[12]

rapper system that all hardware is designed to withstand high energy forces.

Pneumatically or electromagnetically operated rappers may be of the impact of vibratory type. The impact type rapper functions by lifting a weight to a controlled height and then allowing it to fall against an anvil, which transmits the shock to the discharge and collection surfaces. Vibratory rappers impart vibrations to the discharge and collecting surfaces by means of rods extending through the precipitator shell.

Rapping hammers, which are used with rigid discharge electrode ESP's, remove dust very efficiently, but when installed in a moving gas stream may require frequent maintenance. One type of tumbling hammer design is illustrated in Figure 2-11.

The number and size of rappers and rapping frequencies vary with the manufacturer and the nature of the dust. Generally one rapper unit is required for 110 to 150 m^2 (1200 to 1600 ft^2) of collecting area. Discharge electrode rappers serve from 350 to 2000 m (1000 to 7000 ft) of wire per rapper. Intensity of rapping intervals are adjustable over a range of approximately 30 to 600 seconds.

The paramount consideration in rapping is to provide acceleration to dislodge the dust without causing excessive reentrainment. Operation of rappers is discussed further in Section 3.1.

2.5.7 Gas Flow Distribution

Proper gas flow distribution is critical for optimum precipitator performance. The plant flue system and its connections to the ESP are more important than the precipitator itself in determining the quality of gas flow through the precipitator. A set of guide vanes, which is the most common device used to direct gas flow, allows a streamlined flow of gas. Figure 2-12 illustrates how guide vanes prevent flow separation.

Diffusion screens and baffles are also used to reduce turbulence and maintain uniform gas flow. A diffuser consists of a woven screen or a thin plate with a regular pattern of small

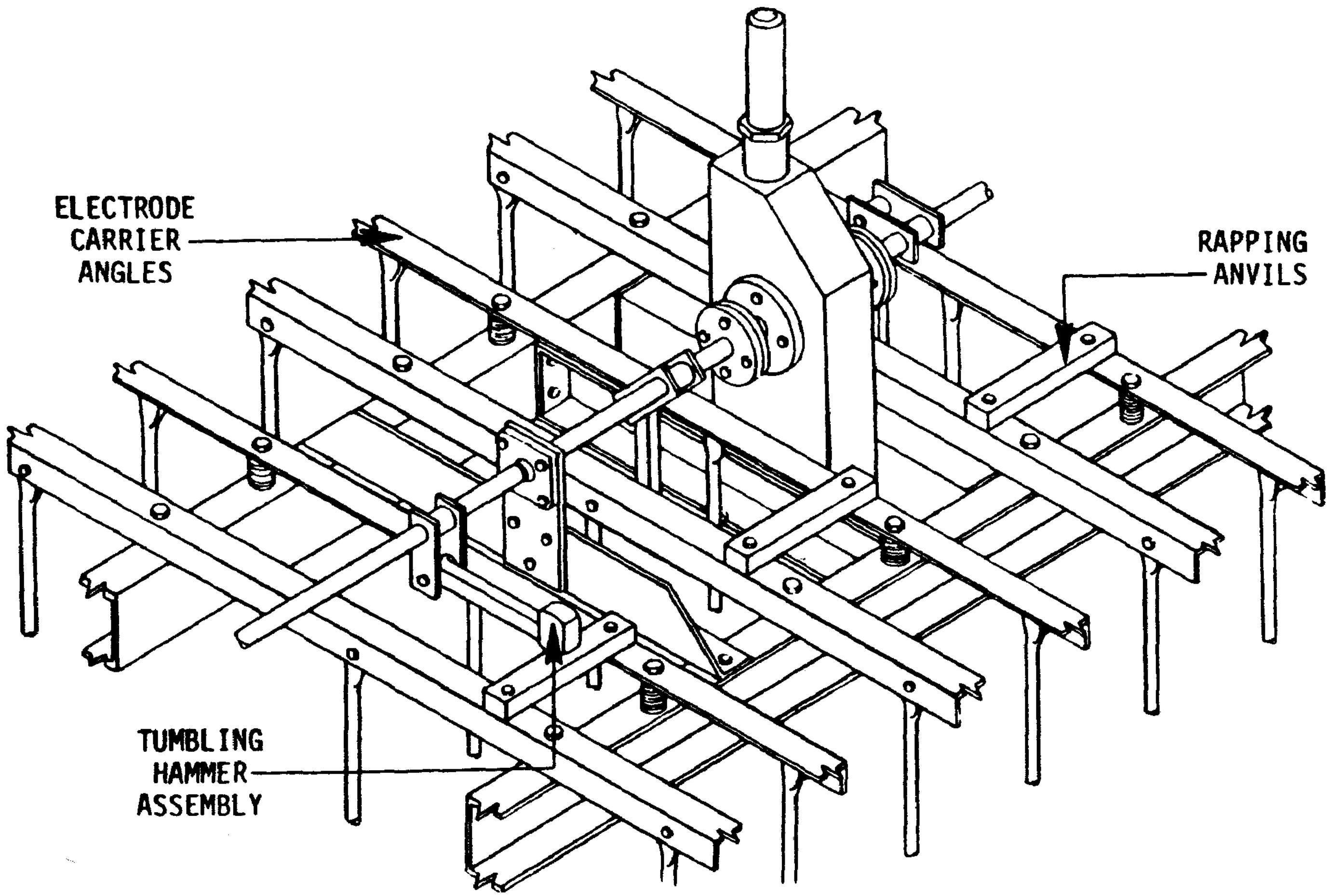
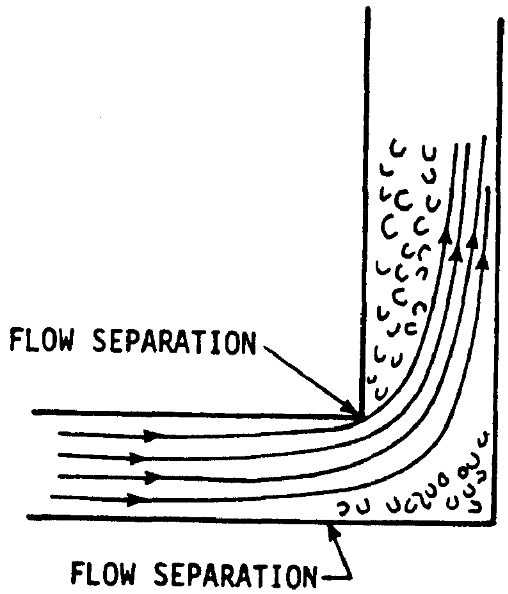


Figure 2-11. Tumbling hammer assembly for use with rigid discharge electrode system.[13]



FLOW CONFIGURATION WITHOUT GUIDE VANES

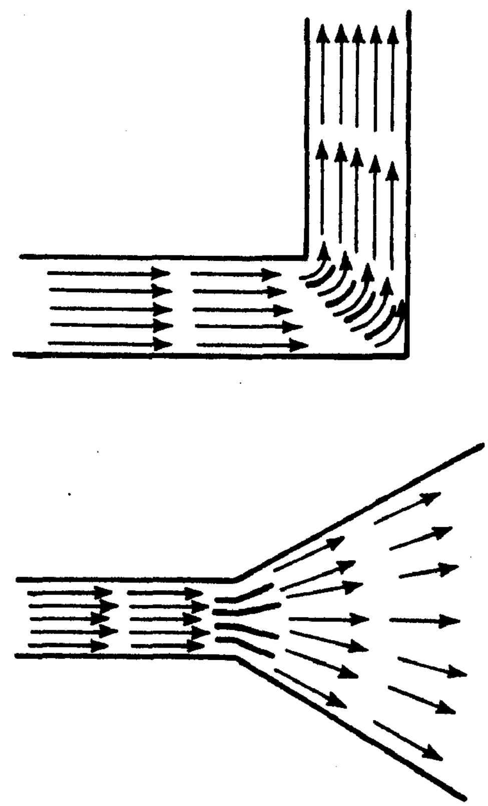


Figure 2-12. Action of guide vanes in preventing gas flow separation at flue turn and at flue expansion.[6]

openings. The effect of a diffuser is to break large-scale turbulence into a large number of small-scale turbulent zones, which in turn decay rapidly and in a short distance coalesce into a relatively low-intensity turbulent flow field.[6] Two or three diffusers may be used in series to provide better flow than could be achieved with only one diffusion plate[6] (see Figure 2-13).

2.6 METHODS FOR SIZING OF ESP SYSTEMS

Methods in current use for sizing electrostatic precipitators include design by analogy to similar installations and by theoretical application of fundamental preciptitation principles. Design by analogy is most reliable for industrial process ESP installations where few process variabilities influence the collection conditions. This method cannot be applied to sizing of ESP's for the collection of fly ash emitted from coal-fired sources, primarily because of the wide range of coals, boilers, and operational methods.

The first equation for predicting particle collection probability was developed by Anderson in 1919. It was derived again by Deutsch, who used a different method, in 1922. In various forms, this equation, $n = 1-e^{-(Aw/v)}$, has become the basis for estimating precipitator efficiency on the basis of gas flow, precipitator size, and precipitation rate parameter. In this equation, n is the precipitator collection efficiency, A is the total collecting electrode surface area, V is the gas flow rate, and w is the migration velocity of the particles. When determined empirically, the precipitation rate parameter, w, includes effects of rapping losses, gas flow distribution, and particle size distribution.

The Deutsch-Anderson model assumes that particulate concentration is uniform in any cross section perpendicular to the gas flow of an ESP. This assumption is made because of the turbulence of the gas, which takes the particles near the collection surface and allows them to become electrically charged. A

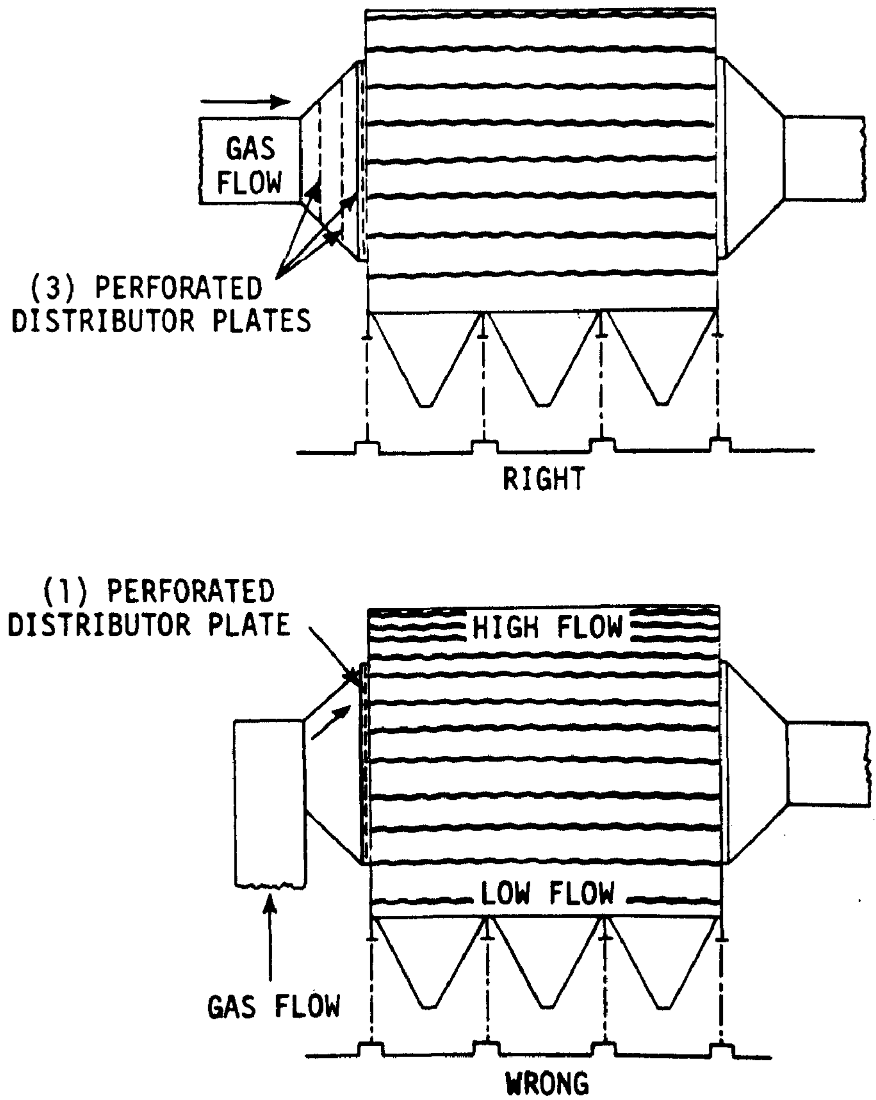


Figure 2-13. Effect of two different methods of gas distribution on flue characteristics in an ESP.[7]

serious limitation in use of the Deutsch-Anderson equation is that it does not account for changes in the particle size distribution and subsequently the effective migration velocity as precipitation proceeds. This limitation affects the accuracy of sizing estimates for units operating at very high efficiencies (approximately 98% and above because of the change in w with particle size.

In practice, factors such as particle reentrainment and gas leakage cannot be accounted for theoretically. In addition, some of the most important physical and chemical properties of the particles and gases often are not known. Therefore, most designers use an effective precipitation rate parameter, w_e, that is based mainly on field experience rather than theory.[8] Data from operating installations form a general basis for selection of w_e, and these data are modified to fit the particular situation being evaluated. Thus, w_e becomes a semiempirical parameter that can be used in the Deutsch-Anderson equation or its derivatives to estimate the collection area required for a given efficiency and gas flow. The most important parameters that determine w_e in practice are resistivity, particle size distribution, gas velocity distribution through the ESP, particle loss due to reentrainment, rapping and gas sneakage, ESP electrical conditions, and required efficiency.[8]

A semiempirical modification of the Deutsch-Anderson equation that essentially removes the size dependency from w was developed by Matts and Öhnfeldt. This equation is $n = 1-e^{-w_k (A/V)^k}$ In most cases, k equals approximately 0.5. The modified migration velocity, w_k, can be treated as being independent of charging voltage and current levels and of particle size distribution within an ESP, as precipitation proceeds in the direction of gas flow. Other changes, however, such as in properties of the gas entering the ESP, resistivity, and size distribution, produce a change in w_k just as they change the conventional w.

Another design technique applied to existing installations or new processes to aid in a full-scale design is the pilot-scale precipitator. The use of analog methods for the investigation of gas flow and precipitation rate may be advisable in view of the complexity of the phenomena and the asymmetry of many gas-flow systems. Theoretical calculations have various limitations. The general principles of fluid mechanics and similitude may be applied to yield useful results by using laboratory size models. Flow patterns can be readily determined by the use of micro-pitot tubes and various types of electrical anemometers. Pilot models enable the use of smoke and several other techniques for flow pattern determination.[9] The main problem with use of a pilot-scale ESP is that the pilot unit almost always performs better than a full-scale unit.[3,8] This can be attributed to better gas flow distribution, sectionalization, and electrode alignment.[3] The result is operation at higher current densities and voltages than in a full-scale unit. Application of a scale-up factor, as in spark-limited operation of a pilot-scale ESP, can cause uncertainties in sizing the full-scale ESP. Therefore, pilot precipitator data should be supplemented as fully as possible by basic data on particle and gas properties, especially resistivity.[4]

Combustors are also used in conjunction with pilot scale ESP's for design purposes. Use of combustors can allow development of design data without transporting tons of coal to a power plant for use in pilot-scale precipitators. Information gained from operation of combustor-precipitator combinations is usually qualitative, and much additional information is needed for application of the data to full-scale precipitator design.[8]

Precipitator designers also make use of laboratory-scale gas-flow models, which are very important to proper operation of a full-scale ESP. Modeling techniques are well documented, and close correlation of gas flow performance in laboratory models and field installations is often achieved.[8]

The Industrial Environmental Research Laboratory (IERL) of U.S. EPA has done significant work in the area of pilot particulate collection systems. Pilot-scale versions of conventional control devices such as electrostatic precipitators, fabric filters, and wet scrubbers are mounted in mobile vans and carried to various test sites.

The mobile ESP facility is designed for the purpose of experimentally determining the effects of dust properties, rapping, dust resistivity, and conditioning agents on electrostatic precipitation performance. Precipitation studies can be conducted as gas flows up to 300 acfm and at gas temperatures up to 540°C (1000°F). Experimental pilot results are able to be reduced and compared to full scale performance results. Further analysis is available through use of the IERL-developed ESP performance computer model.

Pilot ESP performance results have been reported on several utility boiler studies, including: 1) hot-side precipitation, 2) sodium carbonate conditioning, 3) waste-as-fuel co-firing, 4) comparison between conventional and pre-charger ESP performance, and 5) atmospheric-ESP control of pressurized fluidized-bed-combustion emissions. Actual experience from operating, maintaining, troubleshooting, and upgrading the mobile ESP has been obtained from these test programs and incorporated into several sections of this report. The number and variety of applications, "trial and error" experiences, along with technical guidance from IERL staff, sponsored contractors, and several conferences comprise the practical and technical basis for some of the information shared in this report.

2.7 DESIGN AND SIZING PARAMETERS

Table 2-2 summarizes ranges of values for important basic design parameters that are discussed in this section. Additional factors that should be considered in precipitator design specifications and evaluations are summarized in Table 2-3. The three

TABLE 2-2. RANGE OF BASIC DESIGN PARAMETERS IN OPERATING FLY-ASH PRECIPITATORS[8]

Parameter	Range of values
Plate spacing	20 - 30.5 cm
Precipitation rate parameter for Deutsch-Anderson equation (w_e)	0.015 - 0.18 m/sec
Collection surface	18 - 145 m^2/m^3/sec
Gas velocity	1.2 - 2.4 m/sec
Aspect ratio $\frac{\text{(length of plate)}}{\text{(height of plate)}}$	0.5 - 1.5
Corona power	30 - 300 watts/1000 m^3/sec
Corona current density	5 - 75 nanoamps/m^2
Plate area per electrical set	450 - 7400 m^2
No. of high-tension sections in the direction of gas flow	2 - 8
Degree of sectionalization	0.25 - 2.5 $\frac{\text{high-tension bus sections}}{100{,}000\ m^3/\text{sec}}$

TABLE 2-3. DESIGN FACTORS FOR PRECIPITATOR SPECIFICATION AND EVALUATION[8]

1. Corona electrodes: type and method of supporting.

2. Collecting electrodes: type, size, mounting, mechanical, and aerodynamic properties.

3. Rectifier sets: ratings, automatic control system, number, instrumentation, and monitoring provisions.

4. Rappers for corona and collecting electrodes: type, size, range of frequency and intensity settings, number, and arrangement.

5. Hoppers: geometry, size, storage capacity for collected dust, number, and location.

6. Hopper dust removal system: type, capacity, protection against air inleakage, and dust blow-back.

7. Heat insulation of shell and hoppers, and precipitator roof protection against weather.

8. Access doors to precipitator for ease of internal inspection and repair.

9. Provisions for obtaining uniform, low-turbulence gas flow through precipitator. This will usually require a high-quality gas flow model study made by experienced people in accord with generally accepted techniques, with full report to precipitator purchaser before field construction.

10. Quality of field construction of precipitator, including adherence to electrode spacing and rigidity requirements.

11. Warranties: performance guarantees, payment schedules, adequate time allowance for performance tests, penalties for nonperformance.

12. Support insulators for high-tension frames: type, number, reliability. Air venting, if required.

13. Inlet and outlet gas duct arrangements.

14. Structure and foundation requirements.

most important parameters that affect the size of an ESP are collection area, gas velocity, and aspect ratio.

2.7.1 Collection Area

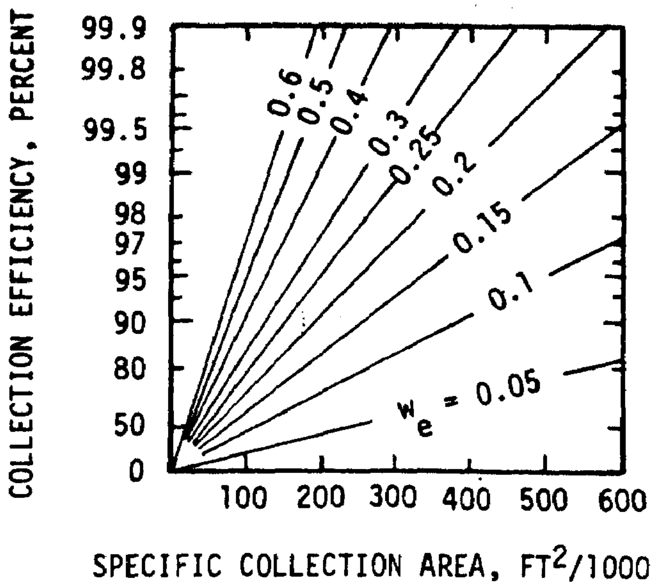
Some variation of the Deutsch-Anderson equation is generally used to estimate the required collection plate area. Figures 2-14 and 2-15 present the relationships of specific collecting areas (SCA's) developed with the Deutsch-Anderson w_e and Matts Öhnfeldt w_k, respectively.

2.7.2 Gas Velocity

Designers calculate an average (superficial) value for gas velocity from gas flow and cross sectional area of the precipitator, independent of the localized variances within the precipitator. The primary importance of the superficial gas velocity is to indicate the average velocity level and to subsequently calculate the average residence time. Above some critical velocity (~2 m/sec) rapping and reentrainment 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. Values for gas velocity in fly ash precipitators range from 0.9 to 1.2 m/s (3.0 to 4.0 ft/s) in high-resistivity, cold-side ESP applications, and in all low-resistivity applications (hot or cold side). For most other applications, the values range from 0.9 to 1.7 m/s (3.0 to 5.5 ft/s).

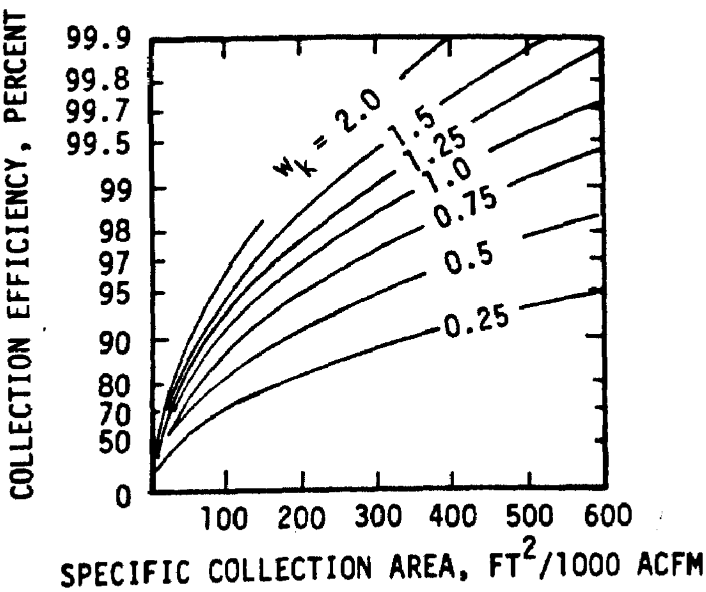
2.7.3 Aspect Ratio

Aspect ratio is defined as the ratio of the length to the height of gas passage. Although space limitations ofter determine precipitator dimensions, the aspect ratio should be high enough so that the reentrained dust carried forward from inlet and middle sections can be collected. In practice, aspect ratios range from 0.6 to 1.5. For efficiencies of 99 percent or higher, the aspect ratio should be at least 1.0 to 1.5 to minimize carry-over of collected dust.



METRIC CONVERSION: FT^2/1000 ACFM x .055 = $m^2/1000\ m^3$/sec

Figure 2-14. Precipitator efficiency versus specific collection area and precipitation rate w_e.[8]



METRIC CONVERSION: FT^2/1000 ACFM x .055 = $m^2/1000\ m^3$/sec

Figure 2-15. Precipitator efficiency as a function of specific collection area and modified precipitation rate parameter w_k.[8]

2.8 ELECTRICAL ENERGIZATION

The way in which a precipitator is energized has a strong effect on its performance. Electrical energization involves the number and size of the transformer-rectifier (T-R) sets, number of electrical sections in half wave/full wave (HW-FW) operation, and changes in the voltage current characteristics as precipitation proceeds in the direction of gas flow.

Corona power is another important design factor, along with being a quantitative indicator of collection performance on an operating ESP (see Section 6 for use in ESP performance evaluations). Corona power is a measure of the presence and intensity of the electrical energy (driving force) used in the precipitation process. The extent of corona power used in precipitation is measured by the primary or secondary voltage and current meters. A technological basis is substantiated in Section 6 which correlates ESP corona power with particulate emission level.[1] Although factors other than corona power are responsible for determining the performance level (e.g., electrode alignment, rapper operation and sequence, etc.), the influence of these degradation factors is reflected by corona power levels. When problems with electrode alignment or rapper operation arise, they evidence themselves by reducing the operating voltage and current levels of the fields affected. Conversely high corona power levels can compensate for some design short comings. Since corona power is the product of voltage and current, reduced operating voltage and current levels produce reduced corona power levels proportional to their products.

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SECTION 3

INSTRUMENTATION AND RECORDS

The continued optimum performance of an ESP depends upon effective control of operating parameters, which can vary because of the physical characteristics of an ESP or changes in characteristics of the flue gas being treated. Recent ESP installations are generally equipped with instrumentation for monitoring and recording the major operating parameters. ESP instrumentation and records of electrical operating levels are the major indicators of ESP performance; the inspector should thoroughly understand the function of each instrument and record to evaluate ESP performance.

3.1 ESP INSTRUMENTATION-LOCATION AND GENERAL DESCRIPTION

ESP instrumentation consists mainly of monitors for power input, gas flow, rapper intensity, and hopper dust levels. The power input parameters are precipitator current, voltage, and spark rate. Gas flow parameters are the input gas flow rate and input gas temperature.

The ESP instruments are generally located in close vicinity of the ESP unit; when a plant has more than one ESP, a centrally located control room houses the instrumentation for all the ESP units. The location of the ESP control room depends upon the availability of space at the plant; however, it is generally located close to ESP units. Two common control room locations are: on top of the ESP units and directly under the ESP unit for an elevated unit. The ESP control room is generally located close to the ESP's and separately from the plant control room to avoid long cable runs from the ESP to the plant control room.

The instruments for each ESP unit are assembled and housed in a simple sheet metal cabinet. A typical ESP control room may consist of a number of control cabinets arranged in a line and each cabinet labeled to identify the ESP unit it serves. A typical ESP control panel and control panel console are shown in Figures 3-1 and 3-2, respectively.

An ESP instrumentation block diagram is shown in Figure 3-3. Figure 3-4 shows the positions of various measuring instruments in an ESP circuit. The ESP in Figure 3-3 has four T-R sets, and each T-R set has two bus sections. Primary voltage and primary current are measured for each T-R set; secondary voltage, secondary current, and spark rate and measured for each bus section. Gas flow rate and temperature are measured at the ESP inlet. An opacity measurement at the ESP outlet roughly indicates emission levels. The ESP shown in Figure 3-3 has four primary voltmeters and four primary ammeters; the secondary side instrumentation consists of eight secondary voltmeters, eight secondary ammeters, and eight spark rate meters. The instrumentation schemes for different ESP installations may vary slightly from the basic scheme shown in Figure 3-3.

The relative location of each instrument in the circuit is decided by its function. The primary ammeter, for example, is always located ahead of the transformer primary in order to indicate the current available for transformation. The inspector should understand the relative positions of various ESP instruments. The function of each ESP instrument is discussed in the following paragraphs.

3.2.1 Primary Instrumentation

Primary Voltmeter--

Energization power for an ESP is supplied at the primary side of the T-R set. The a.c. electrical power is normally

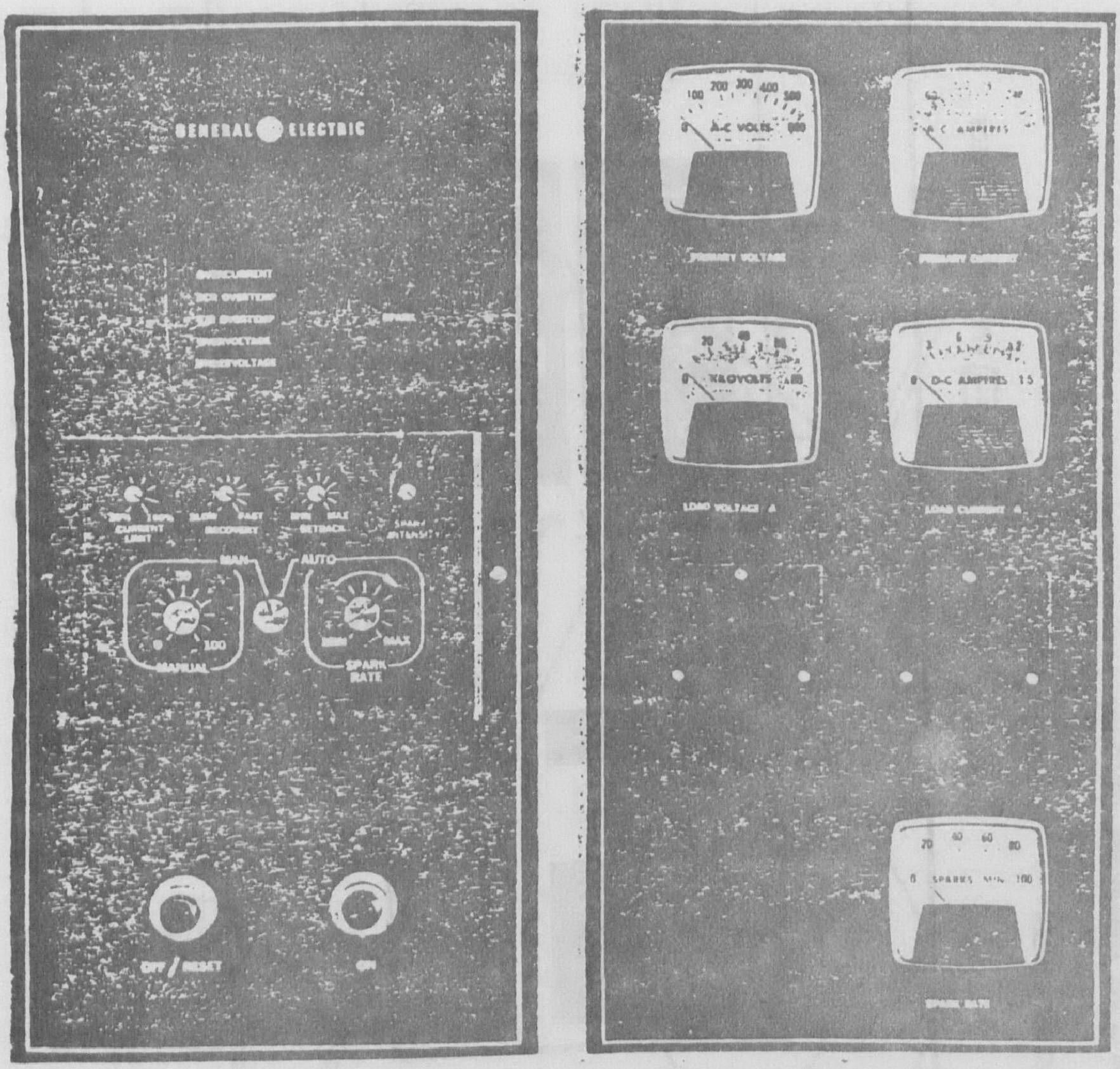

Figure 3-1. Typical ESP control panel.
(Courtesy of Babcock and Wilcox Co.)

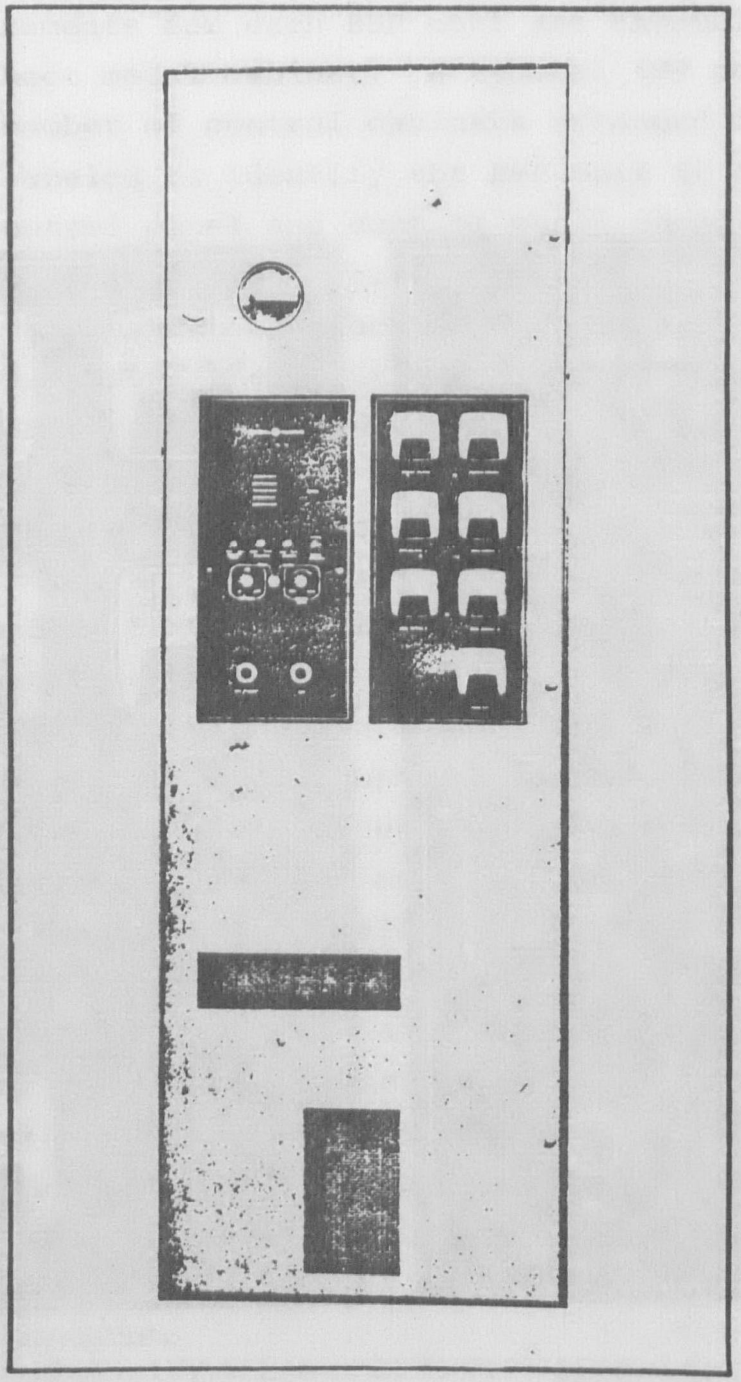

Figure 3-2. Example of ESP control panel console.
(Courtsey of Babcock & Wilcox Company)

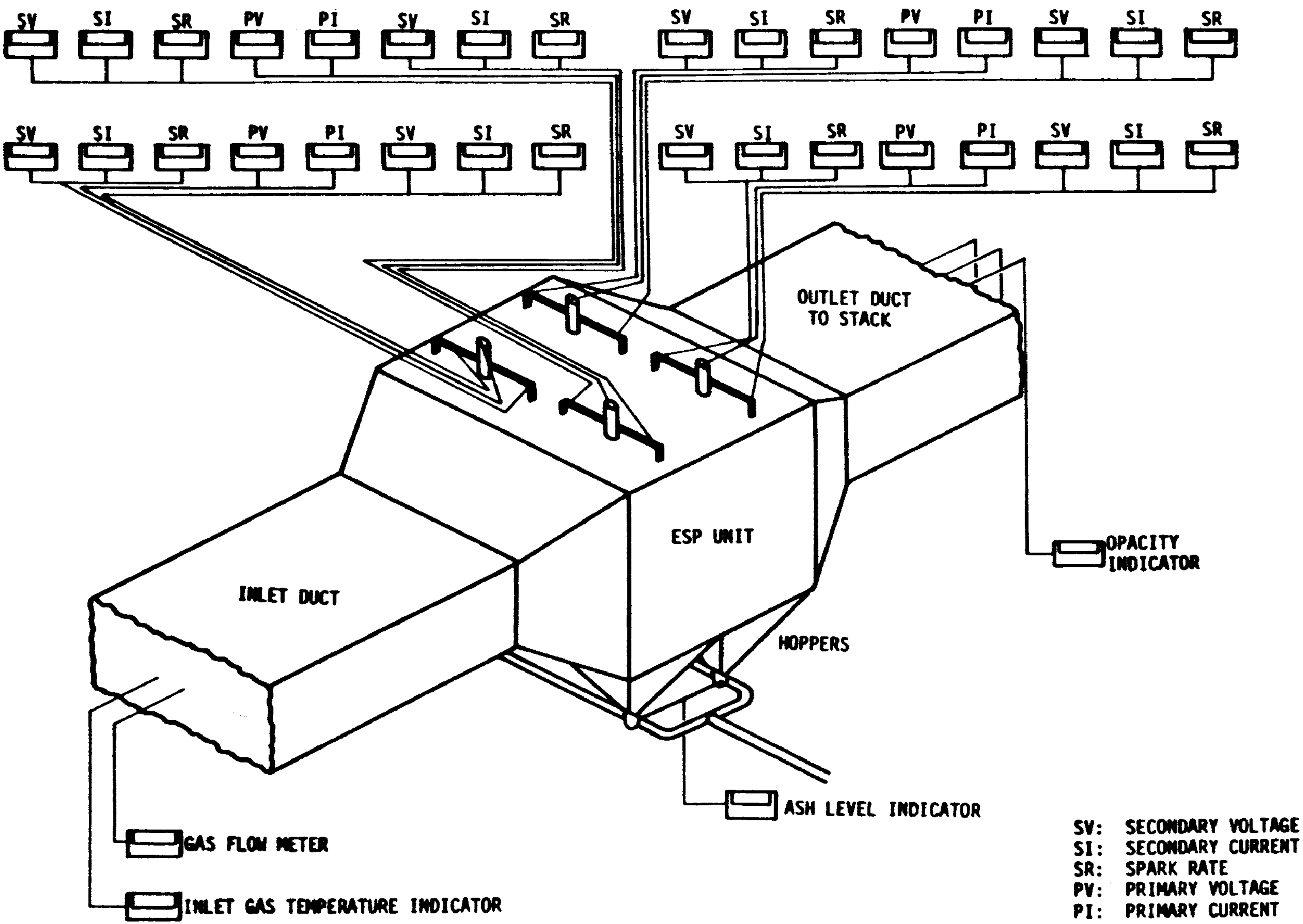

Figure 3-3. ESP Instrumentation diagram.

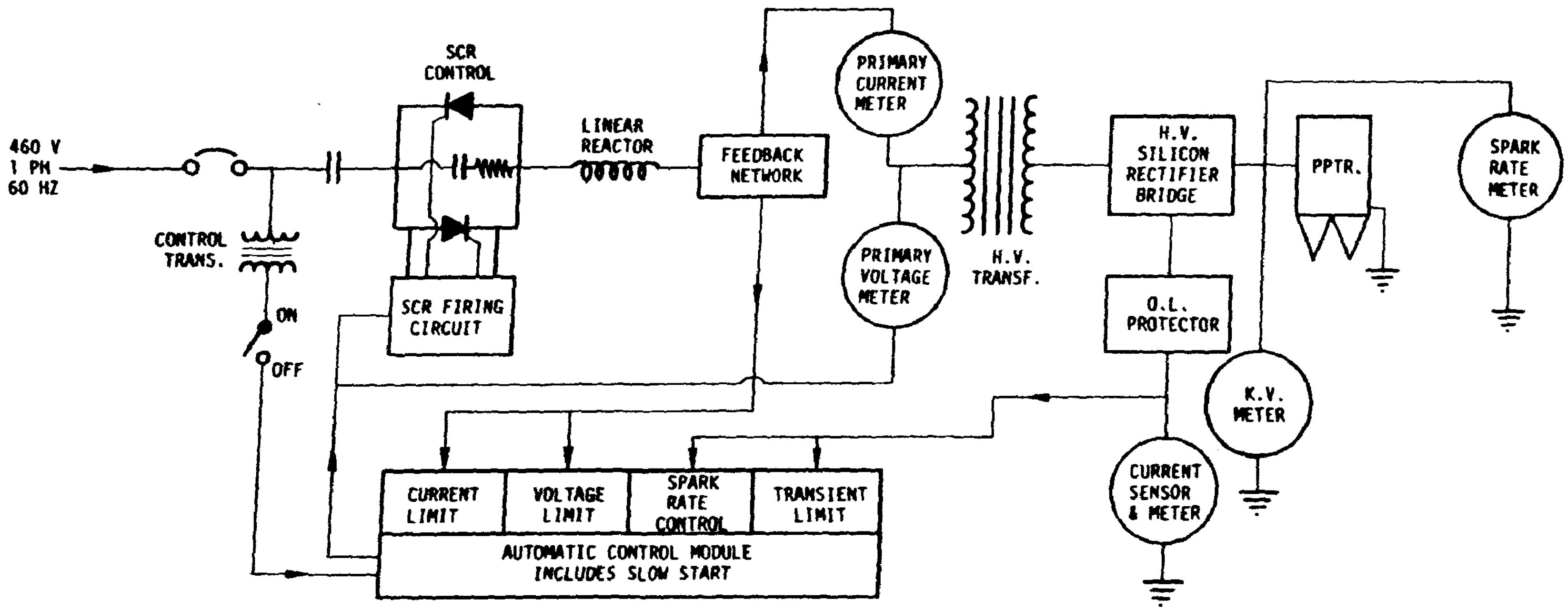

Figure 3-4. Positions of measuring instruments.

supplied at 220 or 460 volts. Each T-R set for an ESP is normally provided with a voltmeter and an ammeter to indicate input voltage and input current.

The range of a voltmeter dial for primary voltage is 0 to 480 volts. Normal operating voltage is around 220 to 460 volts, depending on the selection of supply voltage. A temporary marginal deviation of about 5 percent from the rated supply voltage is common and should not be considered a major operating problem. Generally, a label on the primary voltmeter indicates the maximum permissible voltage reading.

The voltmeter on the primary side is located ahead of the T-R set but after the power control circuit, linear reactor, and feedback network. This positioning of the voltmeter ensures measurement of regulated voltage available at the T-R set for transformation.

An indication of no voltage on the primary side may be due to an open primary circuit. The circuit breaker may be open or tripped, or the reactor secondary may be open. The open circuit breaker can be closed with power on, but replacement of the reactor secondary requires power switchoff and ESP shutdown.

An indication of high voltage on the primary could result from an open transformer primary or improper connection of an ESP. A faulty, open, or disconnected precipitator, an open bus, or a faulty rectifier will cause indication of high primary voltage. An ESP shutdown is mandatory for correcting these faults.

An indication of low voltage on the primary side could result from several conditions such as a leak in the high-voltage insulation, high dust level in hoppers, excessive dust on electrodes, or swinging electrodes. Correction of the fault may require shutdown.

Primary Ammeter--

The ammeter on the primary side indicates the current drawn by the ESP. The current and voltage readings on the primary indicate the power input to a particular section of an ESP.

An ammeter for primary current measurement is located between the T-R set and the power control circuit, linear reactor, and feedback network. Figure 3-4 indicates the location of an ammeter for primary current. Positioning the ammeter between the T-R set and the control circuit ensures measurement of the current available for transformation.

The ammeter is generally labeled to indicate the normal range of primary current. Any deviation from this range indicates abnormal operation of the following ESP section. A reading that shows no primary current associated with no primary voltage indicates an open primary circuit, which may be due to open circuit breakers or an open reactor secondary. Minimal primary current associated with high primary voltage is generally caused by an open transformer primary or open secondary circuit. Precipitator shutdown is mandatory to correct these faults. Indication of low primary current with low primary voltage results from an open d.c. reactor. Again, precipitator shutdown in mandatory.

Irregular primary current coupled with low primary voltage indicates a high resistance short in the circuit. Possible causes are an electrode short with dust in the hopper, excessive dust on collecting surfaces, exccesive dust on electrodes, support insulator arcing, and the presence of foreign materials. A broken swinging electrode causes an intermittent short, which is indicated by low primary voltage and cycling primary current.

3.1.2 Secondary Instrumentation

Instrumentation ont he secondary side of the T-R set indicates the power input parameters to an individual ESP bus section. This instrumentation is of primary importance to the inspector. The secondary instrumentation generally consists of a voltmeter, an ammeter, and a spark rate meter for each bus section. The combination of these meter readings indicates the overall operating conditions on the secondary side of the T-R set.

Secondary Voltmeter--

The secondary voltmeter is calibrated in kilovolts to measure the high voltage of the power input to the discharge electrodes. The secondary voltmeter is labeled to indicate the upper limit and normal range of the operative voltage.

The second voltmeter is located between the rectifier output side and discharge electrodes to indicate the d.c. voltage across the discharge electrodes.

An indication of no voltage on the secondary may be due to an open primary circuit. The circuit breaker may be open or tripped, or a reactor secondary may be open. As indicated earlier, the circuit breaker can be closed with power on, but replacement of a reactor secondary will require power switchoff and ESP shutdown. A faulty, open, or disconnected precipitator, an open bus, or a faulty rectifier will indicate high voltage on the primary side and no voltage on the secondary side. Shutdown of the ESP is mandatory for correcting these faults.

Low voltage on the secondary side coupled with the low voltage on the primary side could result in several operating problems such as those mentioned earlier, a leak in the high-voltage insulation, excessive dust in the hoppers or on electrodes, or swinging electrodes. Correction of the fault may require shutdown.

Secondary Ammeter--

The ammeter on the secondary side indicates the current being supplied to the discharge electrodes. The combination of current and voltage readings on the secondary side indicates the power input to the discharge electrodes. The location of the secondary ammeter is shown in Figure 3-4.

The secondary current is stepped down in the transformer and is measured in milliamperes. The secondary ammeter is therefore calibrated in milliamperes and is labeled to indicate the maximum value and normal range of secondary current. Deviation from the normal operating range indicates improper operating conditions in the precipitator.

A combination of no secondary current with no secondary voltage indicates an open primary circuit. Minimal secondary current associated with high voltage is generally due to an open transformer primary or open secondary circuit. Precipitator shutdown is mandatory to correct these faults. An open d.c. reactor will cause a low current flow and low voltage in the circuit.

As with primary circuitry, irregular secondary current coupled with low secondary voltage indicates a high-resistance short in the circuit; possible causes are the same, usually related to excessive dust, foreign materials, or arcing. Again, a broken swinging electrode causes an intermittent short, indicated by low voltage and cycling current.

Spark Rate Meter--

The spark rate meter on an ESP is a major indicator of its performance. The spark rate meter is generally connected in the secondary circuit; it indicates the number of sparks in the precipitator section and is calibrated in number of electrical sparks per minute.

The number of sparks together with secondary voltage and secondary current give a fair presentation of the ESP operating condition. Theoretically, the power input to a section is maximum when no sparks occur and voltage and currents are at their rated maximum; in actual practice, however, the optimum power input occurs at a preset spark rate. For ESP's on coal-fired utility boilers, the optimum spark rate is around 100 sparks per minute. Optimum spark rate depends on the physical and design characteristics of the ESP.

Because excessive sparking indicates power loss, less power is available for particle charging. A sparking rate below the optimum level indicates a power supply rate below optimum.

3.1.3 External Instrumentation

Certain instruments external to the ESP indicate parameters that relate strongly to ESP operation. These include instruments that measure inlet gas-flow rate, inlet gas temperature, opacity of flue gas at the ESP outlet, hopper ash discharge, and rapping systems.

Inlet Gas Flow and Temperature--

The gas-flow rate and temperature are indicators of ESP loading. Any variations from the normal design ranges will affect ESP performance and should be investigated. At most installations, the gas flow and temperature measurements are taken at the exit of the process unit or boiler. The instruments for recording the flow and temperature are generally located in the main control room. Some installations maintain continuous records of gas flow and temperature.

Opacity at the ESP Outlet--

Federal and state regulations generally regulate the opacity of the flue gases in addition to limiting particulate emissions. The more recent ESP installations are equipped with continuous opacity recorders.

A general configuration of the opacity monitoring system is shown in Figure 3-5. The system includes an opacity detector unit that senses the opacity of the gases passing through the ductwork. This unit includes a light source and a detector, the difference between the amount of light transmitted by the light source and that received by the detector indicates the particulate concentration of the gases. The difference is calibrated as percent by the opacity meter. An opacity reading of zero percent indicates a minimal particulate concentration; an opacity reading of 100 percent indicates a maximum particulate concentration. The variation in opacity gases cannot be solely attributed to the particulate matter; however, it gives a fair indication of particulate concentration.

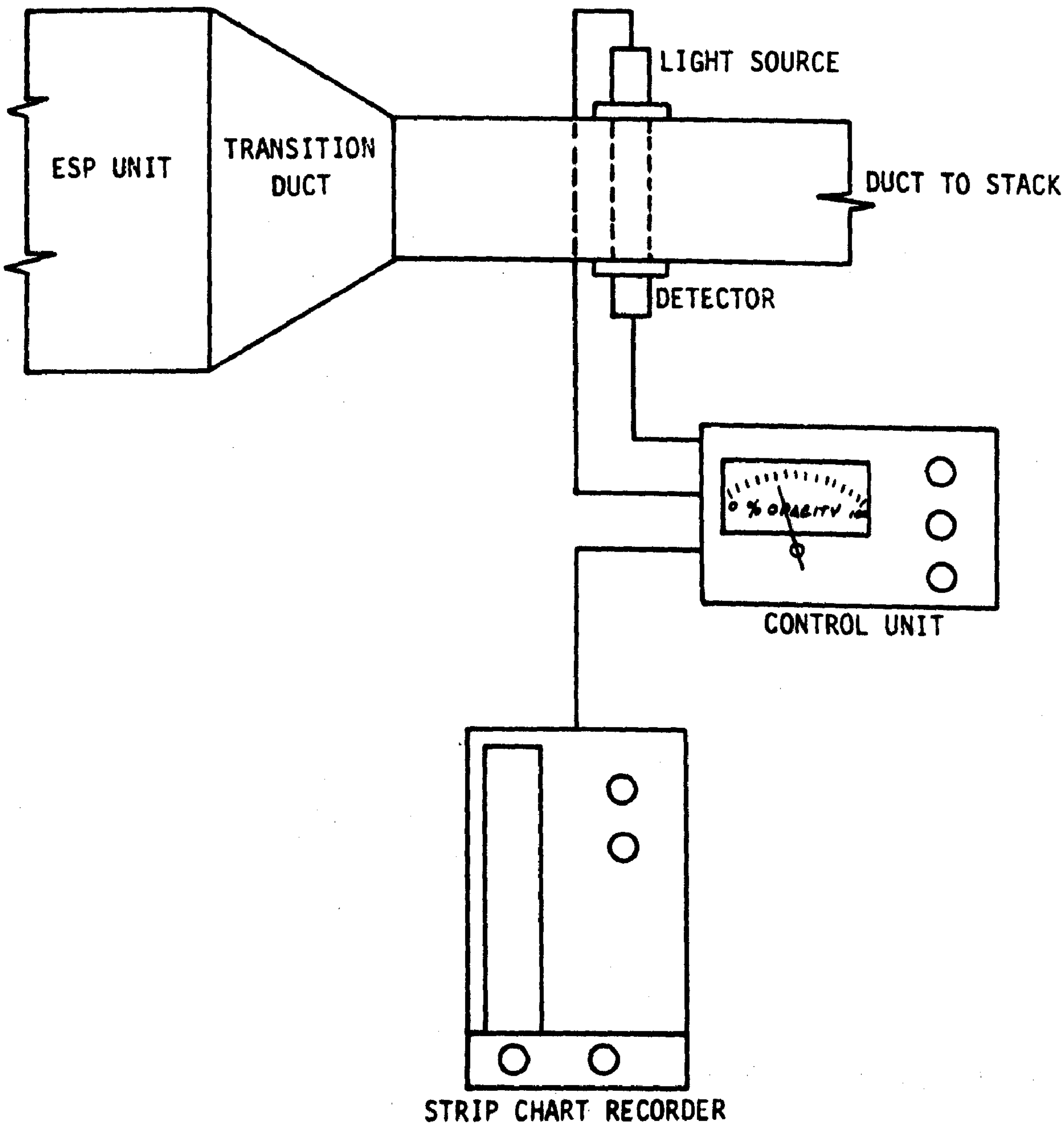

Figure 3-5. Connection diagram of the opacity monitoring system.

Ash Discharge--

Efficient removal of ash from the hoppers is important for proper ESP performance. Ash removal systems at ESP installations are generally equipped with instrumentation that indicates emptying of the hoppers and continuously records the vacuum in the system.

Hopper level alarms are another common and useful type of instrument. Level detectors can utilize gamma radiation, sound capacitance, pressure differential, or temperature. The alarms should be located so that filling of hoppers does not occur but frequent alarms are avoided. A low-temperature probe and alarm can be used in conjunction with the level detector. Control panel lights are used to indicate the operation of hopper heaters and vibrators. Automatic phase-back of T-R sets in conjunction with full hopper level alarms are also incorporated into the instrumentation of some ESP designs.

In general, although various vendors provide different ash discharge systems, the instrumentation and records are similar. Zero motion switches are used on rotary air lock valves to detect malfunction, as well as on screw conveyors. Pressure switches and alarms are normally used with pneumatic dust handling systems to detect operating problems.

Rappers/Vibrators--

Microprocessor type technology is available for a high degree of rapper control flexibility and ease of maintenance. For example, in order to prevent control damage from ground faults, new controls will test each circuit before energizing it. If a ground fault occurs, the control will automatically bypass the grounded circuit and indicate the problem on an LED display, thus permitting fast location and solution of the problem.

Instrumentation should be used in conjunction with a transmissometer to help in troubleshooting ESP problems. Separate rapping instrumentation should be provided for each field.

Readings of frequency, intensity, and cycle time can be used with T-R set controls to properly set rapper frequency and intensity, in the case of the weighted-wire electrodes.

For rigid frame mechanical rappers, cycle time and rap frequency of both internal and external types are easy to measure. Individual operation of internal rappers is not easily instrumented, nor is intensity control possible without a shutdown of the ESP.

3.2 RECORDKEEPING

Recordkeeping of pertinent ESP operating data can be used for:

1. Assurance of proper operating status
2. Diagnostic mean for troubleshooting operational problems
3. An indicator for performance excursion from peak or previously documented performance levels (see Section 6)

Technical engineers for ESP manufacturing and consulting companies customarily use pertinent ESP operating data and specific reference information as feedback on the performance of a precipitator system. Operating data and specific reference information can be interpreted to gain insight into the behavior characteristics of a given ESP unit. ESP behavior is considered to be the electrical operating conditions and associated collection performance levels over the normal range of treatment conditions. In order to interpret the available information, one needs: (1) a general understanding of precipitator technology, (2) familiarity with ESP hardware components, and (3) experience with the normal set of difficulties encountered with conventional precipitators.

The proceeding discussions will identify the tools needed to assess the operational conditions of an ESP. Explanations and examples will be provided to show how these tools (information) can be used (interpreted) to evaluate an ESP system. On-site operators and agency inspectors can readily learn and regularly use this evaluation technique. This technique will provide concerned personnel a reasonable account of the prevailing conditions internal to an ESP. A principal advantage of this technique is that valuable information can be acquired and used without an internal inspection.

3.2.1 ESP Design Specifications

Specifications of the ESP design parameters is the fundamental reference point of any inspection technique. A comprehensive set of ESP design specifications should be provided by the vendor, and if lost, should be requisitioned, copied, filed, and made available to the concerned operating and regulating personnel. A copy of such specifications should be readily available for the ESP operators, inspectors, and/or analysts.

Table 3-1 presents a comprehensive listing of ESP design specifications, organized in three categories: hardware, electrical, and application. The hardware category identifies several mechanical and dimensional characteristics of the ESP system. Corresponding diagrams depicting the layout of the influent and effluent gas manifolding, and the internal chambering should be included with the specifications. These diagrams will provide a useful perspective for the operating staff in understanding the general layout and associated nomenclature of the system. The tabulated specifications will facilitate subsequent troubleshooting and performance analysis over the years of service. The listed electrical specifications include general and specific indicators of voltage and current at both primary and secondary (if available) levels. These design values should be frequently referenced to actual operating electrical data throughout the service life of the equipment. If the electrical

TABLE 3-1. ESP DESIGN SPECIFICATIONS FOR WHICH RECORDS SHOULD BE MAINTAINED

A.	Hardware Specifications
	Manufacturer
	Model
	Year installed
	Collection plate area (total)
	Number of chambers
	Number of fields
	Plate spacing
	Plate height
	Plate width
	Number of lanes/section
	Cross-sectional area/section
	Linear feet of discharge wire
	Rapper type, plate
	Rapper type, wires
	Rapper acceleration, plate
	Rapper acceleration, wires
B.	Electrical Specifications
	Corona power total
	Corona power per unit volume of gas
	Number of T-R sets
	Rating(s) of T-R set
	Average primary voltage
	Average primary current
	Average secondary voltage
	Average secondary current
	Average current density per plate area*
	Average current density per electrode length*
C.	Application Specification
	Gas flowrate, total
	Gas temperature, inlet
	Gas temperature, outlet
	Gas composition (N_2, O_2, SO_x, etc.)
	Gas velocity, superficial*
	Gas velocity, distribution, Standard Deviation
	Specific collection area*
	Collection efficiency
	Particulate concentration, inlet
	Particulate concentration, outlet
	Particle size distribution, inlet
	Particle size distribution, outlet
	Precipitation rate parameter* (particle migration velocity)
	Resistivity value (or range)

* Parameters that can be calculated from other given values.

equipment is replaced, or internal changes or upgrades are made, then corresponding adjustments in the electrical specification package should be entered. The specifications defining the application of this mechanical and electrical hardware includes the important gas and particulate characteristics. The design or expected application parameters should be likewise referenced to measured data.

The hardware and electrical specification packages should and probably will be well-defined. These two design areas represent the technical areas that manufacturing companies are most familiar with, and mainly responsible for. The application details represent an interface area in which both the manufacturing and operating companies participate. This area is probably the most vulnerable area of the three categories, due to possible problems from (1) the extent of technical qualities of each the buyer and seller, (2) the extent of technical cooperation between the buyer/seller, and (3) the extent of technical stability between the initial gas/particulate specification provided and the actual experienced gas/particulate stream. This technique is not offered to replace regularly scheduled internal inspections. Instead, it is offered to discover important symptoms when an ESP is on-line. Furthermore, proper recordkeeping and use of this technique will streamline and prevent unnecessary internal inspections.

3.2.2 ESP Operating Data Recordkeeping

Table 3-2 presents a listing of process and ESP conditions that will provide useful and meaningful information. Compilation of this information on a regular basis will supply an account and history of the operational and performance levels.

The significant descriptors of the process generating the gas particulate stream to the ESP should be identified and logged. It is fundamentally understood that the process characteristics

TABLE 3-2. BASELINE TEST INFORMATION

A. Process Conditions

Gas flowrate
Gas temperature - point A, B, C, etc.
Static pressure
Process level (load, % capacity)
Process feed rate(s)
Process feed descriptor(s)
Process product level(s)
Process product descriptor(s)

B. ESP Operating Conditions

Gas temperature, ESP inlet(s)
Gas temperature, ESP outlet(s)
Primary voltage
Primary current
Secondary voltage
Secondary current
Spark rate

(Primary voltage, primary current, secondary voltage, secondary current: per T-R set for each field)

Rapper frequency, plate
Rapper frequency, wire
Rapper duration, plate
Rapper duration, wire

(Rapper items: per field for each T-R set) impact the design, operating, and performance levels of the ESP. In order to establish a relationship between process and ESP conditions, corresponding records of the significant descriptors must be acquired, tabulated, and organized.

All the significant input and output ratings of the process should be recorded. Qualification of feed materials and/or fuels should be noted, including feed rates, temperatures, pressure, moisture content, and analytical results. Any irregularities concerning these qualifiers should be noted. Additionally, similar treatment should be afforded to noting and qualifying the different outputs or products for the process. An abbreviated record can be created, or a copy of the comprehensive operator's log sheet can be duplicated, to regularly account for the process.

Most processes ential some form of treatment on the gas/particulate stream between the primary process and the ESP systems. This intermediate treatment step varies for the different industrial streams controlled by an ESP, but typically is dedicated to recover viable energy, products, or by-products. Certain process designs include a subsystem dedicated to prepare or condition the process stream for the purpose of improving ESP collection performance. Appropriate qualifications of any changes on the gas/particulate stream should be likewise monitored and recorded. Pertinent changes include physical or chamical adjustments to the stream, regarding energy/material additions or deletions. Records accounting for the intermediate treatment system should be maintained to describe the prevailing conditions and materials input/output.

Primary meters indicate voltage and current levels fed to the T-R sets. The purpose of secondary meters is to measure the voltage and current levels leaving the T-R set, enroute to the internal fields of the ESP. Primary metering is only an <u>indirect</u> measure of the high-voltage power necessary to energize to energize an ESP. Secondary metering is the <u>direct</u> method of measuring the delivered high voltage power.

3.2.3 ESP Operating Conditions

The significant descriptors of the ESP system need to be measured and recorded in order to account for its operationality and associated performance. Since it is an electrostatic device designed to effectively use high voltage levels to charge and precipitate entrained particles, it is necessary that the voltage and current levels be measured and recorded. It is important for inspectors to realize that the primary and/or secondary electrical data are the vital parameters of an ESP. Without exception, all technical engineers of ESP manufacturing and consulting companies realize the cruciality of delivering high voltage power to the internal electrodes. Failure to deliver high voltage power to the electrodes transforms a would-be electrostatic precipitator into a chemical collector. Primary electrical meters are useful instruments to meter the electrical circuitry of an ESP. However, secondary electrical meters are more useful, since they directly indicate the voltage and current levels experienced by the precipitating components.

Unfortunately, there is not a linear relationship (or constant coefficient) between primary and secondary electrical levels.

Obtaining voltage-current data over the electrical operating range of each T-R set is a very useful method for evaluating and/or troubleshooting an ESP. The relationship of the voltages applied...and the resultant currents may be analyzed and, coupled with knowledge of other relevent parameters, gives insight into the operation and expected performance of the precipitator.[9] Data are taken as the manual set control is gradually increased until some current flow is detected. This is recorded as the corona starting voltage. Subsequent points are taken by increasing the control for some increment of current and recording the meter readings at that point. Readings are taken until some limiting factor is reached. This factor is recorded on the right-hand side of the data sheet and is usually excessive sparking, or a current or voltage limitation of the power set. Figure 3-6 is an example of a data sheet used to collect data from which voltage-current relationships may be plotted.[9] The term "V-I curve" will be used subsequently to signify the voltage-current relationship discussed above.

3.2.4 Ideal V-I Patterns

For a multi-field ESP, the assembly of on-line V-I curves should look like the pattern shown in Figure 3-7. Note the inlet field V-I curve is on the far right, and the middle and outlet field curves are progressively shifted to the left, respectively. As the caption in Figure 3-7 states, this gradual shifting is due to space charge effects. The space charge effect diminishes as the particulate concentration diminishes and the gas stream passes through the series of energized fields.

The relative slope of the on-line V-I curve is dependent on several factors, one of which is particulate flux. Particulate flux is the combined product of particulate loading and gas flowrate; an increase in either component will proportionally increase the particulate flux level. Figure 3-8 illustrates the principle of various levels of particulate flux from a theoretical approach. The uppermost left curve represents the expected V-I curve with no particulate flux. The remainder of the V-I curves represent various levels of particulate flux for different gas flow levels (numbers represent SCA levels with SCA values inversely proportional to gas flow levels) and for inlet and outlet fields, respectively. As particulate flux levels increase, the V-I curves progressively shift to the right. For the same gas composition and voltage, increasing levels of particulate loading (especially in the fine particle size range) will reduce or suppress current levels. Charged particles migrate orders of magnitude slower than the rest of the charge carriers (i.e., free electrons and ionized gas molecules). As more charge or current is carried by the relatively slow migrating particles, the slower the overall current-carrying process proceeds, and

POWER SET
VOLTAGE-CURRENT CURVE DATA SHEET
DATE/TIME________ T/R SET NO. _____ COLLECTING AREA _____
VOLTAGE DIV. MULT.
T/R SET DCMA CORRECTION

PRIMARY VOLTS	PRIMARY AMPS	DCKV T/R SET METER	DCMA T/R SET METER	SPARK RATE	DCMA CORR.	VOLTAGE DIV.	DCKV CORR.	$\mu A/f^2$	NA/cm^2	TERMINAL POINT DETERMINED BY: (CIRCLE ONE)
										L. SPARKING 2. SEC. CURRENT LIMIT 3. SEC. VOLTAGE LIMIT 4. OTHER __________ COMMENTS

Figure 3-6. Sample V-I curve data sheet.[9]

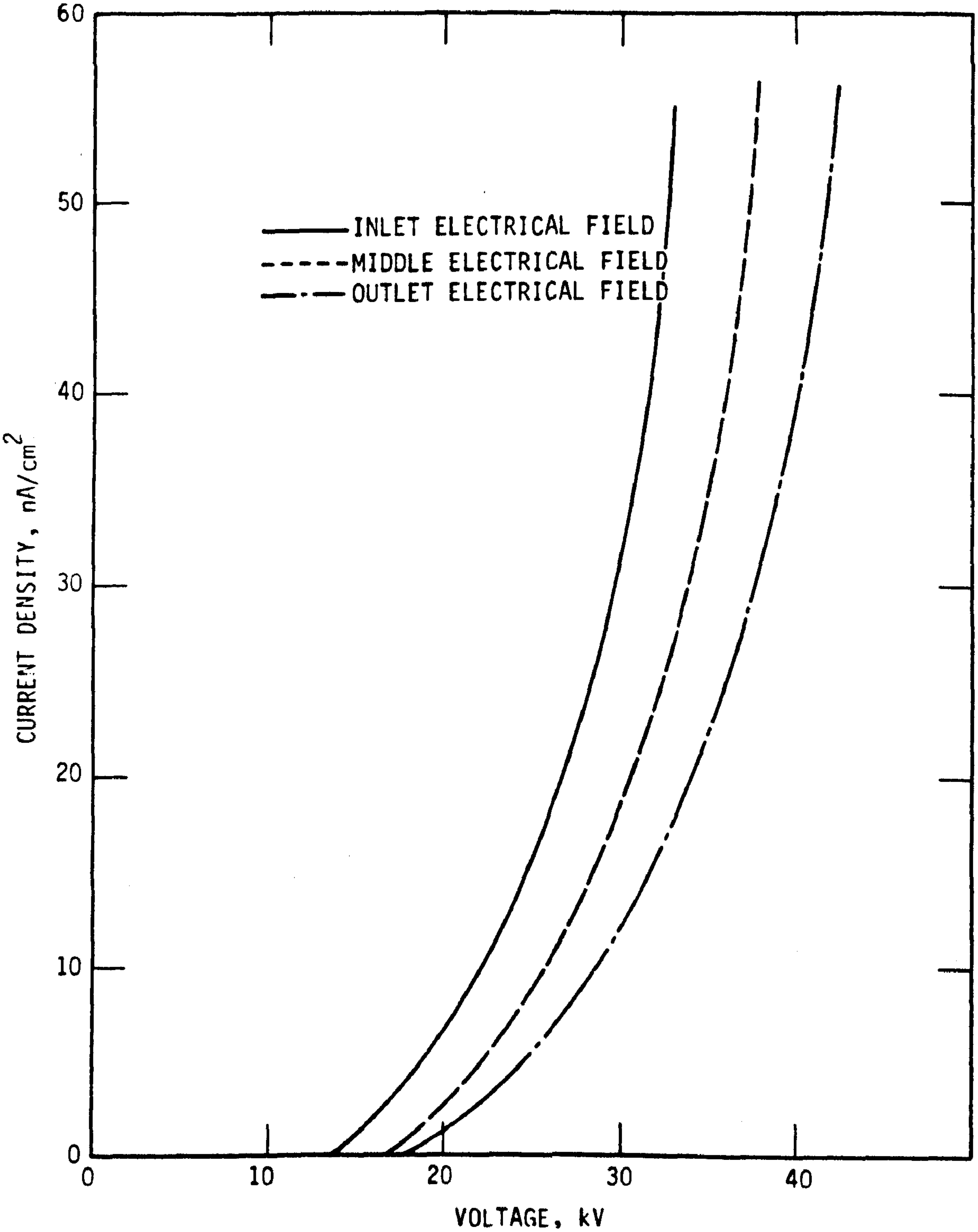

Figure 3-7. Secondary voltage-current curves demonstrating the particulate space charge effect in a full-scale, cold-side precipitator collecting fly ash.[6]

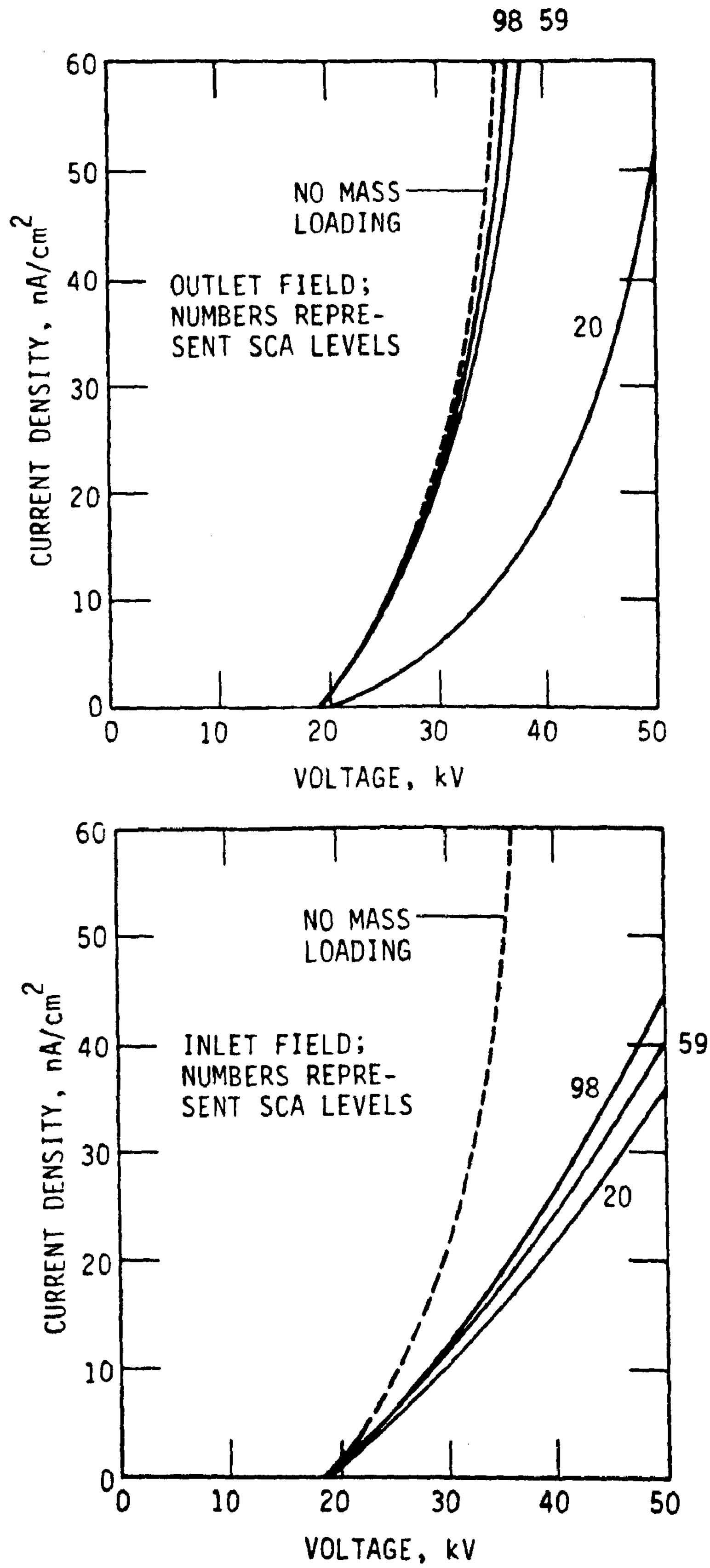

Figure 3-8. Comparison of theoretical voltage-current curves for different specific collection areas.[6]

thus the reduced current levels for the same applied voltage. Technically, the concentration of fine particulate is the controlling factor for space charge or current suppression effects. In other words, a 1 gr/ft^2 stream composed of fine particulate will cause higher space charge effects (lower current levels) than a 2 gr/ft^3 stream of large particles.

The general message concerning this section on on-line recordkeeping is that primary and/or secondary electrical data and profiles (V-I curves) are the telltale indicators of ESP performance. The general rule is that the ideal V-I patterns need to be approached in real systems, and the extent of deviations from the appropriate pattern is a significant measure for performance degradation. Examination of these electrical profiles and other records are very effective for troubleshooting.

Normally-experienced V-I curves and patterns will reflect the prevailing conditions and associated problem areas in an ESP. Some case studies will possess V-I conditions that are a result of several causes. In general, most of these causes will evidence themselves in the form of substantially reduced voltage levels, and corresponding reduced current levels. Only two problems (current leakage and severe back-corona) will be evidenced by higher than design current values. (A complete secondary V-I curve will distinguish between these two exceptional cases, and consequently account for the dependent voltage level). The more general case of reduced corona or operating points (i.e., reduced endpoint of actual V-I curve) may possess such a limited curve that identification or interpretation of significant problem(s) becomes only remotely possible.

The technical principles behind the V-I evidence are steadfast. The following figures and short descriptions will symptomize problems or conditions related to on-line treatment of industrial streams. Cases of cause - singularity are presented from actual field V-I data to illustrate and reinforce the characterizable relationship of V-I patterns and prevailing conditions.

A common factor effecting the slope and relative position of the V-I curve is resistivity. Figure 3-9 compares the V-I curves with and without ammonia conditioning. Figure 3-10 offers convincing evidence that ammonia injection is responsible for this V-I shift.

Figures 3-11 through 3-14 show V-I curves for an ESP indicative of excellent electrical characteristics treating flyash from high sulfur eastern coal. Bushings A and B in these figures represent two ESP's side-by-side.

Sparking is another factor that shows up in V-I traces. Figure 3-15 shows V-I curves with and without SO_3 conditioning. The portions of the curves with positive slopes portray data collected with no sparking or very light sparking. The segments of the V-I curves with negative slopes represent moderate-to-heavy sparking conditions.

Dust layer thickness will influence V-I character. Figure 3-16 compares V-I curves at start-up (no dust layer) with conditions 5 hours later (with dust layer). Note the shift and the reduced operating point associated with a dusty ESP treating flyash from a low sulfur western coal.

Treatment temperature also impacts V-I shapes. Figure 3-17 shows V-I curves from a hot-side ESP treating low sulfur eastern flyash. Note the gently increasing slopes for each of the fields, typical of good electrical characteristics. Figures 3-18 and 3-19 show the dramatic effect on V-I character for full load conditions at 625°F and half-load conditions at 485°F. Figure 3-20 shows typical V-I curves from a hot-side ESP treating low sulfur western flyash. Compare these curves back to Figure 3-17 for low sulfur eastern flyash. Differences in resistivity between the eastern and western low sulfur flyashes account for distinctions in V-I curves.

Since there are a variety of corona electrodes, plates (see Figures 2-6 and 2-7) and vendor designs, each specific ESP application will have slightly different V-I characteristics.

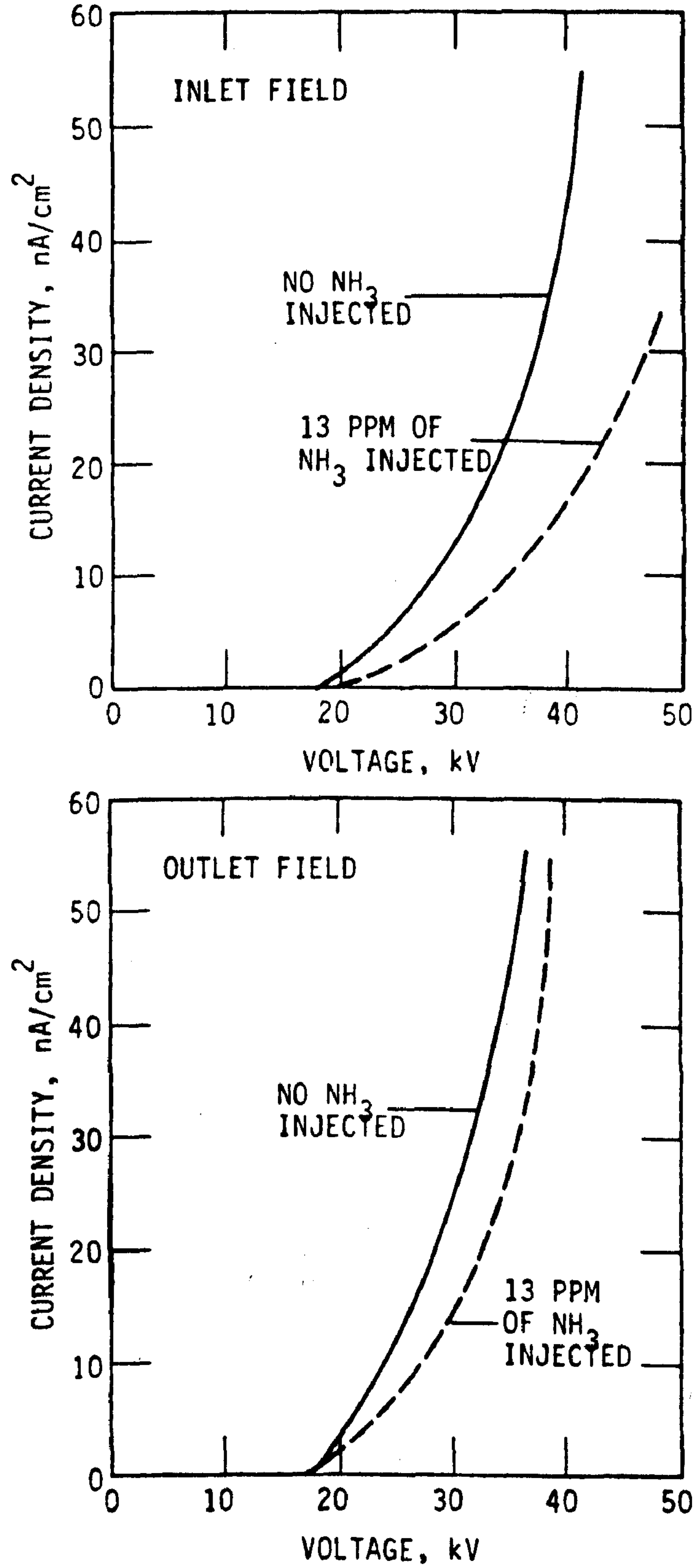

Figure 3-9. Current density vs. voltage for a full-scale, cold-side precipitator without and with NH_3 conditioning low sulfur coal.[6]

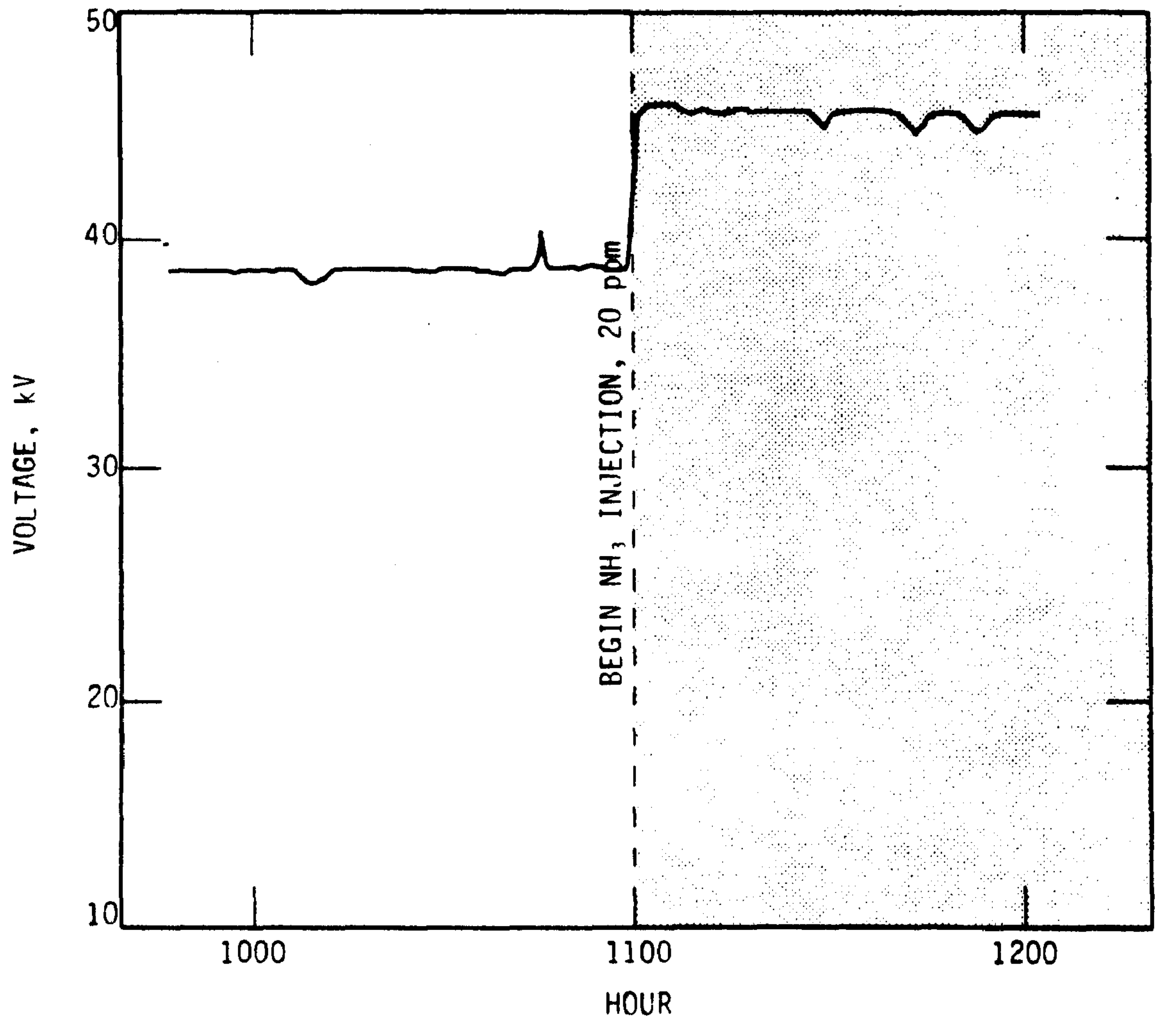

Figure 3-10. Rapidity of the effect of ammonia injection on the voltage supplied to the inlet electrical field of a full-scale, cold-side precipitator (high-sulfur coal).[6]

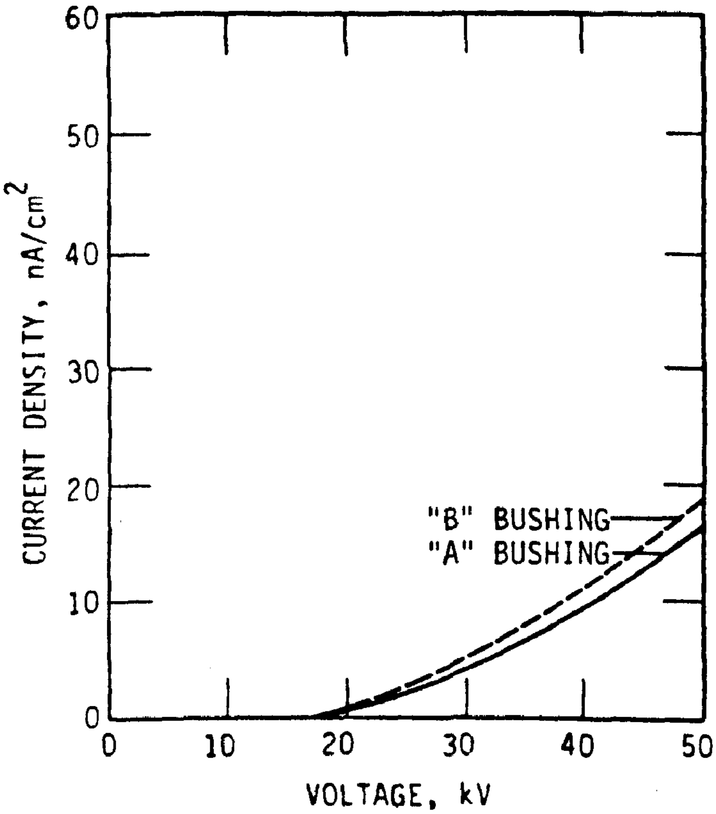

Figure 3-11. Secondary V-I curve for inlet field of ESP controlling high sulfur eastern flyash.[6]

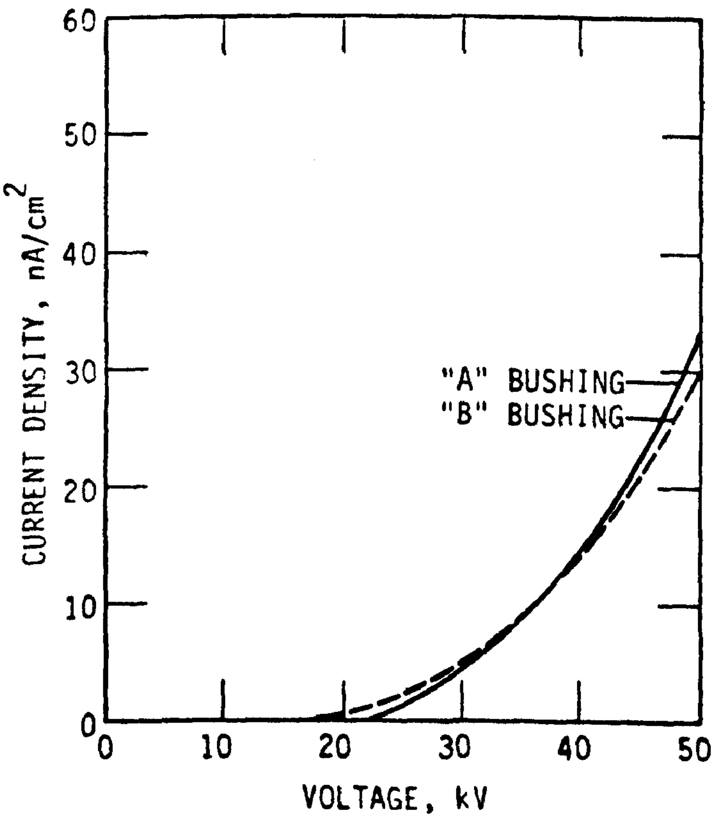

Figure 3-12. Secondary V-I curve for second field of ESP controlling high sulfur eastern flyash.[6]

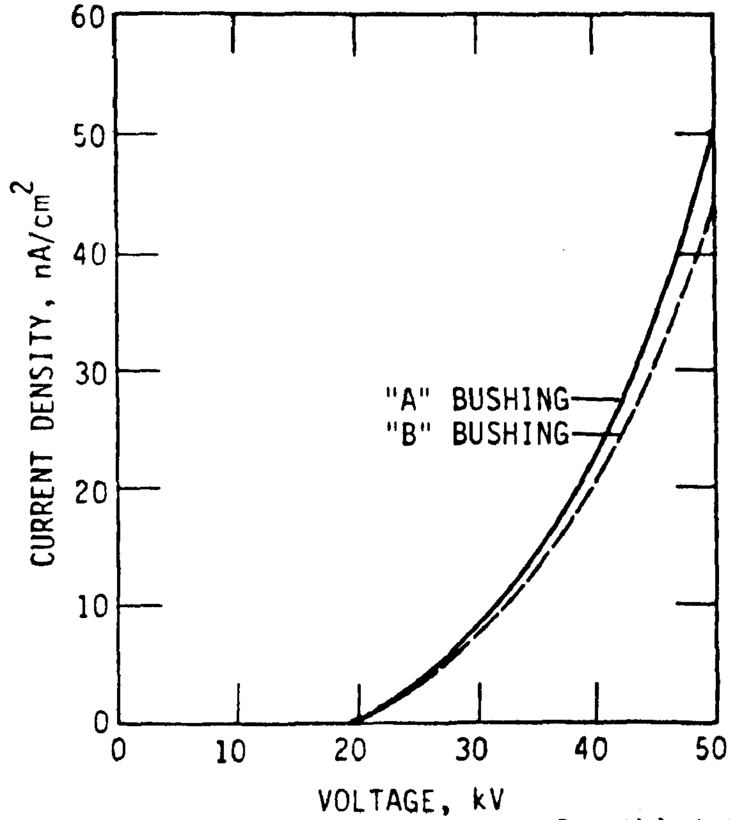

Figure 3-13. Secondary V-I curve for third field of ESP controlling high sulfur eastern flyash.[6]

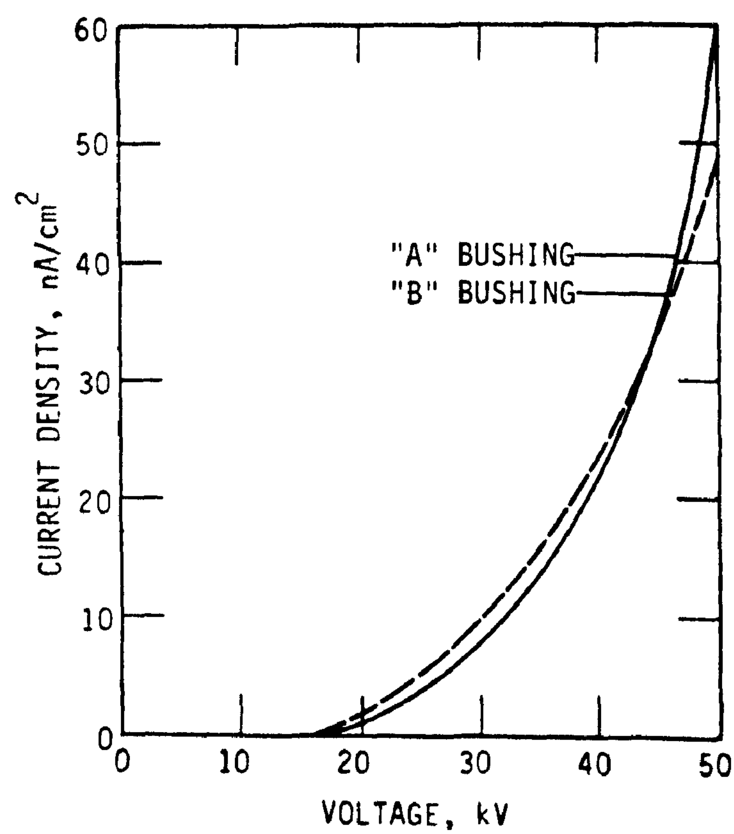

Figure 3-14. Secondary V-I curve for fourth field ESP controlling high sulfur eastern flyash.[6]

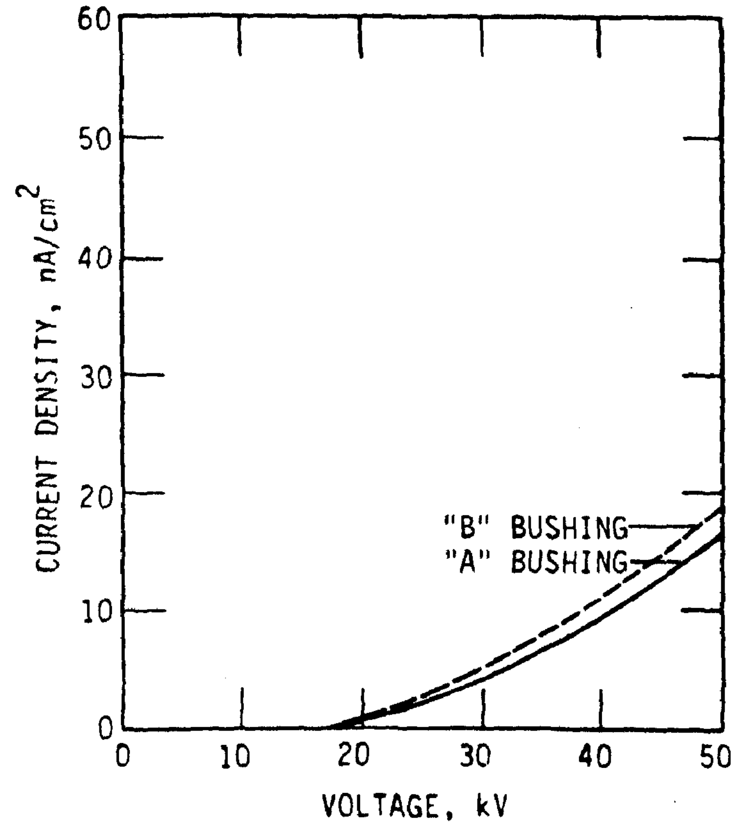

Figure 3-11. Secondary V-I curve for inlet field of ESP controlling high sulfur eastern flyash.[6]

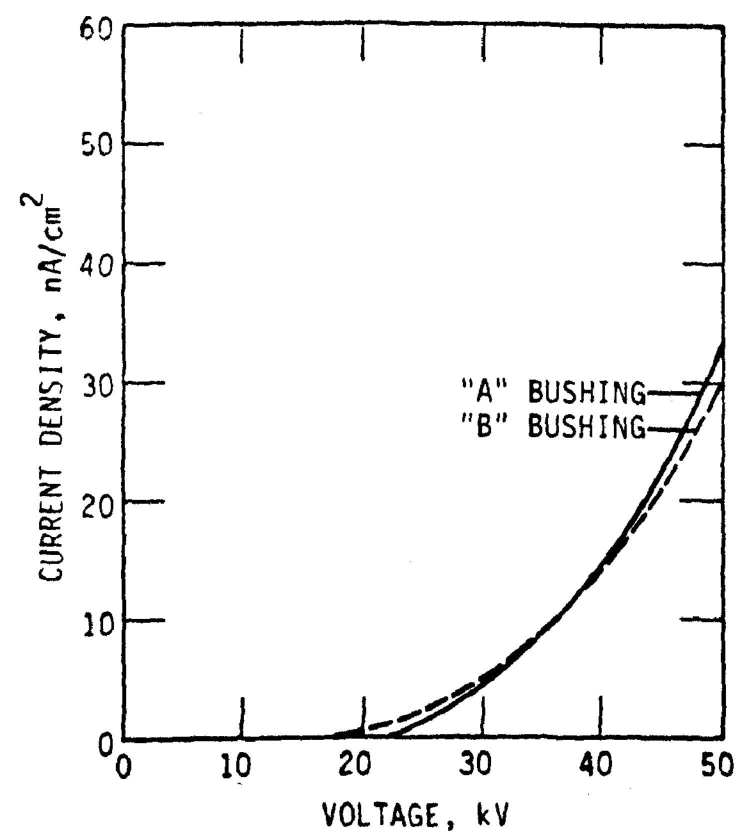

Figure 3-12. Secondary V-I curve for second field of ESP controlling high sulfur eastern flyash.[6]

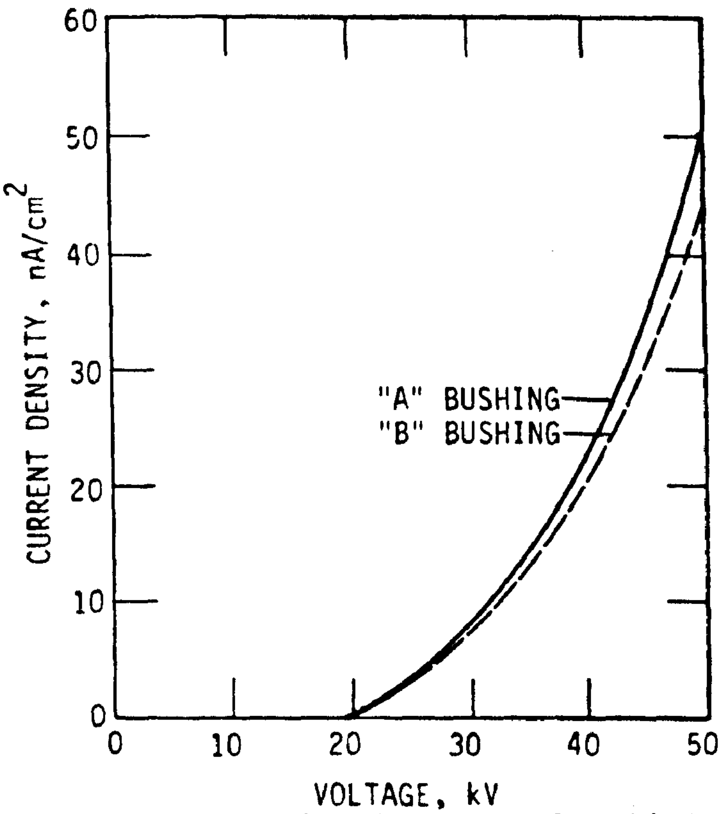

Figure 3-13. Secondary V-I curve for third field of ESP controlling high sulfur eastern flyash.[6]

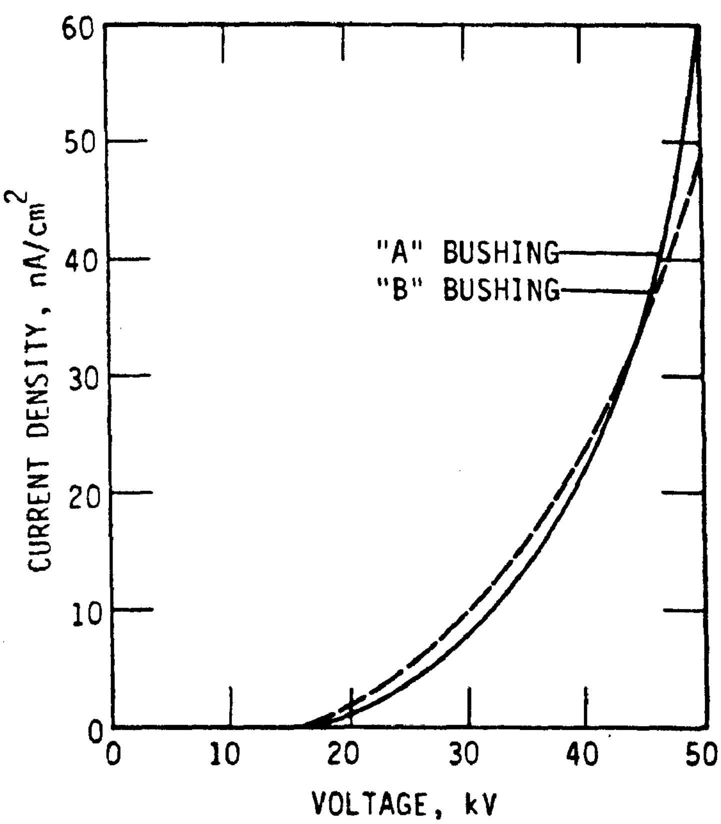

Figure 3-14. Secondary V-I curve for fourth field ESP controlling high sulfur eastern flyash.[6]

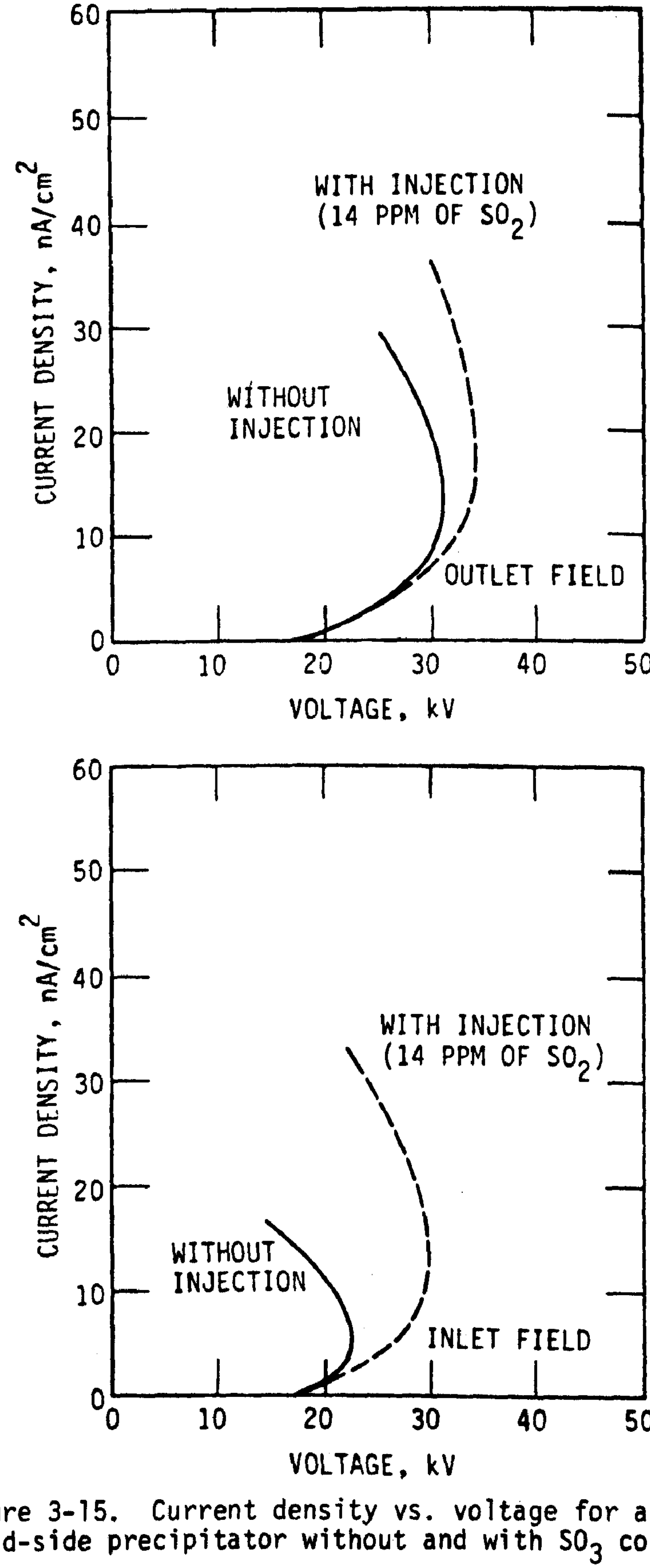

Figure 3-15. Current density vs. voltage for a full-scale, cold-side precipitator without and with SO_3 conditioning.[6]

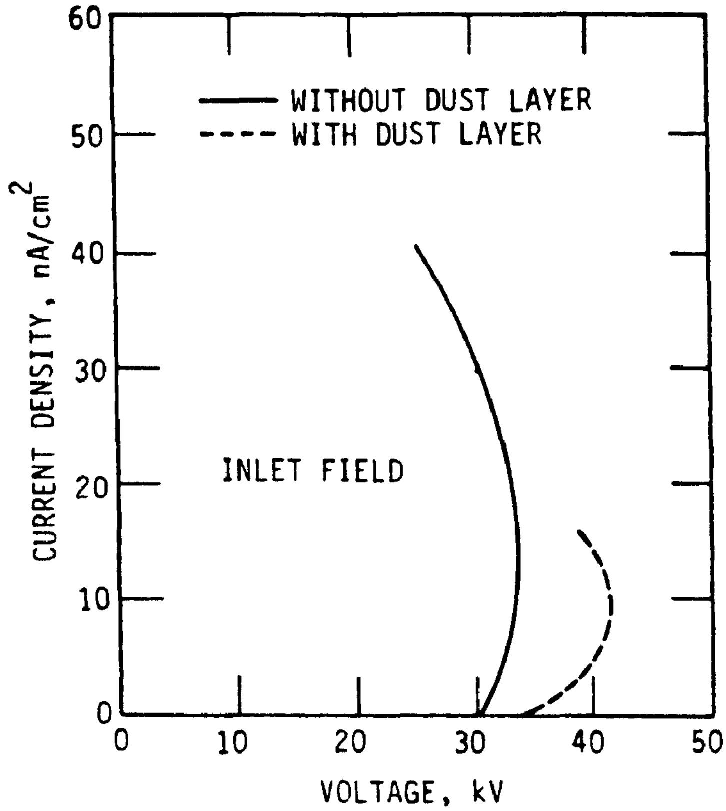

Figure 3-16. Voltage-current characteristics of inlet field showing dust layer effect.[6]

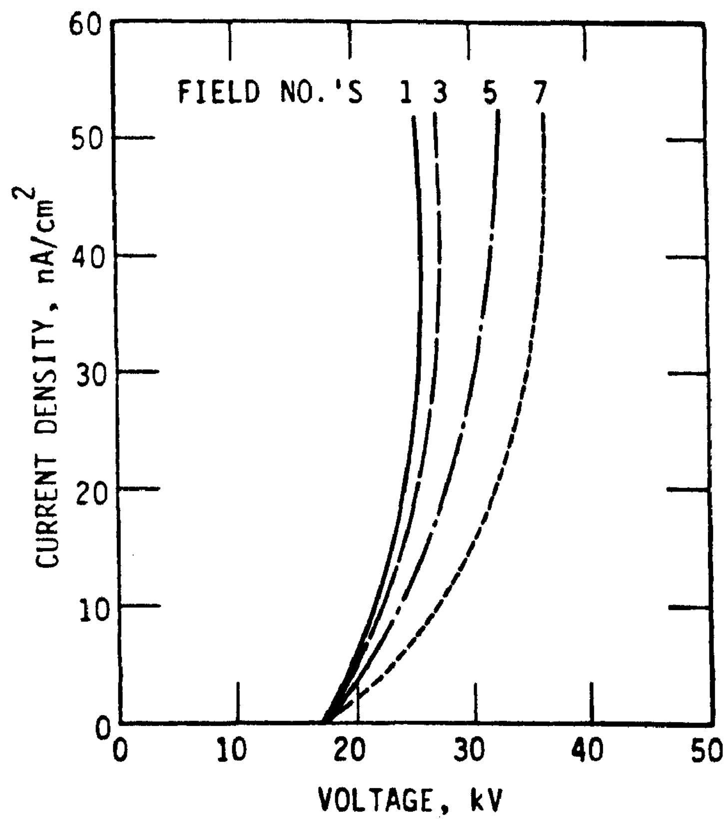

Figure 3-17. V-I curve for hot-side ESP treating low sulfur eastern flyash.[6]

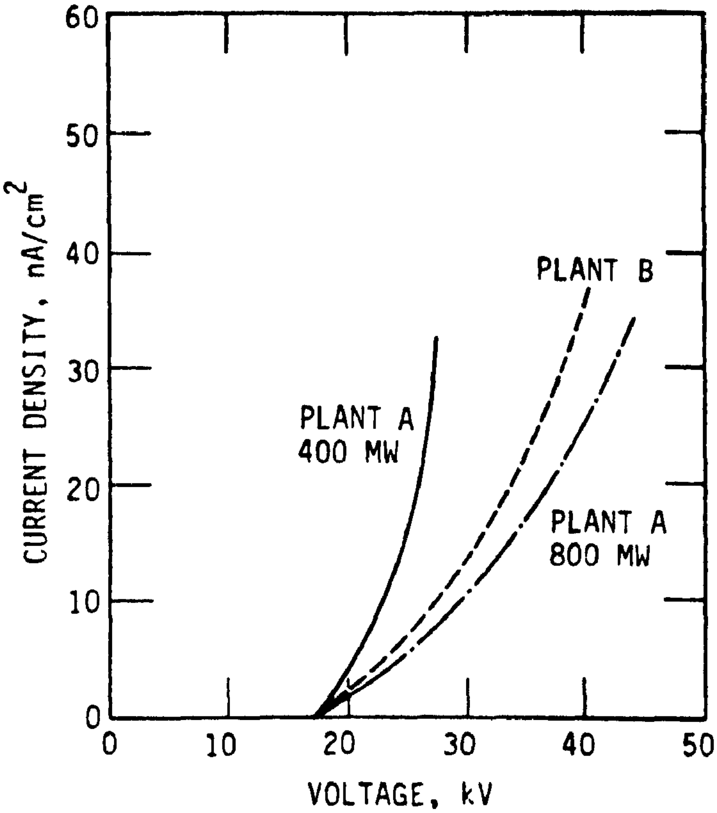

Figure 3-18. Inlet voltage current curves for two power plants at different load conditions.[6]

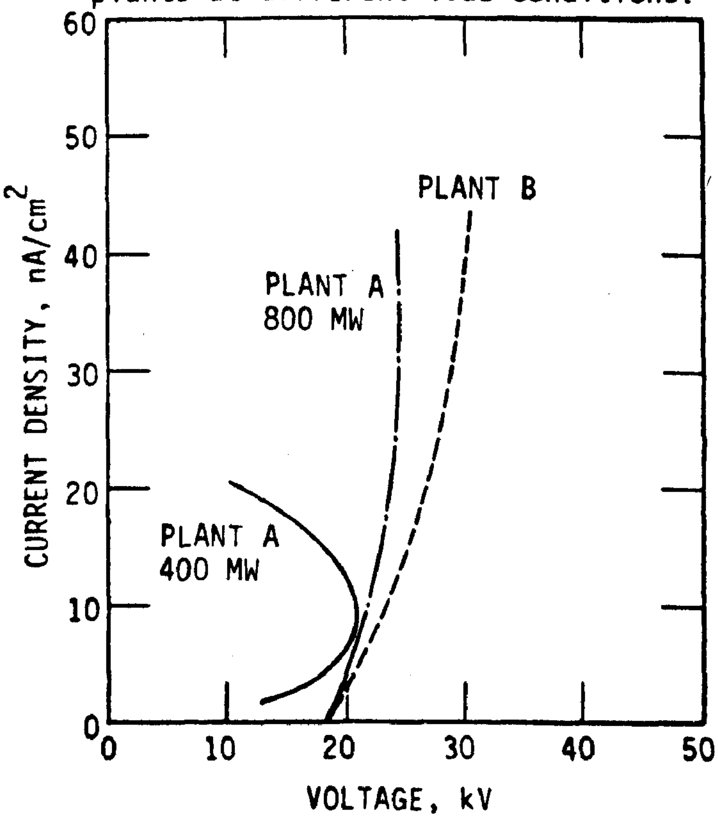

Figure 3-19. Outlet voltage current curves for two power plants at different load conditions.[6]

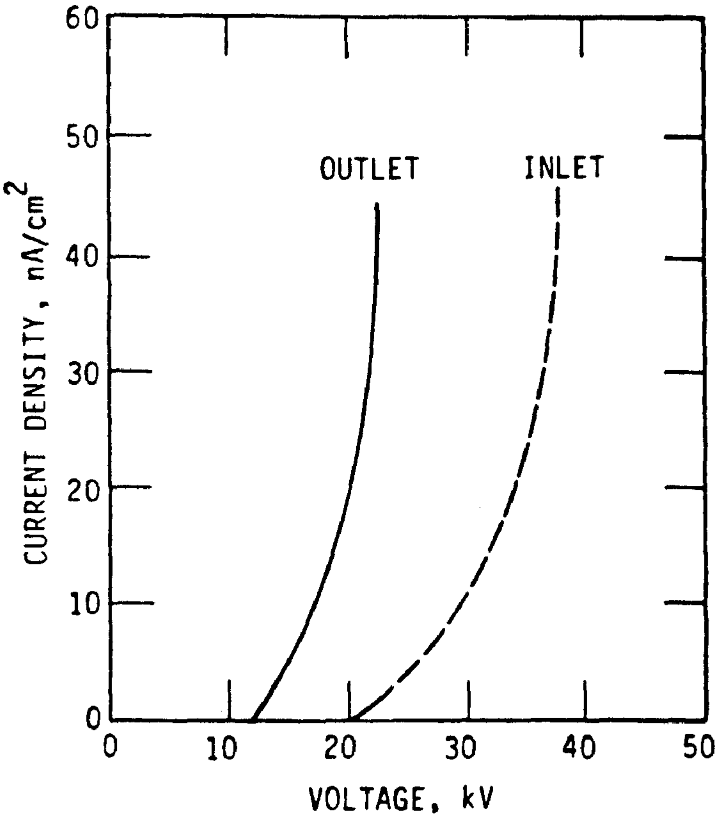

Figure 3-20. Typical secondary voltage-current curves obtained from a hot-side ESP collecting ash from a Western power plant burning low sulfur coal.[6]

Figure 3-21 illustrates several V-I curves from outlet fields on cold-side ESP's treating flyash. These V-I curves reflect the different operating characteristics associated with various wire and spacing designs under similar application.

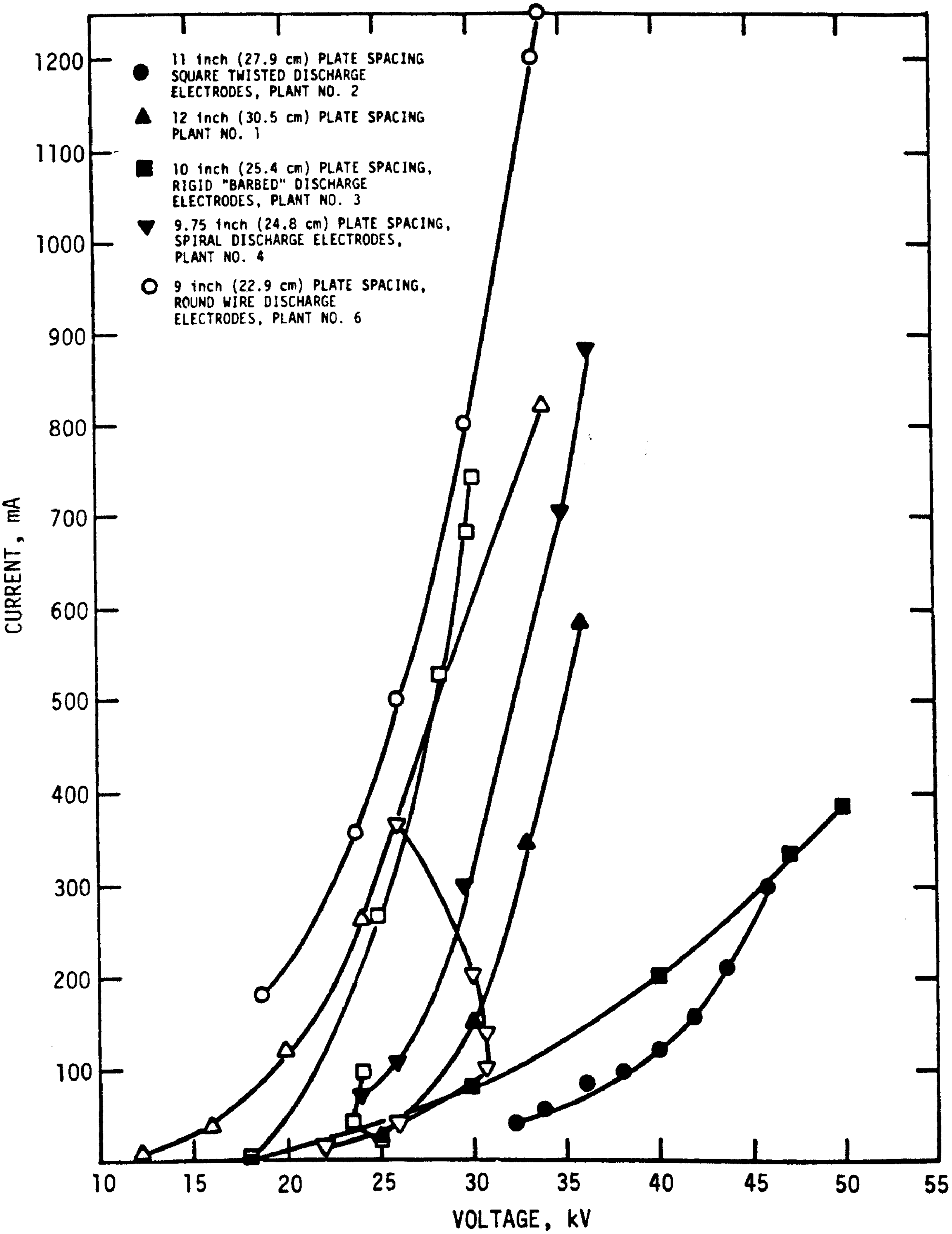

Figure 3-21. Voltage-current curves obtained from outlet electrical fields in several cold-side electrical precipitators.[6]

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4. Banks, S.M., J.R. McDonald, and L.E. Sparks. Voltage-Current Data From Electrostatic Precipitators Under Normal and Abnormal Conditions, In: Proceedings: Particulate Collection Problems Using ESP's In the Metallurgical Industry, EPA-600/2-77-208. October 1977.

SECTION 4

OPERATION, MAINTENANCE, AND COMMON PROBLEMS

The following sections provide the inspector with operating procedures, maintenance requirements, and common malfunctions of modern ESP's. This information is presented to orient the inspector with the operation and maintenance requirements that are necessary to obtain the highest possible collection efficiency. This will aid the inspector in determining whether the company has an adequate maintenance program. The ESP can then be maintained at its highest performance level with minimum loss of time because of malfunctions. Much of the discussion is based on the wire-weight type of ESP as applied in removal of fly ash. However, the inspector can apply many of these procedures to ESP's on other processes. Further, the discussion chiefly concerns dry ESP's since these units are more widely used than wet ESP's and many of the operating problems for different applications are similar. Section 4.5 deals with some procedures specific to operation of wet ESP's.

4.1 NORMAL OPERATING PROCEDURES[1]

Because the basic functions of an ESP are charging and collection of particles, the components and control associated with the power supply, rappers, and vibrators, are the most important operating systems.

4.1.1 Power Supply

During normal operation, the power to the precipitator is optimized by automatic power controls, which vary the power parameters in response to a signal generated by the spark rate.

The automatic controls also make the circuit sensitive to overload and provide safety controls in the event that spark level cannot be reached.

The automatic control circuit controls spark rate, current, and voltage. Although earlier ESP's used saturable reactors for power control, modern ESP's use silicon controlled rectifiers (SCR's); this report discusses only SCR's. The components of an automatic control system were previously shown in Figure 3-2. The silicon controlled rectifiers provide a wide range of precipitator current, and the current-limiting reactor limits the swinging of current during precipitator sparking.

Silicon Controlled Rectifiers (SCR's)--

The SCR's act as a variable impedance in controlling the flow of power in the circuit. An SCR is a three-junction semiconductor that is normally an open circuit until an appropriate signal is applied to the gate terminal, at which time it rapidly switches to the conducting state. Its operation is equivalent to that of a thyroton. The flow of current is controlled by the forward blocking ability of the SCR's, which in turn is controlled by the firing pulse to the gate of the SCR. The current-limiting reactor reshapes the wave form of the current and the peak that occurs during sparking. Current wave form with and without SCR's is illustrated in Figure 4-1.

Sparking Control--

Conventional spark control is based on storing electrical pulses in a capacitor for each spark that occurs in the precipitator. If the voltage of the capacitor exceeds a preset reference value, an error signal will phase the mainline SCR's back to a point where the sparking will stop. Usually this snap-action type of control tends to overcorrect and thus leads to longer downtime than is desirable. At low sparking rates, about 50 sparks per minute, the overcorrection is more pronounced and voltage is reduced for a longer period, with subsequent loss of dust and low ESP efficiency.

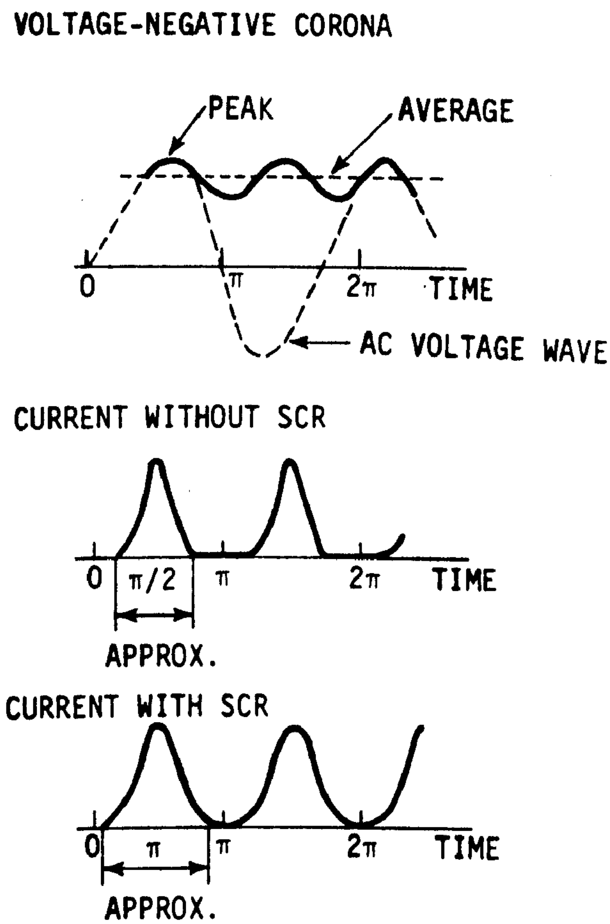


Figure 4-1. ESP current wave form with and without silicon controlled rectifiers.

Proportional control, another method of spark control, is also based on storing electrical pulses for each spark that occurs in the precipitator. In this system, however, phaseback of the mainline SCR's is proportional to the number of sparks in the precipitator. The main advantage of proportional control over conventional spark control is that the precipitator determines its own optimum spark rate, based on four factors: temperature of the gas, dust resistivity, dust concentration, and internal condition of the precipitator. With proportional spark rate control, therefore, the precipitator determines the optimum operating parameters, whereas with conventional spark control, the operator selects the parameters, which may not be optimum.

Some precipitators operate at the maximum voltage or current settings on the power supply with no sparking. In collection of low-resistivity dusts, where the electric field and the dust deposit are insufficient to initiate sparking, a no-spark condition may arise. This condition does not necessarily indicate that the unit is underpowered, since it may have sufficient power to provide charging and electric fields without sparking.

Voltage Limit Control--

The voltage-limit unit of the automatic control module limits the primary voltage of the high-voltage transformer to its rated value. A potential transformer across the primary circuit supplies a voltage signal that is compared with a preset voltage value. The voltage control is set at the primary voltage rating of the high-voltage transformer. Primary voltage above this value generates a signal that retards the firing pulse of the firing module and brings the primary voltage back to the control setting.

Current-limit Control--

For current-limit control, a current transformer in the primary circuit of the high-voltage transformer monitors the primary current. The voltage from this current transformer is compared with the setting of the current control, which corresponds to the rating of the T-R unit. Any primary current that exceeds the unit's rating generates a signal that regards the firing pulse of the firing circuit (as with spark control) and reduces the current to the current-limit setting.

With all three control functions properly adjusted, the control unit energizes the precipitator at its optimum or maximum level at all times. This level is determined by conditions within the precipitator and results in one of the three automatic control functions operating at its maximum, i.e., primary voltage, primary current, or spark rate. When one of the three maximums is reached, the automatic control prevents any increase in power to reach a second maximum. If charges within the precipitator so require, the automatic control will switch from the maximum limit of one function to that of another.

The system also includes secondary overload circuits and an undervoltage trip device that operates when voltage on the primary of the high-voltage transformer falls below a predetermined level and remains below that level for a period of time. Another device provides a delay period in the annunciator circuit while the network of contacts is changing position to stabilize the circuit in response to undervoltage. The corona voltage-current characteristics of ESP's are controlled basically by gas and dust loading, electrode geometry and alignment, and size of the individual section energized.

The electrical equipment ratings must be properly matched with load requirements.[2] Over a wide range of gas temperatures and pressures in different applications, practical operating voltages range from 15 to 80 kV_{av} at average corona current densities of about 100 to 3200 $mA/1000\ m^2$ (10 to 300 $mA/1000\ ft^2$) of collecting area.

The following are some of the problems that can occur when power supply and load are mismatched:[2]

- The ESP is underpowered because of too few electrical sets, sets of wrong capacity, or too much collecting area energized from a single set.

- Reduction of operating voltage with gas temperature, as shown in Figure 4-2, can result from failure to fully evaluate effects of gas density and temperature on required operating levels. While voltage goes down, the current demands go up. At high pressures the reverse can occur.

- A rectifier set larger than is required for the application, as when 1500 mA saturable reactor sets are operating on high resistivity ash at perhaps 100 mA, can lead to loss of control, excessive sparking, and poor efficiency.

4.1.2 Rappers

The rapper system is electrically operated to remove dust from the precipitator's collecting plates. The most common system consists of magnetic-impulse, gravity-impact rappers that are energized periodically to rap the collecting plates to remove dust deposits. The main components of the system are the rappers and the electrical controls.

The magnetic-impulse, gravity-impact rapper, shown in Figure 4-3, is a solenoid electromagnet consisting of a steel plunger surrounded by a coil, both 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. The electrical controls provide separate adjustments so that the rappers can be assembled into different groups, each of which can be independently adjusted from zero to maximum rapping intensity. The controls are adjusted manually to regulate the release of dust from the collecting plates and prevent undesirable "puffing" from the stack.

During normal operation, a short-duration d.c. pulse through the coil of the rapper supplies the energy to move the steel

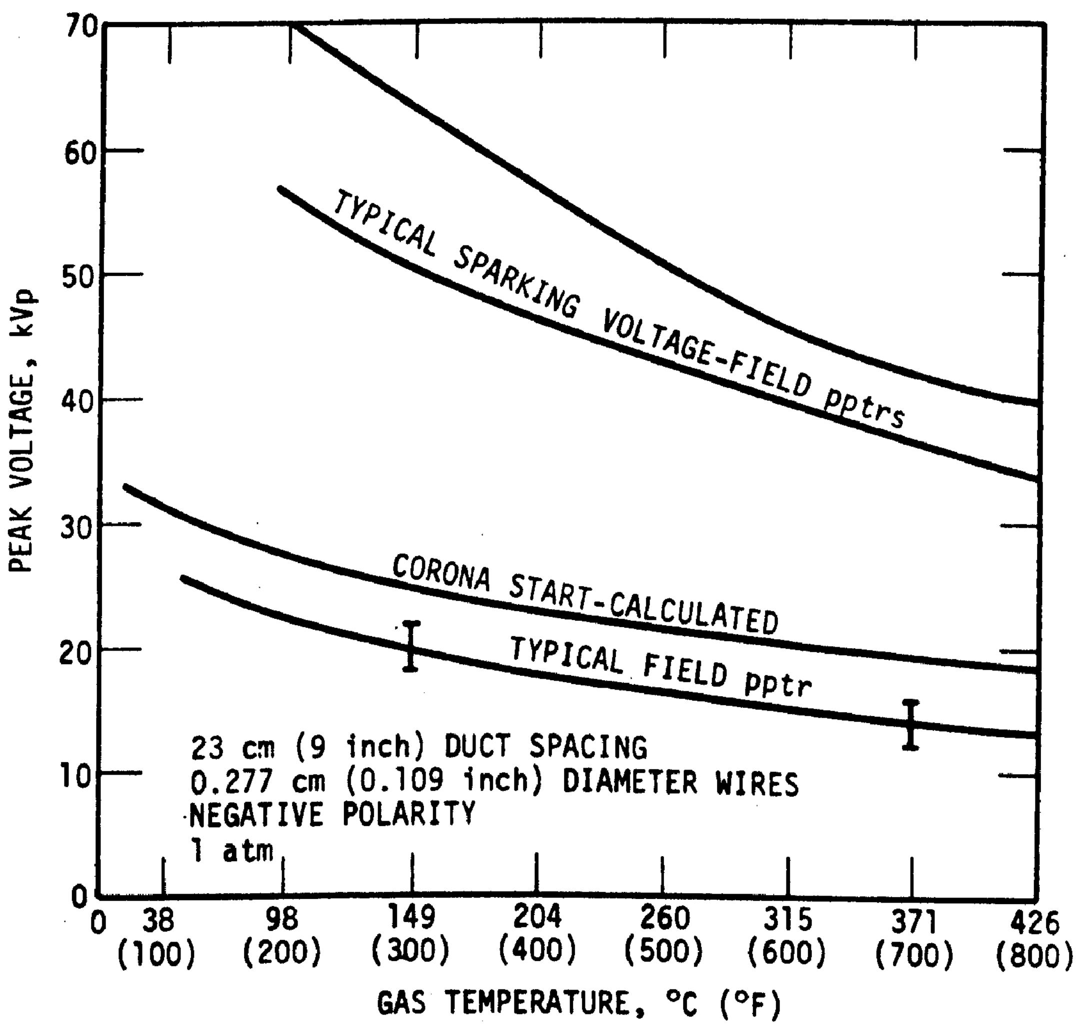


Figure 4-2. Typical precipitator operating voltage as a function of gas temperature.[2]

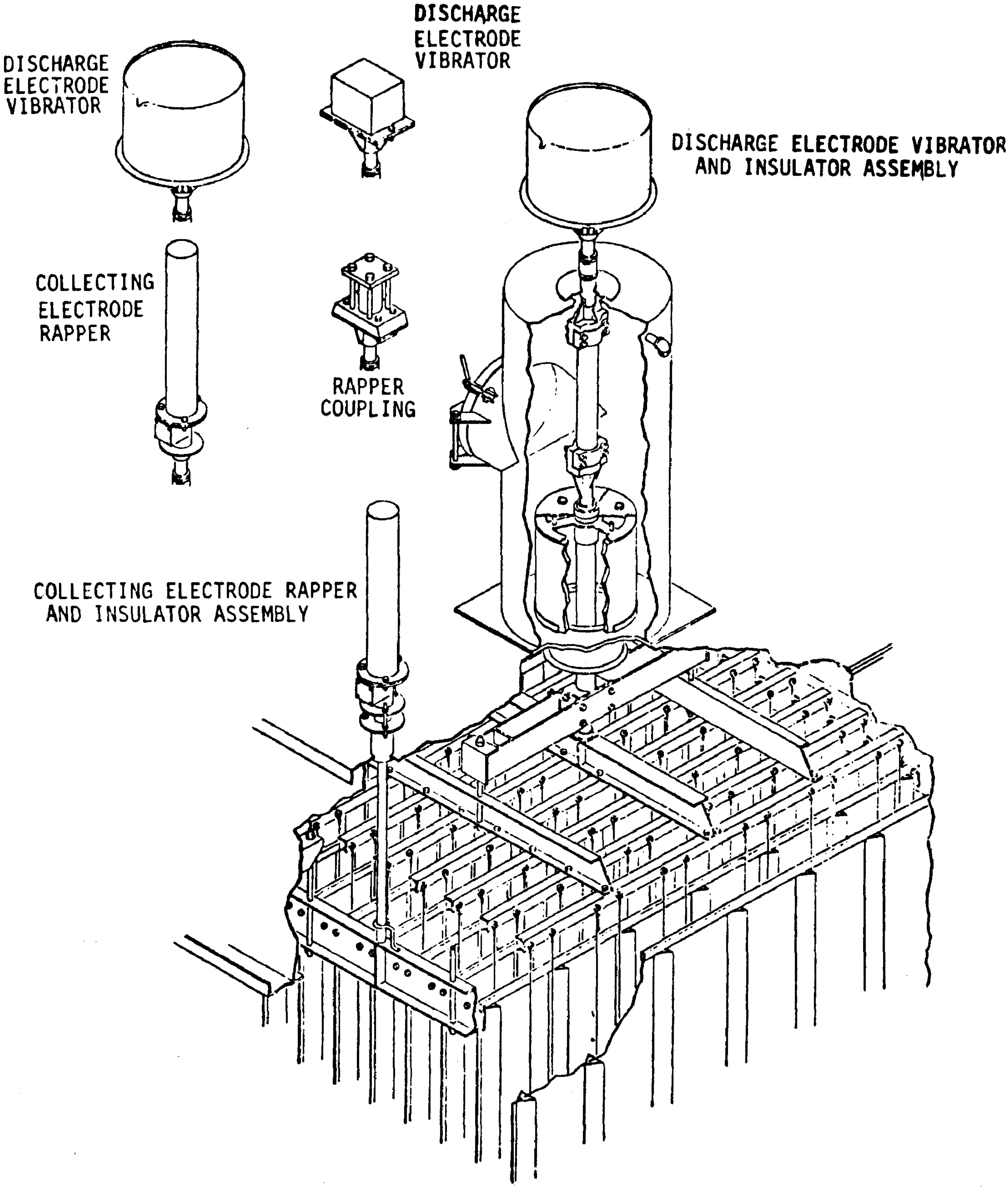


Figure 4-3. Vibrator and rapper assembly, and precipitator high-voltage frame.[1]

plunger. The plunger is raised by the magnetic field of the coil and then is allowed to fall back and strike a rapper bar, which is connected to a bank of collecting electrodes within the precipitator. The shock transmitted to the collecting electrodes dislodges the accumulated dust.

In some applications, the magnetic-impulse, gravity-impact rapper is used to clean the precipitator discharge wires. For this purpose, the rapper strikes the electrode supporting frame in the same manner, except that an insulator isolates it from the high voltage of the frame.

Some installations have mechanical rappers, in which a single hammer assembly mounted on a shaft raps each frame (see Figure 2-11). A low-speed gear motor is linked to the hammer shaft by a drive insulator, fork, and linkage assembly. Intensity of rapping is governed by the hammer weight, and frequency is governed by the speed of rotation of the shaft.

4.1.3 Vibrators

A vibrating system creates vibrations in either the collecting plates or the discharge wires to dislodge accumulations of particles. Vibrators are not normally used to clean the collecting electrodes of precipitators that collect fly ash.

The vibrator is an electromagnetic device, the coil of which is energized by alternating current. Each time the coil is energized, the resulting vibration is transmitted through a rod to the high-tension wire supporting frame or collecting plates (see Figure 4-3). The number of vibrators depends on the number of high-tension frames or collecting plates in the system.

The control unit contains all devices for operation of the vibrators, including means of adjusting the intensity and period of vibration. Alternating current is supplied to the discharge wire vibrators through a multiple cam-type timer to provide sequencing and duration for energization of the vibrators.

For each installation, a certain intensity and period of vibration will produce the best collecting efficiency. Low intensity will result in heavy buildup of dust on the discharge wires. Dust buildup reduces the sparkover distance between the electrodes, thereby limiting the power input to the precipitator. It also tends to suppress the formation of negative corona and the production of unipolar ions required for precipitation. Further, dust buildup alters the normal distribution of electrostatic forces in the treatment zone and can lead to oscillation of the discharge wires and the high-tension frame.

Recent studies have investigated reentrainment caused by rapping in terms of the percentage of material reentrained and its particle size distribution.[3,4] One report describes the testing of six full-scale electrostatic precipitator installations. Losses from rapping ranged from over 80 percent of the total mass emissions from one hot-side unit to 30 percent of emissions from cold-side units. The losses consist mostly of relatively large particles, primarily those larger than 2.0 μm in diameter.

Tests of a pilot-scale precipitator showed that rapping emissions decreased as time between raps was increased.[4]

Because reentrainment from rapping can be a significant portion of the total emissions, it is important that the rapping system is adjusted to minimize reentrainment.

4.2 MAINTENANCE REQUIREMENTS[5,6,7,8]

At each precipitator installation, the inspector should require that a preventive maintenance schedule be kept, listing the precipitator parts to be checked and maintained daily, weekly, monthly, quarterly, and in specified situations. Table 4-1 summarizes the maintenance procedures discussed in this section and can be used by an inspector as an example to be compared with procedures used by the company.

TABLE 4-1. MAINTENANCE SCHEDULE FOR ELECTROSTATIC PRECIPITATORS[8]

Enter on daily log

1. Boiler operating parameters
2. Flue gas analysis
3. Coal characteristics
4. ESP electrical data
5. Transmissometer calibration

Check daily

1. T-R control set readings
2. Rapper and vibrator control settings
3. Ash removal system
4. T-R control room ventilation system

Check weekly

1. Operation of rappers and vibrators

2. Control sets (for internal dirt)

3. Air filters to control sets and precipitator top housing

Enter on weekly log

1. ESP voltage-current data
2. Graph ESP voltage-current data

Check monthly

1. Pressurization of precipitator top housing
2. Standby fan operation (manually)

Perform quarterly

1. Clean and dress contact surfaces of HW-FW electrical distribution

2. Lubricate pivots

Perform semiannually

1. Clean and lubricate access door hinges and test connections

2. Inspect exterior for loose insulation, corrosion, loose joints, other defects

(continued)

TABLE 4-1. (continued).

3. Check for points of gas leakage (in or out)

<u>Perform annually</u>

1. Thorough internal inspection:

   Check for possible leaks of oil, gas, or air at gasketed connections

   Check for corrosion of any component

   Check for broken or misaligned wires, plates, insulators, rappers, etc.

   Check high-voltage switchgear and interlocks

   Clean all insulators and check for hairline cracks or tracking

   Check expansion joints on hot precipitators

2. Check for signs of hopper leakage, reentrainment of particulate, and poor gas distribution

3. Check for dust buildup in inlet and outlet flues

4. Check for dust buildup in hoppers

Startup and shutdown procedures and a maintenance schedule for ESP's are presented in Appendix A. These procedures can be applied to wire-weight and rigid-frame precipitators, with the noted differences regarding rappers. This information is intended to give the inspector an idea of what the company should be doing to properly operate and maintain their ESP.

4.3 PRECIPITATOR MALFUNCTIONS

Many ESP equipment components are subject to failure or malfunction that can cause an increase in emissions. Malfunctions may be caused by faulty design, installation, or operation of the ESP. They may involve electrical, gas flow, rapping, or mechanical problems, which can be minor or severe.[9] The inspector should orient himself with the common ESP malfunctions, their effects on emissions, corrective actions, and preventive measures. Table 4-2 lists common problems associated with fly-ash ESP's. Appendix B identifies and describes the major types of ESP malfunctions, giving probable causes and corrective actions. Two surveys of ESP operating experience are summarized.

To further illustrate the effectiveness of troubleshooting with voltage-current data and curves, a supplementary figure to Table 4-2 is provided. Figure 4-4 presents the same list of malfunctions as Table 4-2 with graphic illustrations of voltage-current (V-I) curves indicative of the respective malfunctions. Two columns of V-I curve comparison, and a multi-field V-I curve comparison. A single field comparison is made by showing a reference V-I curve, representative of proper operating conditions, along with a V-I curve indicative of the respective malfunction. A multi-field comparison is made by showing the V-I curve for the malfunctioning field along with V-I curves representative of normal conditions for the remaining operating ESP fields. The single field and multi-field comparisons are made on the premise of cause-singularity and field-singularity. For the case of back corona, all fields are shown to experience the

TABLE 4-2. SUMMARY OF PROBLEMS ASSOCIATED WITH ESP'S[7]

Malfunction	Cause	Effect on ESP efficiency[a]	Corrective action	Preventive measures
Poor electrode alignment	Poor design Ash buildup on frame and hoppers Poor gas flow	Can drastically affect performance and lower efficiency	Realign electrodes. Correct gas flow.	Check hoppers frequently for proper operation..
Broken electrodes	Wire not rapped clean, causes an arc that embrittles and burns through the wire	Reduction in efficiency due to reduced power input, bus section unavailability	Replace electrode.	Boiler problems: check for insufficient excess air, insufficient pressure reading on gauges, fouled screen tubes, and fouled air preheater.
	Clinkered wire. Causes: poor flow area, distribution through unit is uneven; excess free carbon due to excess air above combustion requirements or fan capacity insufficient for demand required; wires not properly centered; ash buildup resulting in bent frame, same as above; clinker bridges the plates and wire shorts out; ash buildup, pushes bottle weight up causing sag in the wire; "J" hooks have improper clearances to the hanging wire; bottle weight hangs up during cooling causing a buckled wire ; and ash buildup on bottle weight to the frame forms a clinker and burns off the wire.			Inspect hoppers; check electrodes frequently for wear; inspect rappers frequently.

[a]The effects of precipitation 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.

(continued)

TABLE 4-2 (continued)

Malfunctions	Cause	Effect on ESP efficiency[a]	Corrective action	Preventive measures
Distorted or skewed electrode plates	Ash buildup in hoppers Gas flow irregularities High temperatures	Reduced efficiency	Repair or replace plates. Correct gas flow.	Check hoppers frequently for proper operation; check electrode plates during outages.
Vibrating or swinging electrodes	Uneven gas flow Broken electrodes	Decrease in efficiency due to reduced power input	Repair electrode.	Check electrodes frequently for wear.
Inadequate level of power input (voltage too low)	High dust resistivity Excessive ash on electrodes Unusually fine particle size Inadequate power supply Inadequate sectionalization Improper rectifier and control operation Misalignment of electrodes	Reduction in efficiency	Clean electrodes; gas conditioning or alterations in temperature to reduce resistivity; increase sectionalization.	Check range of voltages frequently to make sure they are correct. In-situ resistivity measurements
Back corona	Ash accumulated on electrodes causes excessive sparking, Requiring reduction in voltage charge.	Reduction in efficiency	Same as above	Same as above
Broken or cracked insulator or flower pot bushing leakage	Ash buildup during operation causes leakage to ground. 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 adequate pressurization of top housing.

[a]The effects of precipitation 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.

(continued)

TABLE 4-2 (continued)

Malfunctions	Cause	Effect on ESP efficiency[a]	Corrective action	Preventive measures
Air inleakage through hoppers	From dust conveyor	Lower efficiency - dust reentrained through ESP	Seal leaks.	Identify early by increase in ash concentration at bottom of exit to ESP.
Air inleakage through ESP shell	Flange expansion, improper sealing of inspection hatches	Same as above, also causes intense sparking	Seal leaks.	Check frequently for corrosion around inspection doors and for flange expansion.
Gas bypass around ESP: dead passage above plates and tension frame	Poor design - improper isolation of active portion of ESP	Only a small percent drop in efficiency unless severe	Baffling to direct gas into active ESP section	Identify early by measurement of gas flow in suspected area. around high
Corrosion	Temperature goes below dew point.	Negligible until precipitation interior plugs or plates are eaten away; air leaks may develop causing significant drops 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 acid dew point.

[a]The effects of precipitation 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.

(continued)

TABLE 4-2 (continued)

Malfunctions	Cause	Effect on ESP Efficiency[a]	Corrective action	Preventive measures
Hopper pluggage	Wires, plates, and insulators fouled because of low temperature Inadequate hopper insulaton Improper maintenance Boiler leaks causing excess moisture Ash-conveying system malfunction - gas leakage - blower malfunctions - solenoid valves Misadjustment of hopper vibrators Material dropped into hopper from bottle weights Solenoid and timer malfunction Suction blower filter not changed	Reduction in efficiency	Provide proper flow of ash.	Frequent checks for adequate operation of hoppers; Provide heaters and/or thermal insulation to avoid moisture condensation.
Inadequate rapping, vibrators fail	Ash buildup Poor design Rappers misadjusted	Resulting buildup on electrodes may reduce efficiency.	Adjust rappers with optical dust measureing instrument in ESP exit stream.	Frequent checks for adequate operation of rappers
Too intense rapping	Poor design Rappers misadjusted Improper rapping force	Reentrains ash and reduces efficiency	Same as above	Same as above; reduce vibrating or impact force.

[a]The effects of precipitation 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.

(continued)

TABLE 4-2 (continued)

Malfunctions	Cause	Effect on ESP efficiency[a]	Corrective action	Preventive measures
Control failures	Power failure in primary system Transformer or rectifier failure: insulation breakdown in transformer arcing in transformer between high-voltage switch contacts leaks or shorts in high-voltage structure insulating field contamination	Reduced Efficiency	Find source of failure and repair or replace.	Pay close attention to daily readings of control room instrumentation to spot deviations from normal readings.
Sparking	Inspection door ajar Boiler leaks Plugging of hoppers Dirty insulators	Reduced efficiency	Close inspection doors; repair leaks in boiler; unplug hoppers; clean insulators.	Regular preventive maintenance will alleviate these problems.

[a]The effects of precipitation 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.

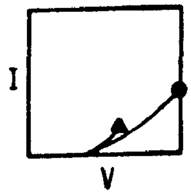
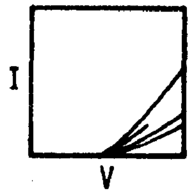
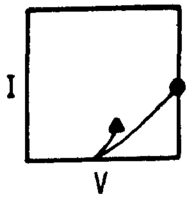
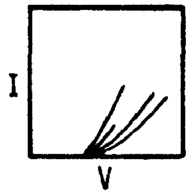
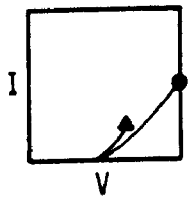
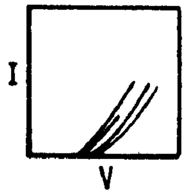
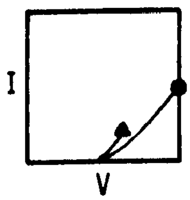
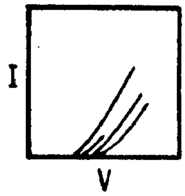
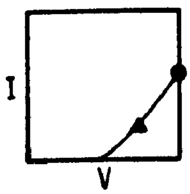
MALFUNCTION	SINGLE V-I CURVE	INDICATOR	MULTI-FIELD V-I CURVE SET
POOR ELECTRODE ALIGNMENT		°REDUCED VOLTAGE AND CURRENT LEVELS	
BROKEN ELECTRODE		A) FREQUENT CIRCUIT BREAKING B) HIGHLY ERRATIC ELECTRICAL LEVELS C) REDUCED VOLTAGE AND CURRENT LEVELS	
DISTORTED OR SKEWED COLLECTION PLATES		°REDUCED VOLTAGE AND CURRENT LEVELS	
VIBRATING OR SWINGING ELECTRODE		A) FREQUENT CIRCUIT OVERLOAD B) HIGH CURRENTS	
INADEQUATE LEVEL OF POWER INPUT		LOOK FOR OTHER OPERATIONAL PROBLEMS; OR COULD BE DESIGN RELATED	

Figure 4-4. Electrical indications of problems associated with ESPS.

Figure 4-4 (continued)

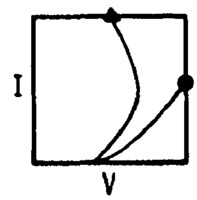
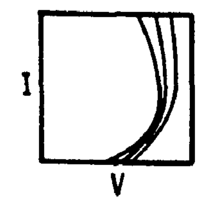
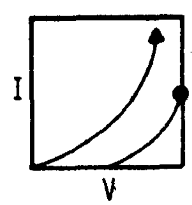
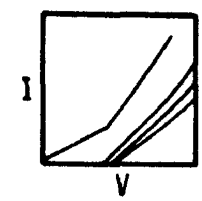
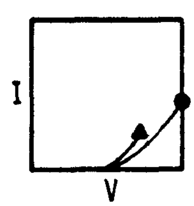
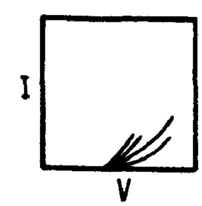
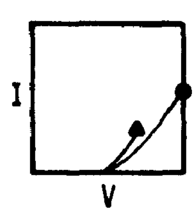
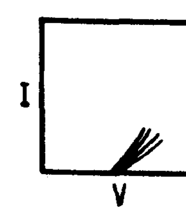
MALFUNCTION	SINGLE V-I CURVE	INDICATOR	MULTI-FIELD V-I CURVE SET
BACK CORONA		A) HIGH CURRENT LEVELS WITH LOW VOLTAGE B) INCREMENTAL CURRENT INCREASES WITH STEADY OR DECREASING VOLTAGE LEVEL	
BROKEN OR CRACKED INSULATOR OR FLOWER POT BRUSHING LEAKAGE		°HIGH CURRENT AT LOW VOLTAGE	
AIR INLEAKAGE THROUGH HOPPERS		°HIGHER SPARKING CONDITIONS	
AIR INLEAKAGE THROUGH ESP SHELL		°HIGHER SPARKING CONDITIONS °REDUCED VOLTAGE AND CURRENT LEVELS	
GAS BYPASS		NONE	

Figure 4-4 (continued)

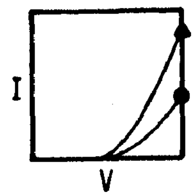
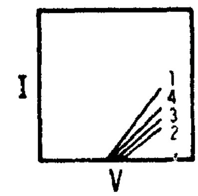
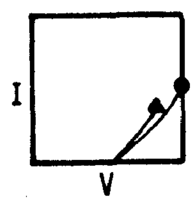
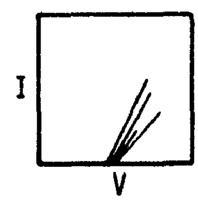
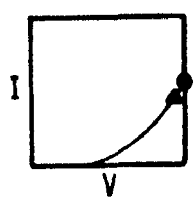
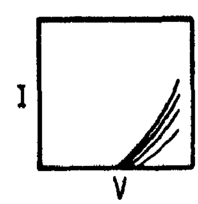
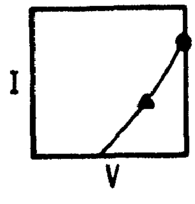
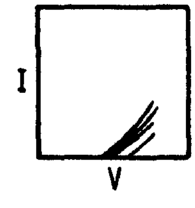
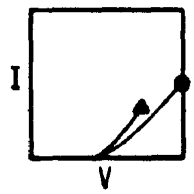
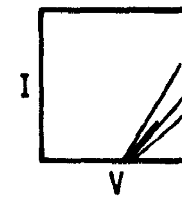
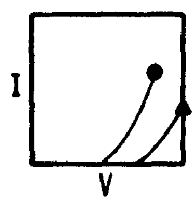
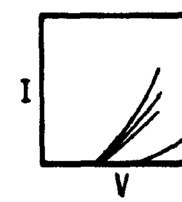
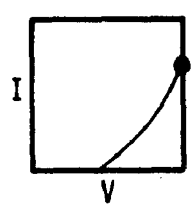
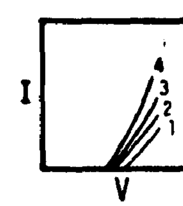
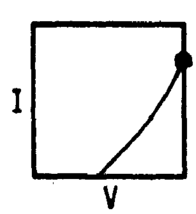
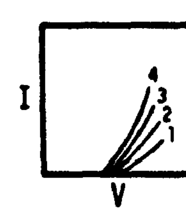
MALFUNCTION	SINGLE V-I CURVE	INDICATOR	MULTI-FIELD V-I CURVE SET
CORROSION		NONE	
HOPPER PLUGGAGE WITH ASH PILING UP INTO THE ENERGIZED FIELD		°HIGH CURRENT AT LOW VOLTAGE	
INADEQUATE PLATE RAPPING		°REDUCED VOLTAGE AND CURRENT WITH SPARKING	
TOO INTENSE PLATE RAPPING		°NORMAL VOLTAGE AND CURRENT LEVELS WITH NOTICEABLE OPACITY SPIKES CYCLES COINCIDENT WITH CAPPING CYCLES	
CONTROL FAILURES		°SLIGHTLY REDUCED VOLTAGE AND CURRENT LEVELS	

Figure 4-4 (continued)

MALFUNCTION	SINGLE V-I CURVE	INDICATOR	MULTI-FIELD V-I CURVE SET
SPARKING		NOTE: SPARKING IS A RESULT OF A MALFUNCTION NOT A CAUSE	
SHARP EDGES		°REDUCED VOLTAGE AND CURRENT LEVELS	
INADEQUATE WIRE RAPPING		°INCREASED VOLTAGE LEVEL WITH REDUCED CURRENT LEVEL	
TOO INTENSE WIRE RAPPING		NONE	
NO MALFUNCTION			

problem, as this is the normal case. Both curve sets are offered without graduated voltage and current axes to extend the applicability for both primary and secondary electrical data. A no-malfunction case is provided to reference the graphical nature of these V-I curves for an ESP with properly operating fields.

4.4 REPORTING ESP MALFUNCTIONS

Generally, plant officials are required to submit a report of excess emissions causes by ESP malfunctions; the inspector should review these reports to keep informed of the ESP operating practices at the plant. Part 60 of Title 40, Code of Federal Regulations, Section 60.7, as amended, December 16, 1975, requires that a source report excess emissions caused by malfunctions or other reasons in a quarterly report to the EPA Administrator.[10] The report, is to include the magnitude of excess emissions above the applicable standards; it is to give the date and time of beginning and end of each period of excess emissions. Periods of excess emissions resulting from startup, shutdown, and malfunction are to be specifically identified. The nature and cause of any malfunction, if known, and the corrective action taken, or preventive measures adopted, are to be reported. Each quarterly report is to be submitted within 30 days following the end of the calendar quarter.

A reportable malfunction is considered to be any sudden or unforeseen malfunction that causes or could cause any of the plant's sources to exceed specified particulate emission limits for a period of 4 or more hours. When this occurs, a procedure such as the one listed below should be followed:

- The malfunction should be reported by phone or telegram to the EPA regional office and to state or local officials. The air quality branch of the company should also be notified.

- The plant superintendent should submit a report to the EPA regional office, with copies to various branches of the utility. The report should include the following:

Time and date excess emissions began and ended

Time and date the breakdown causing the excess emissions began and ended

Type of emission, estimated rate, and copies of the opacity monitor records

Cause of the malfunction

Operation and maintenance procedures, prior to and during the malfunction, designed to prevent such an occurrence

Additional steps taken to minimize the extent or duration of the malfunction

Plans to minimize the possibility of a similar malfunction in the future

Monthly records should be kept by plant and unit of all malfunctions, total hours that T-R sets are operated, number of hours T-R sets are not operating (in intervals of 24 hours and >24 hours), maximum number of sets out at one time, and monthly/yearly availability of the ESP unit (in percent). Daily logs should be kept on each ESP unit, with remarks on outages of various sections of the ESP.

4.5 OPERATION, MAINTENANCE, AND COMMON PROBLEMS OF WET ESP'S[11]

The several available types of wet precipitators can be categorized with regard to structure as the plate type or the pipe type and also with regard to the method in which water is introduced. Plate units have either a combination presaturation continuous spray or a spray with intermittent wash and gas flow in the horizontal or vertical directions. The pipe type usually has a weir-over-flow arrangement or a continuous spray, with gas flow vertically downward. Brief descriptions of the operation of these three types of wet ESP's were presented in Section 2.4.2.

This section describes the operation and maintenance related facets of typical wet ESP installations. Wet precipitators are made in different configurations; they are less widely applied than the more conventional devices, and there is little published information on operating and maintenance practices. When the components of a wet precipitator are similar to those of a dry precipitator, the operation and maintenance procedures outlined in Section 4.2 and Appendix A are considered applicable.

4.5.1 Operation and Maintenance During Normal Operation

Heaters and blowers are usually energized first during normal operation. The spray system is always activated just before the high-voltage system is energized. Gas flow is monitored by damper. Operators must monitor the pH of the water at the waste discharge.

Because inspection and maintenance of wet ESP's are highly specific to the system, operators should follow closely the instructions provided by the manufacturer. Since precipitators operate with very high voltage, precautions must be exercised to ground the precipitator internals properly. The gas flow must be stopped and the unit cooled to a safe temperature before any person enters the precipitator. Protective apparatus such as a respirator may be needed.

The inspector should familiarize himself with the general inspection and maintenance practices that the company should be following; these are briefly outlined below.

Mechanical Maintenance--

All internal components should be checked for alignment, dust buildup, tightness of bolts, structural soundness of welds, and structural integrity of cross bracing and other support members. Since the support insulators perform such a vital function in electrostatic precipitation, the structural support end of the high-voltage insulator in the high-voltage housing must be thoroughly inspected for cracks, chips, or other defects.

Water System--

All pumps, internal spray nozzles, and related valving and piping should be checked. Nozzles are subject to plugging and therefore should be routinely disassembled, cleaned, and/or replaced as necessary. Other required checks include the main supply pumps for water pressure, all pipe joints for leaks, and all couplings for tightness. Nozzle orientation should be checked and adjusted as necessary to maintain the intended spray pattern.

Electrical System--

Inspection should include the high-voltage control panel, heater and blower control panel, high-voltage insulators, heater system thermostats, T-R sets, and all related electrical connections. When components of wet precipitator systems are similar to those of dry units, many of the inspection and maintenance practices outlined earlier will apply.

Schedule--

Table 4-3 summarizes a typical maintenance schedule, as recommended by the manufacturer and given to the plant at the time of wet ESP installation.

4.5.2 Wet ESP Operating Problems

Data on operating problems of wet ESP's are minimal. However, the following information obtained on a recent sinter plant wet ESP installation is considered typical of the problems an inspector might encounter.

Pilot tests of a wet ESP on a sinter plant in New York State showed that use of acidic recirculated water involves great potential for corrosion of reasonably priced alloys such as 316L stainless steel.[12] Operation of pH greater than 7.0, however, caused buildup of calcium and magnesium carbonate scale on spray nozzles and other critical components of the ESP, rendering it inoperable. In pilot tests of a second brand of wet ESP, the water distributor became plugged and recirculation of liquor containing acidic solids caused deposition of solids.

TABLE 4-3. MANUFACTURER'S SUGGESTED MAINTENANCE SCHEDULE FOR WET PRECIPITATORS

Component	Interval	Maintenance procedure
Key interlocks	Yearly	Check for corrosion and clean.
	Yearly	Check that key fits and turns easily; lubricate as required.
	Yearly	Check proper positioning of dust caps.
Ducts and dampers	Quarterly	Open and close dampers; operation must be smooth and positive.
	Quarterly	Check ducts for an accumulation of dust; clean as necessary.
Precipitator	Quarterly	Check condition of paint; retouch as necessary.
	Quarterly	Clean corroded areas inside casing thoroughly.
Access doors	Quarterly	Check seal for tightness.
	Quarterly	Inspect gaskets and replace if damaged.
Collecting plates and discharge electrodes	Quarterly	Clean thoroughly.
	Quarterly	Check hanging fixtures for damage.
Baffles	Quarterly	Clean thoroughly.
Hopper	Quarterly	Clean thoroughly.
	Quarterly	Check drain lines for clogging.
High-voltage system:		
T-R set	Quarterly	Check oil level; add oil if required.
	Yearly	Check and tighten electrical connections.
	Yearly	Replace damaged wiring.
	Yearly	Clean output bushing.
	Yearly	Check output bushing for cracks or damage.
	Yearly	Check continuity of ground wire.
	Yearly	Check grounding switch for positive action.

(continued)

TABLE 4-3. (continued).

Component	Interval	Maintenance procedure
High-voltage system: (continued)		
Insulators	Quarterly	Clean thoroughly and dry.
	Quarterly	Check for cracks or other damage.
	Quarterly	Tighten electrical connections.
Control panel	Quarterly	Check panel switches for positive action.
	Yearly	Check and tighten electrical connections.
	Yearly	Check condition of internal components.
	Yearly	Clean inside and outside of panel.
	Yearly	Check condition of fuses.
Heater and blower system:		
Heaters	Yearly	Check continuity of each shipment.
	Yearly	Check and tighten electrical connections.
	Yearly	Check clearance around insulator.
Blower	Weekly	Replace air filters.
	Yearly	Check condition of blower and blower motors.
Control panel	Yearly	Check panel switch for positive action.
	Yearly	Check and tighten electrical connections.
	Yearly	Check condition of internal components.
	Yearly	Clean inside and outside of panel.
	Yearly	Check condition of fuses.

(continued)

TABLE 4-3. (continued).

Component	Interval	Maintenance procedure
Spray system	Weekly	Check pressure at nozzle head.
	Weekly	Check spray pattern.
Operating checks	Daily	Check pH of water system.
	Daily	Visually check indicators for burned-out lamps.
	Daily	Check input and output meters for correct readings.
Dampers	Monthly	Lubricate operators.

In full-scale testing at the same sinter plant, however, the first wet ESP performed very well with regular weekly maintenance and inspection. Considerable attention to the recirculating water system was required to maintain the water quality that is needed for successful wet ESP operation.[12]

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SECTION 5

INSPECTION PROCEDURES

The most important task of an environmental control agency in terms of ESP performance is to establish and execute a program to ensure that ESP's at each plant continue to operate in compliance with particulate emission regulations. This program should include (1) a system by which the plant reports key information to the control agency, and (2) random unannounced inspections as well as periodic announced inspections.[1] The frequency of inspection will vary with the policy of each control agency and with the size and quality of the enforcement staff. Quarterly inspections are recommended for most plants, but many control agencies can manage only an annual inspection.[2]

Comparison of operating parameters observed during inspection with those recorded in the performance test should indicate whether emissions are within allowable limits. Major emphasis is placed on checking plant records, ESP instrumentation, and emission monitors.[3]

The following sections present step-by-step inspection procedures and a checklist of key process and control equipment components. These guidelines are designed to aid enforcement personnel in conducting on-site assessment and evaluation of ESP performance and operating conditions. In general, a coal-fired power plant serves as an example of a facility regulated by a State Implementation Plan (SIP).

5.1 PERFORMING THE PERIODIC INSPECTION

5.1.1 File Review

Unless it is a first-time inspection, the control agency should have a file containing operating data on the power plant and existing ESP's. Based on a review of these data, the inspector should know whether or not the plant can achieve compliance under normal circumstances. Particular attention should be given to pending compliance schedules and any construction and/or operating permits pertaining to processes or ESP's within the plant. The inspector should also review the number of emissions violations, malfunctions of the ESP, and complaints since the last inspection.

If not already present, the inspector should prepare a concise file summarizing the basic plant and ESP information, process descriptions, flow sheets, and ranges of acceptable operating parameters. An example of these type data is presented in Appendix C-1.[4,5] Section 3.2 provides a more detailed discussion of recordkeeping for ESP and process related parameters.

5.1.2 Arranging for the Inspection

If the inspection is to be announced in advance, lead periods of one day to one week are usually adequate to insure that the necessary personnel will be available. The inspector should obtain a schedule of plant operations during the inspection period, and should request that plant records are current and available for inspection.

Basic equipment the inspector should have to perform his job both properly and safely, are listed below.[5] Optional equipment is marked with an asterisk.

Plume evaluation equipment
Polaroid camera
Compass
Wind-speed indicator
Flashlight

Thermometer (50°-800°F)
Stop watch
Tape measure
6-foot rule
Hard hat
Safety glasses
Safety shoes
Asbestos gloves
*Manometer or pressure/vacuum gage (0-30 in. Hg and 0-10 in. H_2)
*Gas detection equipment
*Full sample containers
*Thermocouple
*Portable millivolt meter (temperature compensated)

5.1.3 External Plant Inspection

Before entering the plant, the inspector should observe the plume and determine its opacity using revised Method 9, as contained in the Federal Register. Opacity of the plume is the most indicative guide to the performance of the ESP. Water vapor condensation should not be mistaken for particulate emissions. If visible emissions are exceeding applicable standards, the inspector should use the standard form and follow established procedures for recording the violation. Table 5-1 lists possible operating factors that may be causing visible emissions.

The inspector should also note any visible emissions, odors, or dust fall in the surrounding area. He should document all significant observations, noting the date, time of day, and weather conditions.

5.1.4 Plant Entry

Upon arrival to the plant offices, the inspector should contact a responsible plant official to gain access to the plant. Visitor release forms should not be signed because this restricts insurance coverage for the inspector and may disqualify him from inspecting certain portions of the plant. The inspector has the legal right to fully inspect the air pollution sources within the plant without signing a release form. If entry to the plant is refused, the inspector should obtain a search warrant.

TABLE 5-1. PLUME CHARACTERISTICS AND OPERATING PARAMETERS FOR COAL-FIRED BOILERS[a]

Stack plume	Associated pollutant	Occurrence	Possible operating factors to investigate
White	Particulate	common	Excessive combustion air
Gray	Particulate	common	Inadequate air supply or distribution
Black	Particulate	common	Lack of oxygen; clogged or dirty burners or insufficient atomizing pressure; improper coal size or type
Reddish-brown	Nitrogen dioxide	rare	Excessive furnace temperature, burner configuration, too much excess air
Bluish-white	Sulfur trioxide	rare	High-sulfur content in fuel
Yellow or brown	Organics	rare	Insufficient excess air

[a] Based on data from Reference 3.

5.1.5 Preinspection Interview

The purpose of the inspection should be discussed with the appropriate plant official. Any changes in plant management should be noted, and data sheets on the process and ESP should be updated to confirm that operational parameters on file still pertain. This includes items such as the results from performance tests of changes in operation since the last inspection.

Examples of operational changes in the process or ESP that an inspector might check are summarized below:

Process Operational Changes

1. Has the rate of production increased or decreased? (Tons per hour, megawatts generated increased or decreased, or any other measure of production changed.)

2. Has there been a change in the product mix? For a boiler this would include a new fuel source, a change in the chemical analysis of the coal or oil. For a cement plant it would include a change in the moisture content of the slurry, or a different coal or oil as a heat source.

3. Has there been a conversion from gas or oil to coal?

4. Operating temperatures could have been changed by the addition of energy conservation retrofits. Examples are the addition of economizers to a boiler, or the addition of air or raw material preheaters in a molten metal process, or in a cement process it should include the addition of more chains in the kiln.

5. Have there been any changes in startup or shut-down procedures? Is there any new day/night schedule changes such as "Bottling Up" the boiler overnight; or, has the unit been shifted from "Baseload" to "Standby" status?

6. Have there been any changes such as the addition of new forced-draft fans or new induced-draft fans? Any addition or removal of afterburners?

7. Has there been any change made in the use of the collected dust in the process, such as, reinjection or return of the dust to the raw material mix?

8. Has the amount of excess air been changed? Has the soot blowing schedule been revised? Where applicable, has the angle of burner tilt been changed?

9. Has there been any change in the size of the fuel, or has there been any change in the fuel preparation and distribution to the burners?

Changes in ESP Operation

1. Has the effective size of the dust collector been altered? (ESP fields out of service, or new fields added.)

2. Have power input levels to the dust collector been increased/decreased? (Additional power supplies, new ESP power controls, additional reactors, power factor or rectification revisions.)

3. Have new sources of emissions been added to the dust collector such as vents from tanks in a paper mill?

4. Have any retrofits been added or removed in the ESP system? Examples are gas conditioning, sectionalization of power, additional or more powerful rappers, power off rapping, new rapping sequence controls, new power controller systems, etc.

5. Have there been changes in the dust removal system, power off rapping, new dust conveying equipment or arrangement of dust conveyors, vacuum/pressure system changes, evacuation sequence changes, combination or isolation of dust removal systems from several units?

Maintenance of Production Equipment and Dust

1. Are there established quality control and periodic maintenance schedules set up for the operations that are pertinent to the dust collector performance. Examples are fuel pulverization, fuel distribution to the burners, air louver maintenance, temperature, pressure drop, oxygen content meter calibration, and air heater cleaning.

5.1.6 Inspection Inside the Plant - Safety Considerations

On the first visit to the plant, the inspector should review all safety rules with plant personnel. He should never tour the plant without an escort, and should not open furnace doors, manipulate valves or controls, or in any way try to change the operating characteristics of the plant equipment. Obviously, the high-voltage electricity used in the ESP is extremely dangerous, and all practical safety measures must be observed even though the system incorporates interlocks and other safety devices.

5.1.7 Procedures for External Inspection of ESP's Control Sets

The first item that the inspector should check is the control sets for the ESP, which are usually located in a room on top of, or remote from, the ESP. Plant personnel should provide a diagram showing which fields are served by which TR sets, as a guide to determining out-of-service fields when reading the TR sets. Control panels can include primary and secondary current and voltage meters, and a spark rate meter. If the ESP has four sections, the voltage, amperage, and spark rate should be recorded for each section. The control set readings should be compared with calibrated or design values for each section. The inspector should check the daily log of control readings to determine whether the readings have been drifting from normal. Drift is indicative of such problems as air inleakage at air heaters or in ducts leading to the ESP, dust buildup on ESP internals, and/or deterioration of electronic control components. He should also make note of inoperative meters, the number of power supplies on "manual" control, and TR sets on "auto" that are held to operating levels below design specifications (such as might be done to reduce wire breakage).

The inspector can utilize the meters to aid in diagnosing other problems with an ESP. General examples of the effect of changing conditions in the gas stream and within the ESP on control set meters are presented below:[6]

1. When the gas temperature increases, the voltage will increase, and the current will decrease. Arcing can develop. When the gas temperature decreases, the voltage will decrease, and the current will increase.

2. When the moisture content of the gases increases for any given condition, the current and voltage will also tend to increase in value.

3. If reduced voltage exists because of a sparkover, a rise in moisture may allow for an increase in the precipitator voltage level.

4. An increase in the concentration of the particulate will tend to elevate voltages and reduce current flow.

5. A decrease in the particle size will tend to raise voltage while suppressing current flow.

6. A higher gas velocity through the precipitator will tend to raise voltages and depress currents.

7. Air inleakage may cause sparkover in localized areas resulting in reduced voltages.

8. A number of precipitator fields in series will show varying readings with voltage-current ratio decreasing in the direction of gas flow.

9. If a hopper fills with dust causing a short, the voltage will be drastically reduced, and the current will increase.

10. If a discharge electrode breaks, violent arcing can be observed with the meters swinging between zero and normal.

11. If a transformer-rectifier unit shorts, voltage will be zero at a high current reading.

12. If a discharge system rapper fails, the discharge wires build up with dust; the voltage increases to maintain the same current level.

13. If a plate rapper fails, the voltage decreases to maintain a current level under sparking conditions.

Table 5-2 presents specific examples of the effect of changing conditions on ESP control set readings. These examples are typical of what the inspector could expect to find. He should become familiar with these meter reading techniques, so that he is aware of problems during his inspection. Sections 3.2 and 4.3 present more detailed analyses of V-I curves and their use in troubleshooting. Corona power readings can also be used to estimate operating efficiency of the ESP, as will be discussed in Section 6.

TABLE 5-2. EFFECTS OF CHANGES IN NORMAL OPERATION ON ESP CONTROL SET READINGS[6]

Condition	Effect	Primary voltage V, a.c.	Primary current A, a.c.	Secondary current mA, d.c.
1. Normal full load	-	300	50	200
2. System load fall by 1/2	Gas volume and dust concentration decrease, resistance decreases	260	55	230
3. System load constant, but increase in dust load	Resistance increases	350	40	175
4. Gas temperature increases	Resistance rises, sparking increases because of increased resistivity	300-350	50-60	20-250
5. Gas temperature decreases	Resistance decreases	280	52	210
6. ESP hopper fills with dust	Resistance decreases	180	85	300
7. Discharge electrode breaks	Resistance may fall to 0 (may vary between 0 and normal if top part of electrode is left swinging inside the ESP). Violent instrument fluctuations. Arcing can be heard outside the ESP	0-300	0-50	0-200
8. Transformer-rectifier shorts	No current passes from T-R set to the ESP	0	100+	0
9. Discharge system rapper fails	Dust builds up on discharge electrodes. Resistance increases because corona discharge decreases. Additional voltage required to keep current constant	330	50	200
10. Collection plate rapper fails	Sparking increases. Voltage must be reduced to keep current constant	265	50	200

5.1.8 Control Room Ventilation

Next the inspector should check control room temperature to see that ventilation is adequate, as well as general housekeeping. He should check the control sets internally for dirt, which can cause false signals and cause components to deteriorate.

5.1.9 T-R Sets, Rapper/Vibrators, and Insulators

Many times the T-R sets and rappers and/or vibrators are located in the same room as the control sets, on top of the ESP. In any event, the T-R sets, insulators, and rapper/vibrators, should be inspected next.

The inspector should examine insulators for moisture and tracking from arc-over. Cracks can be spotted with a bright light during inspection.[6] Corrosion of the insulator compartment (if applicable) is another indication of moisture buildup. The inspector should check to see that the pressurization fan for the top housing or insulator compartment is operating properly, and that air filters for control sets and top housing are not plugged. He should also note the condition of access hatch covers.

The inspector should check rapper and vibrator action visually and/or by feel. A uniform rhythmic tapping of metal to metal should be noted for rappers, and a loud buzzing sound from vibrators. Any irregular sounds are an indication of improper operation of rappers or vibrators. The plant should provide a diagram of the rapping system sequence so that the inspector can verify that all of the rappers or vibrators are operating properly. Rapping intensity should be checked against design as stack opacity can be improved by reducing rapping intensity. Therefore, indications that rapping intensity has been reduced, should be questioned.

5.1.10 Exterior Condition of ESP

The inspector should next examine the exterior of the ESP for corrosion, loose insulation, exterior damage, and loose joints. The ducts entering the ESP should be checked; if they show corrosion, the interior of the ESP may also be corroded. The inspector should check for fugitive emissions at loose joint, and as a result of other exterior damage.

5.1.11 Ash Handling

The inspector should next check to see that the exacuation rate for the ash hoppers is often enough to prevent buildup of ash over the tops of the hoppers. Inlet field hoppers, for example, normally collected from 60 to 80 percent of the total catch, and must be evacuated much more often than the downfield hoppers. If level alarms are used, he should determine that they are operating properly. The inspector can check the temperature at the hopper throat with the back of his hand, and if one is comparatively low in temperature, this could indicate that a malfunction of the ash removal system could cause bridging or plugging of the hoppers and subsequent ash buildup.

Problems the inspector should look for in the ash evacuation and removal system include water pump failure, disengagement of vacuum connections, malfunction of rotary air lock valves, and failure of sequencing controls.

If ash is removed from a collection silo by truck, the inspector should insure that the discharge pipe extends far enough into the truck to minimize fugitive emissions.

5.1.12 Process Instrumentation

After finishing with the ash handling system, the inspector should then proceed to check a number of process parameters that can affect the ESP performance. For example, readings of gas flow, gas velocity, excess air, gas temperature, pressure drop across the ESP, moisture content, flue gas analysis (O_2, CO_2, etc.) soot blowing intervals, and opacity should be taken if possible. Many of these instruments are located in the boiler control room and have continuous readouts. An example trace from a continuous opacity monitor is shown in Figure 5-1. Variations in readings from process instruments from the normal design ranges should be investigated as to their possible effect on ESP performance, in conjunction with ESP control set readings, and visual observations made during the inspection.

5.1.13 Internal Inspection of an ESP During Scheduled or Emergency Outages

If an ESP is down for scheduled maintenance or because of a malfunction, and an inspection is being done, the inpsector should take time to perform some checks in addition to those already mentioned. These inspection techniques are similar to those the company should be doing during an annual inspection, but are not as detailed. These techniques were covered in Section 4 and are discussed further in Appendix A.

As mentioned previously in this section, no inspection should be undertaken until it is certain that the ESP is deenergized and grounded, and necessary precautions are taken to ensure that the equipment cannot be energized during the inspection.

5.1.14 Collection Plates/Discharge Wires

The inspector should observe the dust accumulation on both plates and wires. The discharge wires should only have a slight coating of dust with no corona tufts (doughnut-shaped ash accumulations). Thickness of dust buildup on plates is normally between 0.3 and 0.6 cm (1/8 to 1/4 in.). If the plates have more than 0.6 cm (1/4 in.) of dust, the rappers are not cleaning properly. If the collecting plates are almost metal clean, this may be an indication of high gas velocity, extremely coarse fly ash, too high a rapping intensity, or too low an operating voltage for good precipitation. The inspector may notice this if a section has been shorted out prior to his inspection.

The inspector should note whether or not the discharge electrodes are centered between the collecting plates from top to bottom to ensure optimum performance. He should note any broken

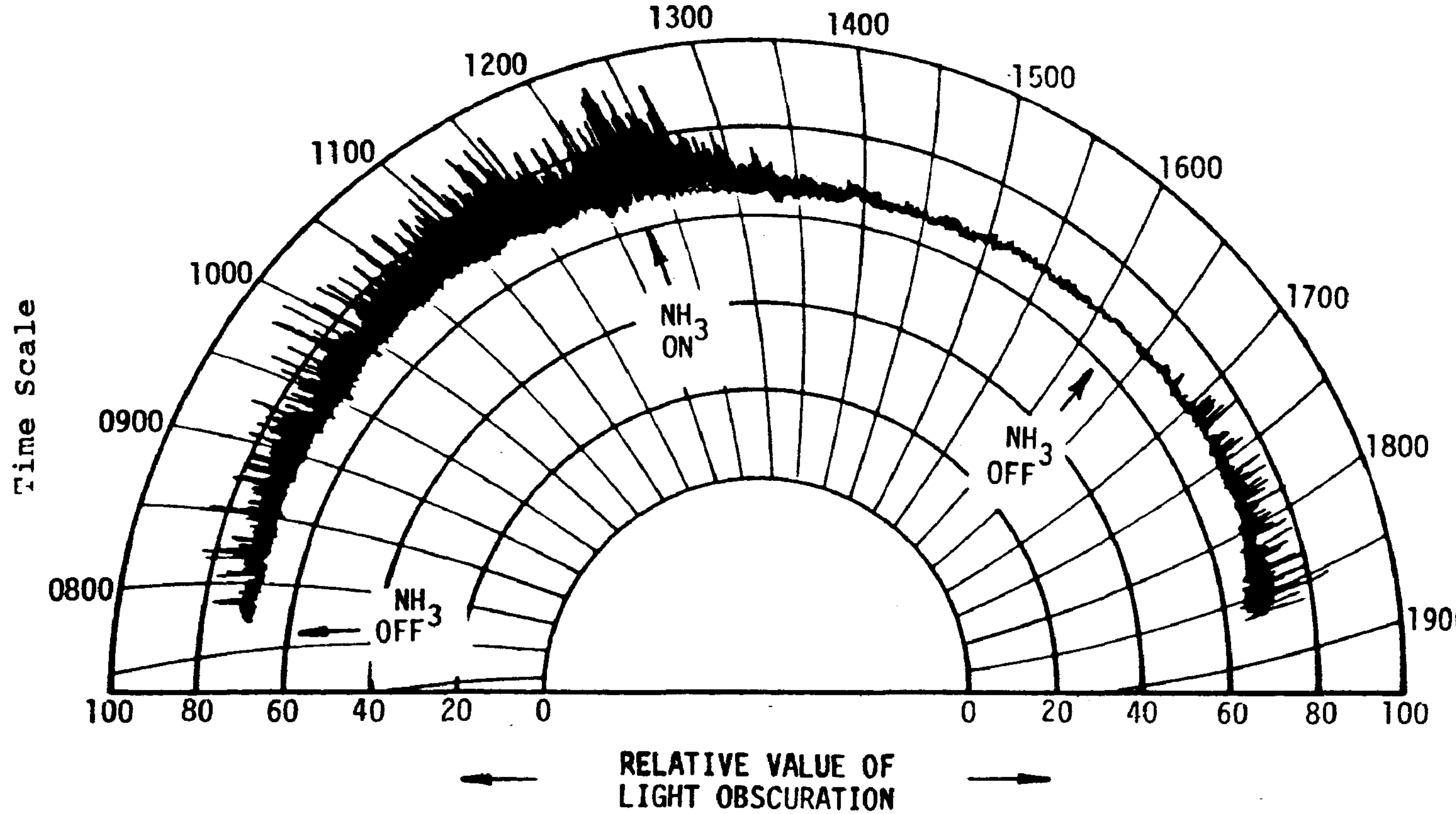

Figure 5-1. A sample opacity chart.[7]

or missing discharge electrodes. Records of wire breakage should be kept by the company to help determine the cause of continued wire breakage in the same area, possibly caused by alignment problems. Random wire breakage is probably caused by dust buildup on wires or plates.[6]

The inpsector can check for air inleakage from door openings by noting the amount of corrosion on collecting plates adjacent to inspection hatches, and from hoppers by checking on the lower portion of the collecting plates. Air inleakage also causes nonuniform gas flow, and can reduce efficiency.

5.1.15 Hoppers

The inspector should have plant personnel open the hopper access door and check for corrosion, which indicates air inleakage as mentioned previously. He should check for dust buildup in the upper corners of the hopper, and debris such as fallen wires and weights in the hopper bottom and valves. If discharge electrode weights have dropped 3 inches or more, this indicates a broken wire. Chronic buildup of ash is an indication of low operating temperatures, insufficient heat insulation, or inadequate hopper emptying.

5.1.16 Review of Operating Records

The inspector should review operating records from the process and ESP, both for completeness and for changes in operation that may have affected ESP performance. Table 5-3 lists a number of items for which records should be kept. Malfunctions from both the process and the ESP should be discussed with plant officials, and the inspector should determine what plant officials are doing to remedy any recurrent problems.

5.1.17 Inspection Form

Data obtained during an inspection should be summarized on a form such as that presented in Appendix C-2. The form also serves as a record of the inspection.

TABLE 5-3. RECOMMENDED RECORDKEEPING REQUIREMENTS[3]

	Frequency	Comments
ESP		
Controls		
Instrument calibration	Initial measurement	Compare daily measurements with redlined readings. Check for gross misreadings or slow drift from redline.
Primary current, A	Daily	
Primary voltage, V	Daily	
Operating current, mA	Daily	
Operating voltage, kV	Daily	
Spark rate, sparks/min	Daily	
Pressure drop through system, in.	Daily	Compare with initial pressure
Rapper operation	Daily	Check frequency and intensity
Insulator condition	Daily	Check for deterioration
Hoppers	Daily	Level alarms, evacuation system
BOILER		
Fuel quality	Monthly	State range of values and average
Sulfur, %		
Ash, %		
HHV, Btu/lb		
Recording instrumentation		
Fuel flow-air flow control	Daily	Maintain circular charts for 3 months
Steam flow-air flow control	Daily	Maintain circular charts for 3 months
Changes in boiler operation	As occurring	
Flue gas analysis, % by vol. (Circle CO_2 or O_2)	Spot checks	
Soot blowing intervals	Daily	State hours or blows per day
Malfunctions (boiler or ESP)	As occurring	Use standard form to describe malfunctions

5.1.18 Compliance Action

If conditions observed during the inspection indicate that a citation is warranted, the inspector must clearly state to plant officials the grounds for such a citation. An onsite citation is justified only by clear-cut violations such as excessive opacity, reduced corona power, or failure of the plant to report malfunctions or to maintain or provide required records for review. Table 5-4 lists important compliance parameters and conditions for issuance of citations.[3]

After a review of the inspection report by the inspector's supervisor, a copy of the inspection checklist should be sent to the utility with a letter confirming that the inspection was made, stating any deficiencies, requesting that they be corrected within a reasonable time. Recommendations can be given for further improvements in operation and maintenance of the ESP, although emphasis should be towards indications of trouble and not the solution.

The utility should know what is expected and the time frame it will have to accomplish the required action. Some type of implementation plan may be requested.

TABLE 5-4. IMPORTANT COMPLIANCE PARAMETERS AND CONDITIONS FOR ISSUANCE OF A CITATION[a]

Compliance parameter	Conditions for issuance of a citation
Visual emissions	Federal Register, Section 60.11 and Appendix A - Method 9 - promulgated.
Opacity monitors	a) Not in operation: issue citation b) Not properly calibrated or zeroed: advise plant personnel to implement a calibration program, which might include services of outside consultants.
ESP instrumentation	a) Not in operation: request in followup letter a schedule for repair of instruments. b) Values indicating unit out of compliance: determine reasons; request that plant take appropriate corrective action.
Records	a) Not kept: issue citation b) Values indicating plant is out of compliance: Monitors - If opacity standard is ever exceeded for more than 2 continuous hours, issue citation. Fuel records - If ash/sulfur content is frequently over values recorded during performance test, determine reason. Generating capacity - Disregard short-term peak loads. If electrical output/fuel usage is consistently higher than emission test values, request another performance test. c) Daily instrument zero/calibration: issue citation if ESP instruments are not zeroed and calibrated within 3 or more consecutive days. d) Fuel analysis: units without SO_2 control equipment must record fuel analysis daily. e) Malfunction records: if complete information (time, levels, malfunction description, problem correction methods) is not recorded for all malfunctions, issue citation.

[a] Based on data from Reference 3.

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SECTION 6

ESP PERFORMANCE EVALUATION

This section presents procedures for evaluating and predicting ESP performance on the basis of previous stack test inspection results. A procedure is provided for relating ESP electrical data (corona power) to emission level, based on previous stack emission test data. Brief discussions are made on the use of advanced modeling techniques including: a) programmable calculator ESP performance model, and b) computerized ESP performance model.

6.1 INTRODUCTION

An approach can be developed which will enable regulating agencies to account and check for continuous compliance for conventional electrostatic precipitators (ESP). Analysis of recordkeeping logs of process and ESP operating conditions can be used along with baseline test results to determine a corresponding emission level for a defined set of ESP operating conditions. A technological basis can be substantiated to correlate ESP corona power input with partiuclate emission levels. This general relationship between corona power and emission level is consistent with theoretical and practical design methodologies. The same empirical (engineering) adjustments that ESP vendors customarily incorporate into their design considerations and criteria can be likewise incorporated and engineered into emission regulations.

A comprehensive set of baseline test results will establish the specific relationship between corona power and emission level for a specific process/ESP combination. Known ranges of the correlation factor are available for several major industries typically using conventional ESP's (see Section 6.2). Once this relationship (and coefficient) is established, both the operating and regulating parties will have a known corona power level to use as a technical measure of ESP performance for a corresponding emission level. Refer to Table 3-2 for an outline of the baseline test information needed for this regulation measure.

The established relationship between corona power and performance level can be verified again during compliance testing. If the ESP is upgraded, or if significant changes in process, feed materials, or fuel quality occur, then an updated baseline test is required to redefine the corona power - emission level relationship.

More comprehensive baselining with sophisticated measurement and analytical techniques can be incorporated into this approach as future air quality needs and resources deem practical. Alternate methods of ESP performance analysis can be performed through use of a calculator program (Section 6.6) or a computerized model (Section 6.7). However, EPA has not endorsed any method other than stack testing for emission level determination. Consequently, these analytical methods can only be used to indicate, but not to define, emission levels. Subsequent stack testing under similar ESP conditions (i.e., with reduced corona power levels) would need to be performed to determine the actual emission level.

6.2 TECHNICAL BASIS FOR CORONA POWER - EMISSIONS CORRELATION[2]

The following demonstration of technical material provides convincing but only fundamental evidence of the relationship between corona power and emission levels. Limited resource dedication restricts the level of treatment for substantiation of this relationship in this text. Additional resource allocation is necessary to expand the basis and technical materials for suitable substantiation for this evolutionary step to occur in a new regulation process.

The preceding sections of this report emphasized the basis and use of secondary electrical data for O&M purposes. This section will likewise use and base electrical data measured and recorded by secondary metering, but will use the term (adjective) corona instead of secondary. The term corona is preferred for use in this treatment for reasons of: 1) consistency with the reference material applied, and 2) technological aptness. The presence, intensity, and distribution of the corona phenomena determine the effectiveness of collecting particulate in electrostatic precipitation. Corona power is a measure of the presence and intensity of the electrical energy (driving force) effectively utilized in the precipitation process. The extent of corona power effectively used in precipitation is measured by the secondary voltage and current meters. The primary electrical meters measure the power components fed to the T-R sets, and represent indirect measurement of the intended power usage level. Furthermore, complications (e.g., O&M difficulties) and energy transmission losses through the T-R set discourage the use of primary electrical levels for definitive purposes. Since secondary metering is direct, available, and cost-effective, its use is emphatically encouraged.

The precipitation rate of particles increases with the electric field strength in the precipitator, evidenced by the two following equations:[2]

$$w = \frac{q\,EP}{6\pi\Theta a} \quad 1 + \alpha \frac{\lambda}{a} \qquad \text{Equation 1}$$

and

$$w = \frac{Z\; e_o\, E_c\, E_p\, a}{\theta} \qquad \text{Equation 2}$$

where w = precipitation rate parameter (or migration velocity)

q = particle charge

Ep = the precipitating field

θ = gas velocity

a = particle radius

λ = mean free path

α = dimensionless parameter ≈ 0.86

E_c = charging field strength

e_c = permittivity of free space

The electric field strengths are dependent on the corona (secondary) voltage and current levels experienced in the precipitator. Corona power may be calculated by the formula:

$$Pc = (V_{avg})\ (I_{avg}) \qquad \text{Equation 3}$$

where Pc = corona power, watts

V_{avg} = corona voltage, volts (secondary voltage)

I_{avg} = corona current, amps (secondary current)

For a multi-field precipitator, Pc is the sum of the individual corona power levels for each of the fields. Power consumed in excessive sparking or lost in leakage represents wasted power and should not be included. Since wasted power due to current leakage is not utilized for precipitation, it becomes necessary to qualify that the ratio of corona voltage to corona current be specified by the manufacturer to establish appropriate boundaries for effective current usage.

The precipitation rate parameter w_e is related to the corona power by the approximate formula

$$w_e = K_1 \frac{Pc}{A}$$ Equation 4

where K_1 = dimensionless parameter

A = collection surface area

Numerical values of K_1 can be calculated from performance test data taken during the baseline test, and are usually in the range of 0.1 to 0.7 for conventional ESP's over the spectrum of industrial source categories.[2]

Corona power may also be related to collection efficiency by substituting the value of w_e given by Equation (Deutch-Andersen equation):

$$n = 1 - e^{-(A/V)w}$$ Equation 5

where n = collection efficiency

V = volume of gas treated

w = particle migration velocity

to give:

$$n = 1 - e^{-K_1(Pc/V)}$$ Equation 6

where Pc/V = corona power density, watts/unit of gas volume.

If corona power density is expressed in watts per 1000 acfm, then Equation 6 can be rewritten in the form

$$n = 1 - e^{-0.06K_1(Pc/V)}$$ Equation 7

Approximate values of K_1 can be theoretically determined; accurate values of K_1 can be empirically determined from performance tests, especially over the limited range of normal process and precipitator operating conditions.[2]

The use of penetration facilitates calculation of emission levels, as penetration levels are directly proportional to emission levels. Equation 7 can be rearranged and simplified in the form of penetration as:

$$p = e^{-0.06\ K_1 (Pc/V)} \qquad \text{Equation 8}$$

where p = penetration = 1 - efficiency

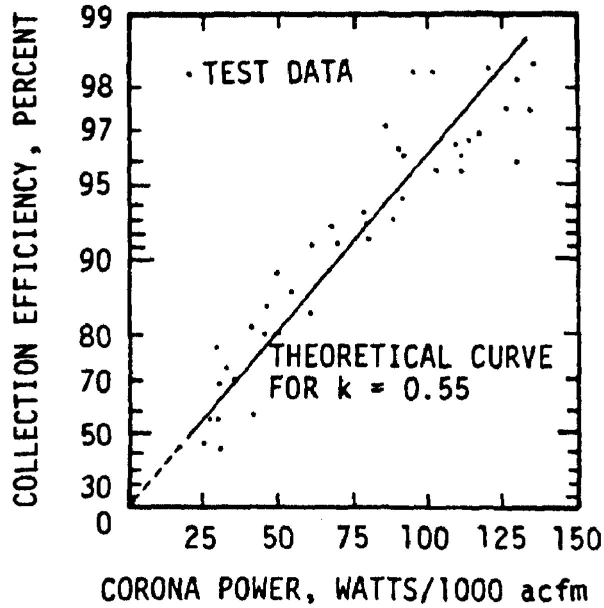
Actual performance results on precipitator efficiency versus specific corona power (Pc/V) from many fly ash studies are shown in Figure 6-1. The solid line in Figure 6-1 represents the theoretical relationship between efficiency and specific corona power for $K_1 = 0.55$ using the following equation (Equation 9) to account for variations in gas throughput:

$$\frac{A}{V} w = \ln \frac{1}{P} \qquad \text{Equation 9}$$

where P = penetration = 1 - efficiency

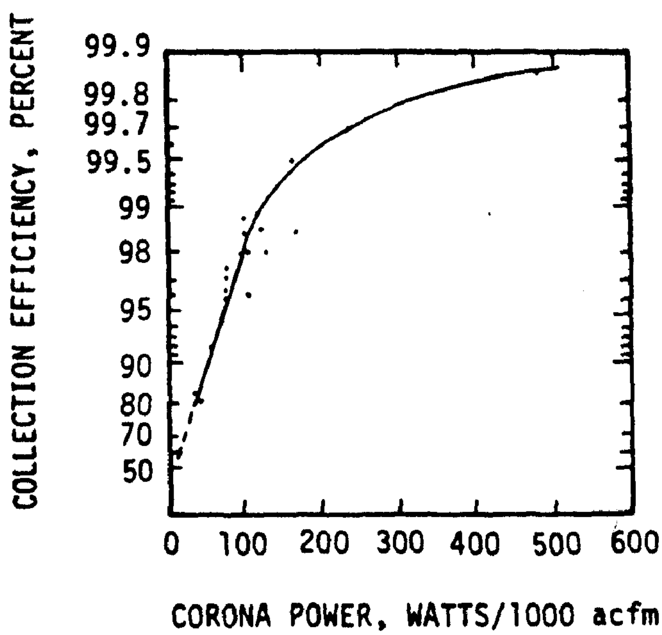
Reasonable correlation exists between the theoretical curve and experimental results, considering that the experimental results represent a large number of preciptiator installations on sources of fly ash.

During recent years it has become common practice to install high performance ESP's exhibiting higher collection efficiencies (99+%) than earlier installations. Another common practice of recent ESP installations is that large-sized units are becoming popular due to their cost-effective control of larger sized industrial processing facilities. These modern day trends do not change the theoretical basis of electrostatic precipitation, but do impact ESP performance characteristics and engineering design details. Extension of ESP performance results to include high performance cases of 99+% efficiency are shown in Figure 6-2. The above-mentioned change in performance characteristics is reflected by the inflection point of the best-fit curve at or near the 99.0% efficiency level. The significant change in the slope of the curve relating efficiency to specific corona power reflects the substantial increase in corona power to attain higher performance. The linear relationship plotted on the semi-log graph for the below 99% cases does not depict the actual relationship for the above 99% cases.



METRIC CONVERSION: (watts/1000 acfm) (2500) watts/1000 m^3/sec

Figure 6-1. Relationship between collection efficiency and specific corona power for fly ash precipitators, based on field test data.[1]



METRIC CONVERSION: (watts/1000 acfm) (2500) = watts/1000 m^3/sec

Figure 6-2. Efficiency versus specific corona power extended to high collection efficiencies, based on field test data on recently installed precipitators.[2]

Further inventory and inspection of performance results need to be conducted in order to qualify the general relationship of corona power and emission level in this high performance range ($\geq$99%). Until further resources are dedicated to examine and better define the characteristics in the high efficiency range, a concession will be made for the remainder of this text, and exclusion of the characteristically different regime will be made.

Table 6-1 presents values or range of values for the coefficient (K_1) relating corona power and collection efficiency for several industrial source categories. These coefficient values were calculated using Equation 7 and Reference 1. More source categories and corresponding coefficients are achievable with further inventorying.

TABLE 6-1. CORONA POWER - EMISSIONS COEFFICIENT FOR SEVERAL INDUSTRIAL CATEGORIES[1]

Industrial category	K_1 coefficient
Electric utility fly ash	0.55
Pulp and paper	0.129
Recovery boiler	0.106
Cement plants (range with wet and dry process)	0.785 (wet) 0.226 (dry)
Municipal incinerators (range)	0.57 → 1.88
Steel - open hearth furnace	0.19

6.3 PRACTICAL BASIS FOR CORONA POWER - EMISSIONS CORRELATION

Fundamental in this treatment of ESP performance is the axiom (and later the demonstration) that conventional ESP performance will degrade with time. This axiom simply means that normal "wear and tear" occurrences with ESP's cause deterioration in collection performance. Almost without exception, the performance of any system will degrade over a period of time, and servicing of components is needed to restore performance. Conventional precipitator performance becomes less effective as a direct result of usage. The intentional collection of particulate material on the plates and wires reduces collection performance relative to clean internal conditions. Other factors contribute to degradation, such as reentrainment. ESP reentrainment losses are at a minimum level with clean internal conditions due to the reduced availability of particulate material to become reentrained.

Factors that affect the rate and extent of performance degradation are:

1. Competency of engineering design,
2. Competency of O&M practices, and
3. Characteristics of process operations.

It is not pertinent in this text to delineate or prioritize these factors and their relationship with performance degradation. It is, however, pertinent to establish the reality, typical rates, and extent of performance degradation to be expected, and the means of identifying performance degradation. Identification is the first step for resolving performance degradation. This degradation is real and can be proven by a number of facts such as:

1. The common sense realization that all control systems have wear and tear factors which lower performance.
2. ESP performance will diminish due to the presence and accumulation of particulate material.
3. ESP operators "strategically" schedule compliance testing during peak performance periods.
4. ESP vendors acknowledge performance degradation due to a) particulate accumulation and b) a need for regularly scheduled ESP outages for servicing and cleaning for performance maintenance.

5. Regulating and inspecting ESP personnel have evidence of degradation from stack emission and visual emission data.

The rate and extent of degradation cannot be quantified at this time by referenceable material. Variation in degradation characteristics is expected to be extensive across the spectra of industrial source categories, ESP types and vintages, and O&M practices. Non-referenceable sources (i.e., private communication with ESP operators, vendors, and researchers) indicate that ESP degradation is analogous to other natural decay phenomena. Figures 6-3 and 6-4 illustrate the expected degradation profile of typical ESP performance and corona power levels. The performance and corona power trends in Figures 6-3 and 6-4 are:

1. Presumed for full-scale systems, projected from EPA's mobile pilot ESP performance trends taken from several short-term performance test programs;

2. Time-extrapolated to asymptotically approach a minimum performance level;

3. Independent of severe, sudden changes in ESP-internal conditions or significant process variations; and

4. Offered to be qualitative and not quantitative.

A continuing performance tracking over a continuing time period is the object of a continuing compliance pursuit. Failure to account for continuing emissions tracking will preclude and negate continuing compliance pursuits. The particulate emissions curve in Figure 6-3 portrays real-time emission tracking for a hypothetical ESP-controlled emission source. The curve in Figure 6-3 includes the scenario of "strategic" compliance testing shortly after washdown/servicing and the "acceptable" stack emission results. As time continues from washdown/servicing, performance degradation occurs, resulting in a gradually increasing emission level. Eventually, the actual emission level

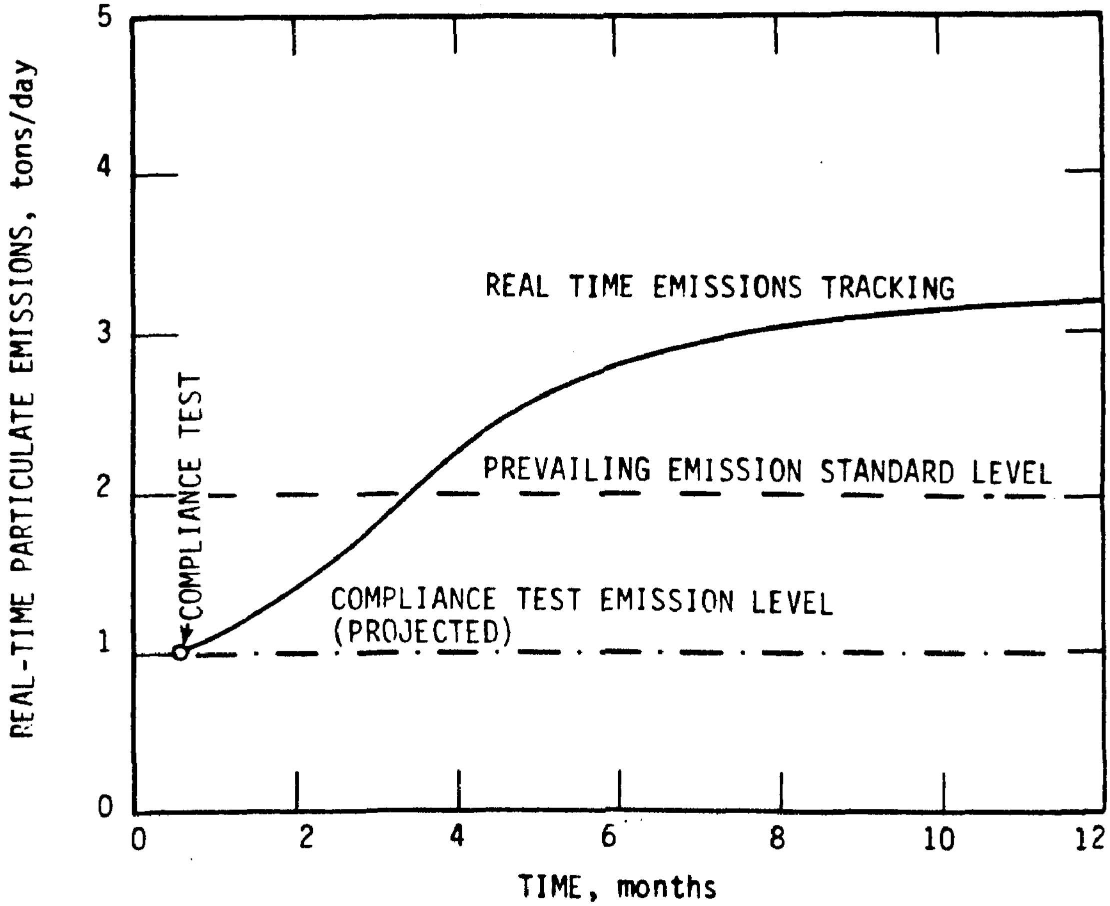


Figure 6-3. Real-time particulate emission scenario.

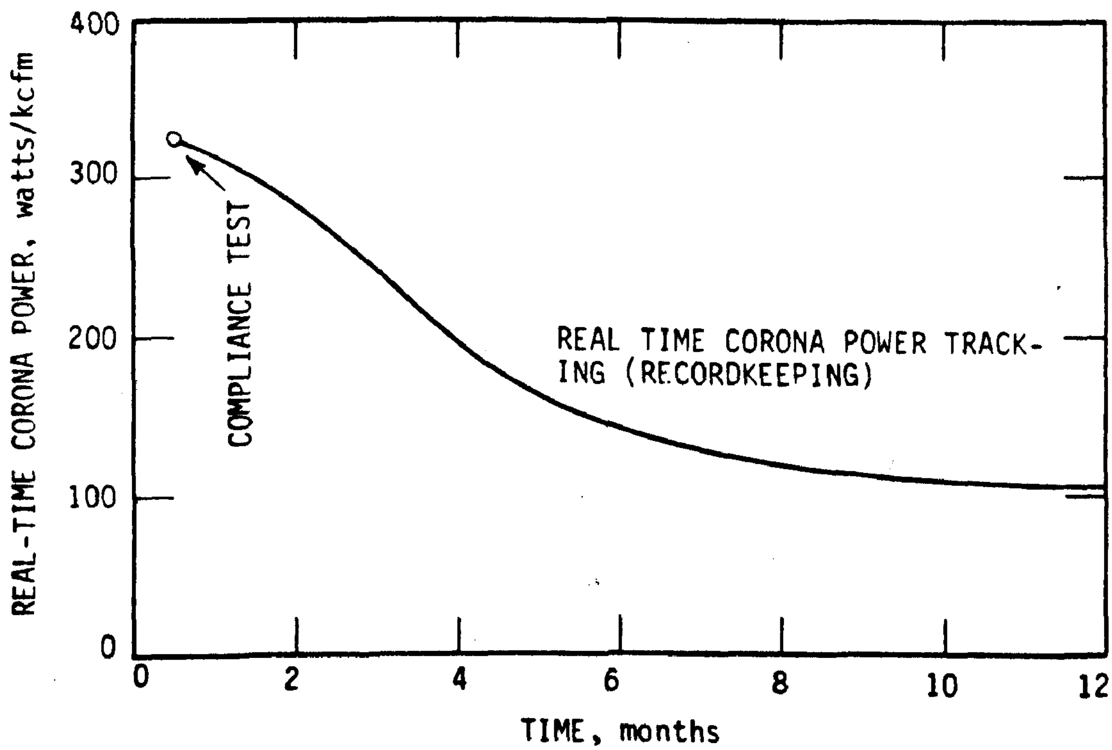


Figure 6-4. Real-time corona power scenario.

rises above the prevailing emission standard level, and approaches steady-state performance and emission level conditions.

The curve in Figure 6-4 illustrates the corresponding corona power levels over this presented scenario. As demonstrated previously, a relationship exists between collection performance and specific corona power. Recordkeeping of corona power levels with secondary electrical metering would provide real-time evidence for correlation with emission levels, once this relationship is established.

Time integration of the projected and actual emission inventories is illustrated in Figure 6-5. The difference between the projected (assumed) and actual emission inventory levels is significant, and, without adequate instrumentation and recordkeeping, "strategic" compliance testing scheduling is effective in circumventing compliance standards. Actual emission levels become several-fold higher than projected levels, and ambient concentrations of particulate material fall short of modeled (projected) levels. Excessive ambient concentration levels then become construed to indicate a need for lower emission levels, and/or inappropriate dispersion modeling methodology. Erroneous conclusions then promote ineffective appropriations to study the economic impact of lower emission levels, and/or improved ambient modeling methodology. Since the fundamental problem has yet to be realized, the solution to restoring cleaner air quality levels is not achieved even though money is appropriated and spent to further study the symptoms.

Certain qualifications in determining effective corona power levels will need to be provided if/as corona power relationships with emission levels are to be implemented. There are two circumstances which serve as exceptions to the corona power correlation. However, both exceptional cases can be qualified in exactly the same manner. Both problem-related cases involve secondary-current levels which are excessive to design current

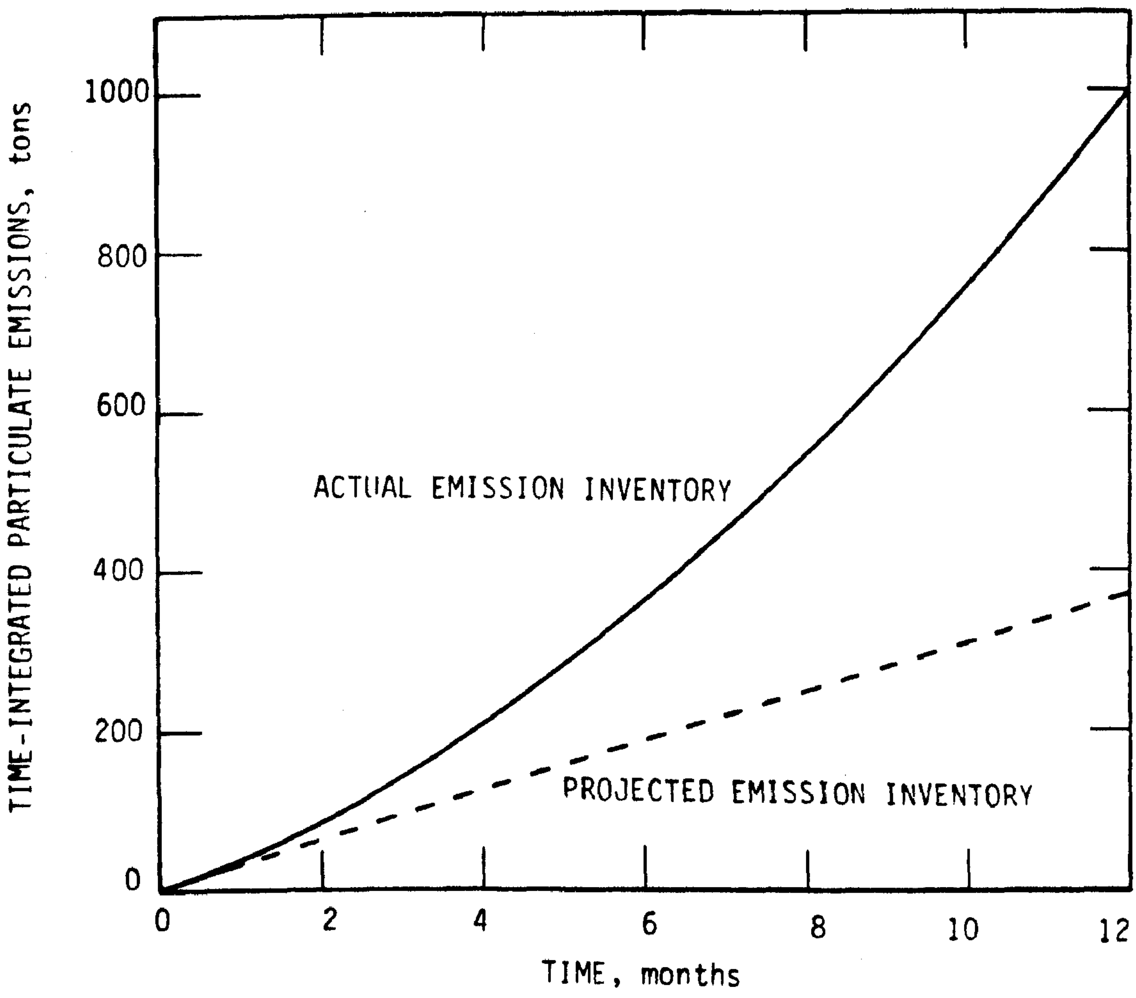


Figure 6-5. Integrated particulate emission inventory scenarios.

levels, and the excessive current levels are not effectively used in the precipitation process. These two problem-related exceptional cases are: 1) primary or secondary current leakage (leakage meaning current levels that are generated, but not delivered to the corona wires), and 2) back-corona conditions due to excessive resistivity. Since corona power is the product of secondary voltage and current levels, either of these exceptions will increase corona power levels without a corresponding increase in collection performance.

An appropriate qualification or criterion can be made to assure that the effective corona power determined is indeed "effective" in the precipitation process by the use of Ohm's law: resistance = voltage/current. Stipulation of a minimum secondary resistance denotes that this determination is made from secondary voltage and secondary current levels. The minimum secondary resistance level criterion can be stipulated on a general or specific basis. A general basis will be offered in this text, but a more specific resistance criterion could (and perhaps should) be stipulated for nontypical ESP design cases. Based on typical secondary voltage and current density levels experienced in conventional ESP's, a minimum secondary resistance level near or at 1×10^9 ohm/ft^2 is usable as the necessary criterion. This criterion includes consideration of collection plate area in the units (ohm/ft^2) for resistance to allow for flexibility and variation in ESP size across the spectrum of industrial application.

6.4 BASELINE TECHNIQUE USING STACK TEST RESULTS

When recent stack test results are available and complete (use Table 3-2 for a guide to evaluate completeness), the corona power-emissions relationship can be used to estimate the emission level using the corona power levels obtained during the inspection. The following example case will demonstrate this technique for a power plant, using data from Table 6-2, and Equation 8.

TABLE 6-2. EXAMPLE DATA FROM STACK TEST AND INSPECTION RESULTS

	Stack test results	Data from inspection
Production rate, MW net	640	640
Gas temperature, °F	300	300
Total corona power, W	156,250	125,000
Gas flow rate, acfm	1,250,000	1,250,000
Specific corona power, watts/kacfm	125	100
Particulate emission level, lb/10^6 Btu	0.32	?

Table 6-2 presents abbreviated results from a recent stack test and inspection. For the sake of simplicity, abbreviated results are provided in this hypothetical, but representative example. Most other operating data and conditions listed in Table 3-2 are virtually the same for the stack test and inspection time periods. Notice, however, that the total corona power and specific corona power levels are at reduced levels during the inspection as compared to the power levels during the stack test. The following calculations will demonstrate a method of estimating the emission level during the inspection.

Use Equation 8 and stack test results to determine penetration:

$$P = e^{-0.06\ (.55)(P_c/V)}$$

$$= e^{-0.06\ (.55)125} \qquad \text{where } P_c/V = 125 \text{ watts/kcfm}$$

$$= 0.0161$$

Since penetration is proportional to emission level, the coefficient of proportionality can be calculated by:

$$P(C) = E.L.$$

where c = coefficient

E.L. = emission level

Rearranging to determine the coefficient value, and using stack test results for E.L. = 0.32 lb/10^6 Btu

$$c = E.L./P$$

$$= {}^{0.32}/_{0.0161}$$

$$= 19.8$$

Using Equation 8 and the inspection data to determine penetration:

$$P = e^{-0.06(.55)100}$$

$$= 0.0369$$

Using the coefficient value from the stack test, and the calculated penetration value for the inspection period, calculate the estimated emission level by using:

$$\begin{aligned} E.L. &= P(c) \\ &= 0.0369(19.8) \\ &= 0.73\ lb/10^6\ Btu \end{aligned}$$

A graph can be constructed to show the relationship between emission levels and specific corona power. Figure 6-6 illustrates such a relationship, using the data supplied in Table 6-3.

6.5 CORONA POWER DATA AND EFFICIENCY ESTIMATES

6.5.1 Control Set Data

Read secondary currents and voltages for each field of the precipitator. Calculate delivered corona power for each section according to the following formula:

Delivered power = (secondary voltage) x (secondary current)

If there are no meters for secondary voltage and current, calculate delivered power for each precipitator field as follows:

Delivered power = (input power) x (power supply efficiency)
Input power = (primary current) x (primary voltage)

Typical power supply efficiency is 90 percent.

Determine total corona power input by summing the delivered power for each section. Calculate corona power input as watts per 1000 m^3/s (1000 ft^3/min) of flue gas. Obtain precipitator collection efficiency value from Figures 6-1 or 6-2.

If one or more bus sections are not operating, this will be reflected in the reduced total corona power available, resulting in lower collection efficiency.

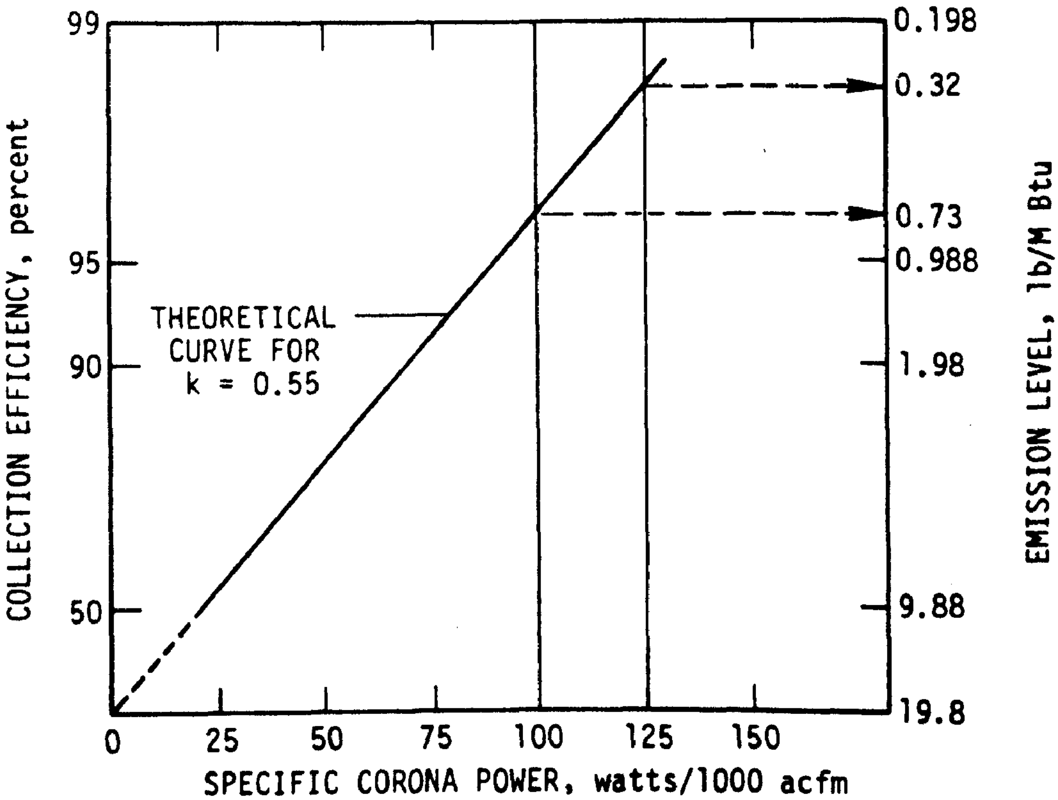


Figure 6-6. Relationship between collection efficiency, emission levels and specific corona power (for the example case specified by Table 6-2).

TABLE 6-3. INPUT DATA FOR ESP COMPUTER MODEL

ESP specifications	Gas/particulate specifications
Estimated efficiency	Gas flow rate
Precipitator length	Gas pressure
Superficial gas velocity	Gas temperature
Fraction of sneakage/reentrainment	Gas viscosity
Normalized standard deviation of gas velocity distribution	Particulate concentration
Number of stages for sneakage/reentrainment	Particulate resistivity
Number of electrical sections in direction of gas flow	Particulate density
For each electrical section:	Particle size distribution
Length	Dielectric constant
Area	Ion mobility
Applied voltage	Ion speed
Current	
Corona wire radius	
Corona wire length	
Wire-to-wire spacing (1/2)	
Wire to plate spacing	
Number of wires per linear section	

6.5.2 Design Data

From ESP design data, obtain gas flow, temperature at ESP inlet, total ESP plate area, plate area for each bus section, and precipitation rate parameter (may need to be recalculated when coal sulfur content has changed significantly). Make sure that the design values for gas flow and temperature at ESP inlet are still accurate for the current operating conditions.

Using the Deutsch equation or one of its derivatives (see Section 2), calculate the ESP collection efficiency, accounting for loss in plate area because of bus section outage. Consider the following example (English units):

- precipitation rate parameter (w) = 0.35 ft/sec (21 ft/min).
- gas flow (V) = 300,000 acfm @ 300°F
- total plate area (A) = 84,000 ft^2 (21,000 ft^2/bus section, four bus sections total). One bus section is out of service, reducing effective plate area to 63,000 ft^2.

From the Deutsch equation:

$$n = 1 - \exp - \frac{A}{V} w$$

$$= 1 - \exp - \left(\frac{63{,}000}{300{,}000}\right) (21)$$

$$= 1 - 0.0122 = 98.78\%$$

Note that the outlined procedures are based on generalized or design data and are not precise enough to reflect quantitatively the changes caused by readily measurable variations in operating parameters. Thus emission estimating procedures are normally used as a part of the initial permit evaluation process to judge the adequacy of the system for complying with emission regulations.[3]

6.6 CALCULATOR PROGRAM FOR ESP PERFORMANCE EVALUATION[5]

A report describes the latest version of calculator programs to simulate and predict ESP performance, and to use the predicted particle size data penetrating the ESP to predict venturi scrubber performance and, similarily, project in-stack opacity from the scrubber effluent particle size distribution. The programs are written specifically for a Texas Instruments, Inc. TI-59 programmable calculator with a PC-100A printer. The advantates of using a programmable calculator for these purposes are convenience, economy, and simplicity. The program results are considered to be as accurate as the input data, meaning the errors in the input data are likely to be more than errors introduced by the program. Complete listing of the calculator programs are included in the report, along with step-by-step instructions and examples.

The ESP calculator programs are based on the EPA/Southern Research Institute (EPA/SoRi) ESP Computer Model Revision I. A more complete discussion of the theory and programming details is contained in References 7 and 8. The programs are equipped with computations to determine particle charging and particle collection levels. Corrections for non-ideal factors are provided to account for non-uniform gas flow, gas sneakage, and particle reentrainment.

Two ESP programs are provided to use either log-normal or histogram formats of particle size distribution data as input. Other input data required to exercise the model include the following:

ESP specifications	Gas/particulate specifications
Wire to plate spacing	Temperature
Specific collection area	Pressure
Length of precipitator	Gas velocity
Superficial gas velocity	Dielectric constant
Applied voltage	Ion mobility
Secondary current density	Ion speed
Number of sections for sneakage	Particle size distribution
Normalized standard deviation of gas velocity	
Sneakage fraction	

The calculator programs run 30 minutes for the log-normal particle size input and 60 minutes for the histogram particle size input. The program will calculate the overall penetration, the ideal and corrected outlet size distribution, ideal migration velocity as a function of particle size, and the ideal and corrected penetrations as a function of particle size. A copy of the results will be displayed by the printer. These results can be used with other input data in the opacity programs to calculate the associated in-stack opacity level.

The calculator program can be used to evaluate precipitator performance and to indicate emission levels based on ESP operating conditions and previous stack test results. An approach, similar to the one described in the previous section, can be used to correlate secondary voltage and current levels (corona power) with emission levels. Comprehensive stack test results can be incorporated into the program to establish a relationship between ESP conditions and emission level. Iterative exercise of the program will probably be needed to adjust estimated values for sneakage and gas distribution in order to obtain reasonable agreement between predicted and measured emission levels. Once these empirical factors are obtained and agreement between predicted and measured emissions is reached from use of stack test results, then reasonable prediction of emission levels can be made for other cases of ESP conditions.

6.7 COMPUTER MODEL FOR ESP PERFORMANCE EVALUATION

An ESP mathematical model has been developed under EPA sponsorship by Southern Research Institute (SoRI) which relates collection efficiency to ESP size and operating parameters. [The model is applicable for dry, wire-plate ESP's.] The computerized mathematical model has been revised in order to reduce computer time and extend its use for different levels of analysis. Complete discussions on the programming, use, and revisions of the

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SECTION 7

CASE HISTORIES

The purpose of presenting these case histories is to familiarize the inspector with some actual operating problems of ESP's in the field, and the attempts made to correct these problems. Although it is not the responsibility of the inspector to tell the company how to resolve problems with a precipitator, he may be able to provide some suggestions as to what a problem might be, and methods that could be used to rectify it.

7.1 COLD-SIDE ELECTROSTATIC PRECIPITATOR ON A COAL-FIRED UTILITY BOILER

This section presents the operating history of a cold-side ESP installation at a coal-fired power plant located in the Southern United States. The information presented here was obtained during a site visit and from discussions with engineering personnel.

7.1.1 System Description and Operating History

The precipitator was originally installed in 1960 and was guaranteed for 90 percent efficiency with an SCA of 18 $m^2/m^3/s$ (91 $ft^2/1000$ acfm). Actual precipitator efficiency was 55 percent or less at the normal gas temperature of 132°C (270°F) and about 90 percent at 155°C (310°F). This is a common effect observed in marginally designed precipitators operating at average gas velocities of approximately 2.4 m/s (8 ft/s) with medium- to high-sulfur coals. Studies with ammonia injection showed a significant improvement in performance at 132°C (270°F), with efficiencies ranging from 85 percent at 0.0009 m^3/s (2 scfm) ammonia per ESP to 95 to 97 percent with 0.005 to 0.01 m^3/s (10 to 20 scfm) ammonia.

In 1970-72, the ESP was modified to improve performance. The SCA was increased from 18 $m^2/m^3/s$ to 27 $m^2/m^3/s$ (91 $ft^2/1000$ acfm to 136 $ft^2/1000$ acfm), and the number of T-R sets per collector was increased from 2 to 5. The present arrangement consists of four separate collectors, each with four fields in the direction of gas flow. Collection efficiencies about 98 percent were obtained with ammonia injection in 1972, when the utility began using ammonia on a full-time basis.

Recently, however, performance has decreased to 90 percent or less, and outlet emissions are several times greater than the state regulation of 47.26 ng/J (0.11 $lb/10^6$ Btu). Some of the major causes for poor performance at this unit are summarized below.

1. Initial design was marginal, calling for a small ESP to operate at excessively high gas velocities for the sulfur and temperature conditions. The expected level of performance for the system at the time of the modifications was only 95 percent.

2. Poor equipment availability and component malfunctions.

3. Unstable T-R electrical sets, limited power output capability, poor match to load conditions, and uncontrolled sparking, causing excessive dust reentrainment.

4. The ammonia injection rate is now limited to 8 to 10 ppm because sticky ash buildup on ID fans has caused severe imbalances and buildup in hoppers has caused difficulty in ash removal. Higher levels of ammonia injection are needed to prevent excess air reentrainment, which is caused by low ash resistivity with the high-sulfur coal used by the utility at gas temperatures of 116° to 138°C (240° to 280°F). The untreated ash can be readily collected but is easily reentrained before being rapped off of plates into the hopper.

5. Cyclic boiler load operation aggravates the problems of condensation and sticky ash, especially in ash hoppers, which are marginally sized and have no heaters. In addition, boiler tubes leak frequently.

6. Possibly serious gas sneakage under the plates through the top of the hopper has resulted in untreated gas and or reentrainment of ash that has build up in the hopper. The plant reports that although ash buildup occurs often, there is little problem with T-R sets being shorted out by the ash. This suggests the possibility that gas sneakage carries dust across the top of the hoppers and out of the precipitator, thus preventing ash buildup beyond a certain level.

7. Possible electrode misalignment, loose wires, or other factors prevent operation at optimum electrical conditions. During the plant visit about five T-R sets (25% of total) were operating far below normal capability.

8. A recent preliminary test with ammonia indicated a performance that was typical of the expectations without an additive. It is possible that many nozzles are plugged with ash encrustations and the ammonia distribution is poor enough to negate its usefulness in retention of collected ash.

Some pertinent recommendations to improve performance, suggested by a well-known ESP consultant, are as follows:

1. A major reduction in the amount of dust reentrained is needed. This involves many aspects:

    a. Proper hopper baffling and baffles between fields to eliminate gas flow under collecting plates and dust sweepage out of hoppers. Proper gas distribution should be assured. Gas must enter the ESP horizontally with no significant upward or downward vectors, particularly the latter, which can reentrain hopper dust. Regions of excessively high gas velocity in the ESP should be eliminated.

    b. Continued use of a properly functioning ammonia injection system with good distribution and design to minimize ash deposition and pluggage. A high injection velocity should be maintained through the nozzles into the gas stream [minimum 60 m/s (200 ft/s)]. The minimum amount of ammonia to effect desirable agglomeration and ash retention should be used. At low boiler loads, less ammonia may be needed, but caution should be taken to ensure that plugging does not occur. If the ammonia system is shut off, suitable air flow through nozzles should be maintained.

c. Increasing gas temperature to a minimum of 140°C (280°F), preferably to 155° to 160°C (310° to 320°F), can be a corrective measure in lieu of ammonia injection. The able level to aid retention. The correct level is one that will not seriously degrade electrical conditions. High power input aids collection and retention of dust, but less power is required for a somewhat higher ash resistivity than is prevalent with high-sulfur coal and low gas temperature.

d. Boiler additives to chemically absorb excess SO_3/H_2SO_4 in flue gas are also a possible alternative to injection or increased gas temperature. The advantage of such additives is some control of ash resistivity at low gas temperature where boiler efficiency is good. Possibilities could be investigated.

e. The location of the ID fan suggests the possibility of downward pull of gases through the precipitator if outlet vaning is not adequate. A vertical profile of dust concentration in outlet or precipitator is useful. Perhaps a 0.9 to 1.2 m (3 to 4 ft) high baffle at the outlet of the ESP would be helpful.

2. The voltage ratings of the T-R sets and saturable reactor type control should be improved to provide a better match to the requirements of the precipitator load. The electrical control circuits can be modified to improve stability and response and to provide additional corona power capability. It is recommended that linear reactors be added in the primary circuit in series with the present saturable reactors.

   For conditions at this plant, electrical sets should be operated with very little or no sparking. It is particularly important in the outlet sections to operate at just under the sparking threshold.

3. Rapping effectiveness and optimum conditions (duration, frequency, and force) should be investigated. A program to accomplish this is now underway. Determining the extent of dust being reentrained is the first step. With regard to rapping frequency and force, fairly frequent, light blows are probably best. With vibrators installed at this plant, the operating duration must be reduced to the minimum possible. Outlet section rapping can also be very critical; usually only the minimum amount of rapping needed to maintain electrical conditions used.

4. The best possible effort should be made to control condensation and sticky ash.

7.2 ELECTROSTATIC PRECIPITATOR TO CONTROL PARTICULATE EMISSIONS FROM CEMENT KILNS

This case history covers the use of an ESP on a cement kiln in a plant located in the Eastern United States. The information was obtained during a site visit and from discussions with engineering personnel.

7.2.1 System Description

The plant has two cement kilns, which consume over 500 metric tons of coal per day. The ESP, which controls particulate emissions from both kilns, was manufactured by Western Precipitation and installed in 1962. It is designed to handle 172 m^3/s (430,000 cfm) at approximately 260°C (500°F) and, according to plant personnel, operated within ± 15 percent of design rate.

Gas flow is split into an upper and a lower precipitator. Both have four active fields and an empty one. The first three upper and lower fields are each energized by one T-R set, whereas the outlet fields on the upper and lower precipitators are each energized by a separate T-R set. Thus, the entire system contains a total of five T-R sets.

Approximately 70 percent of the collected dust is recycled to the kilns, and the remainder is sluiced to a spray pond. Sluice water is recycled.

7.2.2 Operating History

Many modifications have been made to the precipitator since 1972 to meet state particulate emission regulations. The modifications have eliminated most maintenance problems, and the collection efficiency is reported to be as high as 99.5 percent with outlet loadings as low as 16 kg/h (36 lb/h). Following is a brief discussion of the total maintenance problems that have plagued this installation and the efforts that have been made to alleviate these problems:

1. A 1972 inspection revealed that the discharge and collection electrode alignment were not correct at the bottom of the frame because of expansion and contraction of the frame and hoppers, and weak guide supports; warpage and buckling of some plates were also noted. Correction of the frame misalignment has markedly improved collection efficiency.

2. Air inleakage into screw conveyors continued to cause reentrainment of dust and corrosion of metal on the screw conveyors. Holes are patched as they occur, and a new design of screw conveyor with better slide gate seals is gradually being substituted. Because expansion joints at the inlet and outlet of the precipitator initially were not insulaed, the metal rotted out and caused air in-leakage. Proper insulation solved this problem.

3. Because insulator compartments on top of the ESP are not insulated, pressurized, or heated, moisture condensation has caused severe corrosion in a number of the compartments and occasional failure of an insulator. The company has designed a new insulator compartment, which is insulated and may be pressurized with heated air. Present insulator compartments are gradually being replaced.

4. Shafts of vibrators on discharge wires have failed repeatedly. Two men are engaged full time in welding crecked vibrator shafts. A new Syntrom vibrator used on some sections of the ESP has been successful, requiring almost no maintenance.

5. Difficulties caused by control panel overheating were compounded by numerous failures of fans used to cool the control compartments. This was solved by moving the saturable reactors to a better ventilated room behind the control compartment.

6. Excessive sparking in the inlet fields of the ESP has caused failure of a large number of wires because of arcing. The company is considering replacing the saturable reactors on these sections with silicon controlled rectifier/linear reactor combinations in an attempt to improve current limit control and current wave form to reduce sparking.

7. Gas distribution has always been a problem with this ESP because the gas flow is split into an upper and lower ESP. The addition of a damper in the common

ductwork on top of the ID fan has improved the balance of flow; turning vanes would probably improve gas distribution even further, but the company believes they are too expensive.

8. The rapping system was improved by installing stronger supports for the discharge electrode vibrators on the top level and on bent collecting electrode supports. The rapping duration and intensity were then readjusted until satisfactory results were obtained.

7.2.3 Maintenance Procedures

A regular maintenance schedule is followed, and malfunctions are recorded. The state environmental control agency is notified when serious problems arise.

7.2.4 Conclusion

Plant personnel have shown great initiative in making the modifications needed to improve the performance of the precipitator and bring the kiln emissions into compliance with state particulate emission regulations. By following a regular maintenance schedule and continuing to improve the quality of the precipitator components, plant personnel are confident that the present high level of performance can be maintained indefinitely.

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APPENDIX A

STARTUP AND SHUTDOWN PROCEDURES AND MAINTENANCE SCHEDULE FOR ELECTROSTATIC PRECIPITATORS (ESP's)

PRECIPITATOR STARTUP AND SHUTDOWN PROCEDURES

Operation of an electrostatic precipitator (ESP) involves dangerously high voltage. Although all practical safety measures are incorporated into the equipment, extreme caution should be exercised at all times. An ESP is, in effect, a large capacitor that when deenergized can retain dangerous electrical charges. Grounding mechanisms provided at each access point should therefore be used before entering the precipitator.

Preoperational Checklist - Before placing the equipment in operation, plant personnel should perform a thorough check and visually inspect the system components in accordance with the manufacturer's recommendations. Some of the major items that should be checked are summarized below:

Control Unit

Proper connections to control

Silicon Rectifier Unit

Rectifier-transformer insulating liquid level
Rectifier ground switch operation
Rectifier high-voltage connections made
High-voltage bus transfer switch operation

High-Tension Connections

High-tension bus duct
Proper installation
Vent ports properly installed

Equipment Grounding

Precipitator grounded
Transformer grounded
Rectifier controls grounded
High-tension guard grounded
Conduits grounded
Rapper and vibrator ground jumpers in place

Air Load Tests - After the precipitator is inspected (i.e., preoperational check adjustment of the rectifier control and check of safety features), the air load test is performed. Air load is defined as energization of the precipitator with minimum flow of air (stack draft) through the precipitator. Before introduction of an air load or gas load (i.e., entrance of dust-laden gas into the precipitator), the following components should be energized:

Collecting plate rappers
Perforated distribution plate rappers
High-tension discharge electrode vibrators
Bushing heaters - housing/compartments
Hopper heaters - vibrators - level indicators
Transformer rectifier
Rectifier control units
Ventilation and forced-draft fans
Ash conveying system

The purpose of the air load test is to establish reference readings for future operations, to check operation of electrical equipment, and to detect any improper wire clearances or grounds not detected during preparation inspection. Air load data are taken with the internal metal surfaces clean. The data consist of current-voltage characteristics at intervals of roughly 10 percent of the T-R milliamp rating, gas flow rate, gas temperature, and relative humidity.

For an air load test, the precipitator is energized on manual control. The electrical characteristics of a precipitator are such that no sparking should occur. If sparking does occur, an internal inspection must be made to determine the cause. Usually, the cause is (1) close electrical clearances and/or (2) the presence of foreign matter, such as baling wire, that has been left inside the precipitator.

After the precipitator has been in operation for some time, it may be necessary to shut it down to perform internal inspections. At such times, it would be of interest to take air load data for comparison with the original readings.

Gas Load Tests - The operation of a precipitator on gas load differs considerably from operation on air load with respect to voltage and current relationships. The condition of high current and low voltage characteristizes the air load, whereas low current and high voltage characterize the gas load. This effect governs the operation of the precipitator and the final setting of the electrical equipment.

MAINTENANCE SCHEDULE FOR ESP's

Daily

An accurate log should be kept on all aspects of precipitator operation including electrical data, changes in rapper and vibrator operation, fuel quality, and process operations. Such a log can provide clues to the probably cause of any change in performance.

For example, it is obvious that gross departures from normal readings on the T-R meter and transmissometer indicate trouble. It is not so widely recognized that small variations, often too slight to be noticed without checking daily readings, can indicate impending trouble.[1]

Problems that usually affect precipitator performance gradually, rather than suddenly, include (1) air inleakage at heaters or in ducts leading to the precipitator, (2) dust buildup on precipitator internals, and (3) deterioration of electronic control components. Such problems are often indicated by slight but definite drift of daily meter readings away from baseline values.[1]

Grossly abnormal readings, usually indicating a serious problem, also may aid in diagnosing the probable cause. For example, sudden tripout of an apparently normal electrical set probably indicates a short or ground in the secondary circuitry. A low but steady Voltage reading indicates a high-resistance ground, such as that from discharge wires, which may be caused to ground by accumulation of ash above a plugged hopper or formation of clinker on a wire.[1]

Fluctuating voltage that dips to low values suggests a broken and swinging discharge electrode. Fluctuation of spark-rate meter readings does not necessarily indicate a problem unless voltage or current readings fluctuate also.[1]

An operator should never try to correct deviant meter readings by adjusting control set points. An automatic-control response range should accommodate normal variations in load. When major changes occur, such as would result from firing a coal substantially different from that for which the precipitator was designed, the precipitator manufacturer should be called in to retune the installation.[1] If no such major changes have occurred, then variant meter readings indicate problems that must be detected and corrected. Figure A-1 exemplifies a log of electrical readings that are checked several times each day at a coal-fired utility. These readings are used in troubleshooting problems with ESP operation.

Probably 50 percent of all electrical set tripouts are caused by ash buildup. Short of set tripout, buildup above the top of hoppers can cause excessive sparking that erodes discharge electrodes.[1] Further, the forces created by growing ash piles can push internal components out of position, causing misalignment that may drastically affect performance. Sometimes utility operators attempt to preserve alignment by welding braces to hold collecting-electrode plates in position. This practice is inadvisable because restraining the plates reduces the effectiveness of the rapping action that keeps them clean.[1]

Although various indicators and alarms can be installed to warn of hopper-ash buildup and of ash-conveyor stoppage, the operator can doublecheck by testing temperature at the throat of the hopper with the back of the hand. If the temperature of one or more hoppers seems comparatively low, the hopper heaters may not be functioning properly.[1] Generally, however, low temperature indicates that hot ash is not flowing through the hopper and that bridging, plugging, or failure of an automatic dump valve has held ash in the hopper long enough for it to cool. The ash subsequently will pile up at the top.[1]

PRECIPITATOR LOG SHEET UNITS 1 & 2

	NO 1 PRECIPITATOR	12 MID	3 AM	6 AM	9 AM	12 NOON	3 PM	6 PM	9 PM
SET 4	PPTR CABLE 1 KV								
	AVG SPARK RATE								
	PPTR CABLE 2 KV								
	TRANS PRI VOLTS V								
	PPTR AVG CURRENT MA								
	TRANS PRI CURRENT								
SET 3	PPTR CABLE 1 KV								
	AVG SPARK RATE								
	PPTR CABLE 2 KV								
	TRANS PRI VOLTS V								
	PPTR AVG CURRENT MA								
	TRANS PRI CURRENT								
SET 2	PPTR CABLE 1 KV								
	AVG SPARK RATE								
	PPTR CABLE 2 KV								
	TRANS PRI VOLTS V								
	PPTR AVG CURRENT MA								
	TRANS PRI CURRENT								
SET 1	PPTR CABLE 1 KV								
	AVG SPARK RATE								
	PPTR CABLE 2 KV								
	TRANS PRI VOLTS V								
	PPTR AVG CURRENT MA								
	TRANS PRI CURRENT								
NO 2 PRECIPITATOR									
SET 8	PPTR CABLE 1 KV								
	AVG SPARK RATE								
	PPTR CABLE 2 KV								
	TRANS PRI VOLTS V								
	PPTR AVG CURRENT MA								
	TRANS PRI CURRENT								
SET 7	PPTR CABLE 1 KV								
	AVG SPARK RATE								
	PPTR CABLE 2 KV								
	TRANS PRI VOLTS V								
	PPTR AVG CURRENT MA								
	TRANS PRI CURRENT								
SET 6	PPTR CABLE 1 KV								
	AVG SPARK RATE								
	PPTR CABLE 2 KV								
	TRANS PRI VOLTS V								
	PPTR AVG CURRENT MA								
	TRANS PRI CURRENT								
SET 5	PPTR CABLE 1 KV								
	AVG SPARK RATE								
	PPTR CABLE 2 KV								
	TRANS PRI VOLTS V								
	PPTR AVG CURRENT MA								
	TRANS PRI CURRENT								

REMARKS ______________________________

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OPERATORS 12-8 __________ 8-4 __________ 4-12 __________

DATE __________ DAY __________

Figure A-1. Precipitator log sheet.

If the temperatures of all hoppers seem low to the touch, the ash-conveyor system should be checked; the system may have stopped or dust agglomeration may be so great that the conveyor can no longer handle all of the fly ash.

Hopper plugging is sometimes caused by low flue gas temperature, which permits moisture condensation.[1] Temperature of gas at the boiler exit may be too low, or ambient air may be leaking into the flue gas duct. Hoppers are particularly prone to plugging during startup after an outage, when they are cold and usually damp.

Daily checking of the control room ventilation system minimizes the possibility of overheated control components, which can cause the control set points to drift and can accelerate deterioration of sensitive solid-state devices.

Weekly

Solenoid-coil failures, fairly common when high voltage was used, are rare with modern low-voltage equipment.[1] Still, a weekly check of all units is advisable. Rapper action should be observed visually, and vibrator operation confirmed by touch. If inadequate rapping force is suspected, an accelerometer mounted on the plates should be used to verify that rapping acceleration is adequate (often, up to 30 g is required). This is best done on a pretest check.

Control sets must be checked internally for deposits of dirt that may have penetrated the filter. Accumulation of dirt can cause false control signals and can damage such large components as contactors and printed circuits.

Finally, filters in the lines supplying air to control cabinets and to the precipitator top housing should be checked and cleaned if necessary to prevent plugging.[1]

Monthly

Most new precipitators incorporate pressurized top housings that enclose the bushings through which high-voltage connections are made to the discharge electrodes within the precipitator box. Pressurization ensures that if gas leakage occurs where the bushings penetrate the precipitator hot roof, gas will flow into the precipitator rather than out from it. Leakage from the precipitator into the housing could cause ash deposits or moisture condensation on the bushings, with risk of electrical breakdown at the typical operating potential of 45 kV d.c.[1]

Monthly maintenance also should include inspection of bushings visually and by touch for component vibration, checks of differential pressure to ensure good operation of the fan that pressurizes the housing, and manual operation of the automatic standby fan to make sure it is service-ready.

Quarterly

Quarterly maintenance includes inspection of electrical-distribution contact surfaces. These should be cleaned and dressed and the pivots should be lubricated quarterly if not more frequently,[1] since faulty contacts could cause false signals. Further, because transmissometer calibration is subject to drift, calibration should be verified to prevent false indications of precipitator performance.

Semiannually

Inspection, cleaning, and lubrication of hinges and test connections should be done semiannually. If this task is neglected, extensive effort eventually will be required to free test connections and access doors, often involving expensive downtime. Performance tests may be required at any time; they should not be delayed while connections are made usable. An effective preventive measure is to recess fittings below the insulation.[1]

Inspection of the exterior for corrosion, loose insulation, surface damage, and loose joints can identify problems while repair is still possible. Special attention should be given to points at which gas can leak out as fugitive emissions.[1]

Annually

Scheduled outages must be long enough to allow thorough internal inspection of the precipitator. Following is a summary of items to be checked during an annual inspection, abstracted primarily from Reference 2.

1. Dust Accumulation - The upper outside corners of a hopper usually show the greatest accumulation. A spotlight can be used to check for dust buildup, eliminating the need to enter the hopper.

2. Corrosion - Inaccessible parts of the ESP are often attacked by corrosion. Access doors and frames, which are difficult to insulate, are usually attacked first. Condensation can occur in penthouses that contain support insulators; the penthouses are at lower temperature than the gas, and moisture is added also by purge air from the outside.

Corrosion can occur at several places in the ESP housing: the underside of roof plates, the outside wall, the space between outside collecting surface plates and sidewall, the back of external stiffening members that act as heat sinks, and any area not continuously subject to gas flow, such as corners and the upper portion of the hopper connection to inlet and outlet ducts. All gas connections should be checked for inleakage of oil, gas, or air.

Corrosion in these areas can be minimized by keeping interior surfaces hot and by effective thermal insulation of outside surfaces, use of heaters during routine shut downs or operation at low loads also may help prevent corrosion.

3. Rappers - Maintenance of the magnetic-impulse, gravity-impact rapper has been discussed. Many rigid-wire ESP's, however, have mechanical rappers. The drives for collecting and discharge electrode rappers should be checked for high motor temperature, unusual noise, and level and condition of the lubricant.

Mechanical rappers should be checked for excessive wear, shifting of point of impact, free movement of wire-frame rapper release, free movement of hammers, and wear on hammer shaft bushings.

4. Hoppers - On both wire-weight and rigid-wire precipitators, the hopper discharge should be checked for such objects as broken pieces of rappers, wires, shotcrete, and scale. Presence of foreign objects indicates a problem that should be investigated further.

5. Gas Distribution Plates - Although perforated plates usually do not become plugged, uneven distribution of uneven low gas load can sometimes cause plugging of a portion of the plates. If a rapping system is not used, manual cleaning is required.

6. Discharge Electrodes - Frames in rigid-frame, discharge-electrode-type precipitators should be centered between two rows of collecting surface plates with a maximum deviation of ± 0.6 cm (± 0.15 in.). Discharge wires must be straight and securely connected to the discharge frame.

Wire-weight precipitators should be checked for missing or dropped weights. Common causes of wire failure and remedial action are discussed in the following section on malfunctions. Removal of a broken wire that is not replaced should be recorded on a permanent log sheet.[3] Discharge wires should be cleaned manually as required.

7. Collecting Electrodes - Collection plates should be inspected for warping due to excessive heat. Corrosion of lower portions of the plates and portions of plates adjacent to door openings indicates air inleakage through hoppers or around doors.[3] Plates should be cleaned manually as required.

8. Suspension Insulators - When insulators become heavily coated with moisture and dust, they may become conductive and crack under high-voltage stress. Cracks can be spotted with a bright light during inspection. Faulty insulators can cause excessive sparking and voltage loss and can fail abruptly or even explode if allowed to deteriorate.

9. Housing - Thick dust deposits on interiors of housings indicate high gas velocities resulting from excessive gas volumes, a condition that should be corrected.

If the precipitator is located between the air heater and the boiler, expansion joints must be checked and slide plates lubricated. Finally, if necessary, all collection plates and electrode wires should be cleaned manually.[1]

Situational Maintenance

Certain preventive maintenance and safety checks are so important that they should be performed during any outage of sufficient length, without waiting for scheduled downtime. Air load readings should be compared with baseline values to detect possible deterioration in performance. Readings taken immediately upon restoring the precipitator to service can serve as a check on any changes resulting from maintenance done during the outage.

Critical internal alignments should be checked whenever an outage allows; any misalignment warrants immediate corrective action. Interiors of control cabinets and top housing should be checked during any outage of 24 hours or more and cleaned if necessary. Any outage of more than 72 hours provides an opportunity to check grounding devices, alarms, interlocks, and other safety equipment and to clean and inspect insulators and bushings.[1]

Safety

Because high-voltage electricity can be extremely dangerous, all practical safety measures must be observed even though the system incorporates interlocks and other safety devices.[4]

The system should never be adjusted with the high-voltage power on.

Rectifiers and diodes have heat sinks that could seriously shock a person touching them.

The rapper circuitry, which is independent of the high-voltage circuitry, is nonetheless also dangerous and must be so treated.

Spark-rate feedback signals are often taken from the primary of the high voltage supply and can be 400 V a.c. or more. Fuses on these lines should be removed before maintenance or adjustment is attempted.[4]

Explosive gas mixtures could be created if air is introduced into the systems. If necessary, a system should be purged with an inert gas before air is introduced. A system should always be purged with fresh air before it is entered.

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APPENDIX B

TYPES OF ELECTROSTATIC PRECIPITATOR MALFUNCTIONS

TYPES OF ELECTROSTATIC PRECIPITATOR MALFUNCTIONS

Discharge Wire Breakage

Probably the most common problem associated with suspended wire electrode ESPs is wire breakage, which typically causes an electrical short circuit between the high-tension discharge wire system and the grounded collection plate. The electrical short trips the circuit breaker and disables a section of the ESP, which remains disabled until the broken discharge wire is removed from the unit.

Following are the principal causes of discharge wire breakage:

1) Inadequate rapping of the discharge wire causes an arc, which can embrittle the wire and eventually break it completely.

2) Clinkered or improperly centered wires cause a continual spark from the wire to the bracing.

3) A clinker or wire bridges the collection plates and shorts out the wire.

4) Ash buildup under the wire causes it to sag and short out.

5) Improper clearance of "J" hooks to the wire causes it to short out.

6) Hangup of a bottle weight during cooling causes a wire to buckle.

7) Fly ash buildup on a bottle weight forms a clinker or burns off the wire.

8) Corrosion caused by condensation around cooler areas of the wire.

9) Excessive localized sparking causes erosion of the wire.

Electrical erosion, the predominant cause of failures, occurs when repeated electrical sparkovers or arcs occur in a localized region. Heating and vaporization of a minute quantity of metal occur with each spark. Sparkover at random locations will cause no serious degradation of the discharge electrode.

Repeated sparkover at the same location, however, can remove significant quantities of material, with subsequent reduction of cross-sectional area and ultimate failure at that point.[1]

Localized sparking can be caused by misalignment of the discharge electrodes during construction or by variations in the electric field resulting from "edge" effects of adjacent discharge and collection electrodes at the top and the bottom of the plates. Measures that will eliminate failure at these points are adding shrouds, such as those shown in Figure B-1, and providing a rounded surface at the edge of the collection electrode to reduce the tendency for sparking.[1]

Electrical erosion can also be caused by "swinging" of electrodes, which can occur when the mechanical resonance frequency of the discharge wire and weight system is harmonically related to the electrical frequency of the power supply. The power supply adds energy to the swinging wire, and sparking occurs with each close approach to the collection plate. This action leads to erosion of the electrode and mechanical failure.[1]

Poor workmanship during construction can also cause electrical failure of the discharge electrode. If pieces of the welding electrode remain attached to the collection plate, localized deformation of the electric field can lead to sparking and failure of the discharge electrode.

Mechanical fatigue occurs at points where wires are twisted together and mechanical motion occurs continually at one location. This occurs at the top of a discharge electrode where the wire is twisted around the support collar. Methods of reducing mechanical fatigue include selection of discharge electrode material that is resistant to cold work annealing after attachment.

Chemical attack is caused by a corrosive material in the flue gas, which can occur when high-sulfur coal is burned and flue gas exit temperatures are low and near the acid dew point. Use of ambient air to purge insulator compartments also can cause

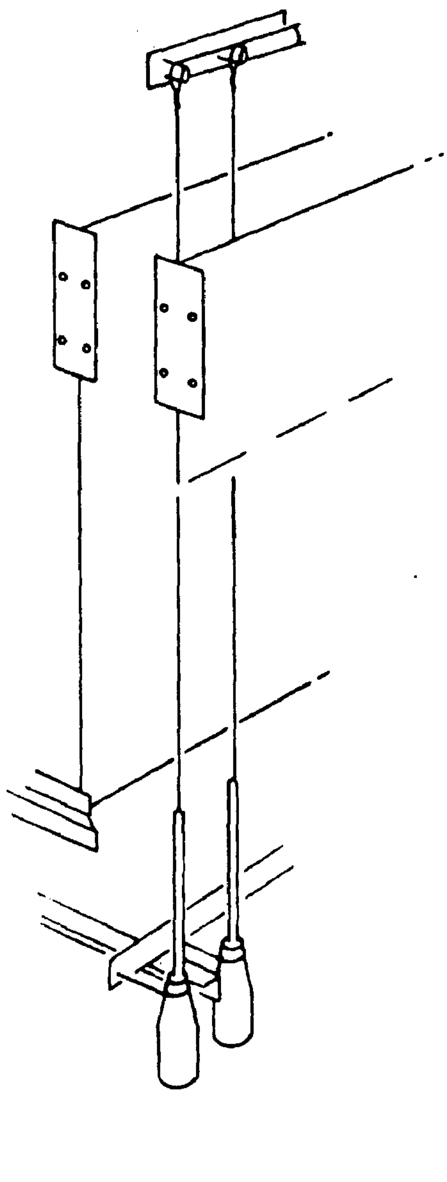


Figure B-1. Shrouds for wire-weighted discharge electrodes.[1]

the temperature to drop below the acid dew point in a localized region. Corrosion can be minimized by operation at higher flue gas temperatures or by use of hot, dry air to purge insulator compartments. Use of good insulation on the ESP shell to maintain high temperature also provides adequate protection within the usual range of operating temperatures and fuel sulfur contents.[1]

The other causes of discharge wire failure, such as inadequate rapping, could be minimized by routine checking of vibrators and rappers. Inspection helps to prevent wire failures and tripouts when potential problems are detected before they become serious. Because an ESP contains many wires, however, some discharge wire failures are to be expected, even with good design and preventive maintenance.

Collection Hoppers and Ash Removal

Hoppers and ash removal systems often constitute problems in precipitator operation. If the hoppers become full, the collected dust may short-circuit the precipitator. Electrical power may fuse the dust, causing formation of a large, clinkerlike structure called a "hornet's nest," which must be removed. Most problems associated with hoppers are related to flow of the dust. Flow may be inhibited by improper adjustment of the hopper vibrators or failure to empty the hoppers. Heat and/or thermal insulation of the hoppers may be required to prevent condensation of moisture and resultant cementing of the collected dust.

Malfunctions of the ash evacuation and removal system include water pump failure, water-jet nozzle failure, disengagement of vacuum connections, and failure of sequencing controls.

The best measure for preventing malfunction of an ash removal system, aside from proper design, is a good program of operation and maintenance. Since dust buildup can affect so many of the ESP components, proper ash removal will minimize or eliminate many of the most common ESP malfunctions.

Gas flow problems occur as a result of the inleakage of air into hoppers from the dust conveyor systems. This results in reentrainment of collected dust into the ESP, as discussed earlier. Air inleakage can also occur through the ESP shell or inlet flanges if operation is at pressures lower than atmospheric. Often enough air is bled in to cause intense sparking.

The term "gas sneakage" describes gas flow that bypasses the effective ESP section. Sneakage can occur through dead passages of the ESP above the collector plates, around the high-tension dust concentration at the bottom of the outlet section of the frame, or through the hoppers. It will reduce ESP efficiency by only a few percent unless it is unusually severe. Gas sneakage can be identified by measuring gas flows in suspected areas in a nonoperating or cold test. Corrective measures usually involve baffling to direct gas into the active ESP action.

Reentrainment of dust from hoppers caused by air inleakage or gas sneakage is often indicated by an increase in dust concentration at the bottom of the outlet section of the ESP. Corrective measures for air leakage would include proper design and fit of components and sealing of areas where inleakage occurs.

Rappers or Vibrators

In dry removal systems, rapping of the collection electrode to remove dust is normally done periodically. Effective rapping can occur only when the accumulation of material on the plate is thick enough that it falls in large agglomerates into the hopper. Although there is always some reentrainment of dust, effective rapping must minimize it. As discussed earlier, rapping forces that are either too mild or too severe can cause poor performance.

Poor gas flow and the condition of the dust can also cause formation of deposits on discharge electrodes, often as much as 5 cm (2 in.) thick. Their deposits are generally composed of the finer dust particles and often cling tenaciously to the discharge wire. Deposits on the discharge wire do not necessarily lead to poor performance, but efficiency may be reduced, depending on resistivity, power supply range, and uniformity of the deposit.

Design of the support structure and of the electrodes can also cause inadequate rapping. Recent investigations of rapping acceleration in fly-ash ESP's have shown measured accelerations of 5 g when as much as 30 g may be required.[2] The first step in dealing with problems related to rappers and vibrators is to determine the adequacy of the rapping acceleration with an accelerometer mounted on the plates. A common method of adjusting rappers is with the use of an optical dust-measuring instrument in the exit gas stream of the ESP.

Discharge electrodes should be kept as clean as possible. Rapping intensity is limited only by the possibility of mechanical damage to the electrodes and support structure.

The vibratory types of cleaning mechanisms usually require more maintenance than the impulse types.

Insulator/Bushing Failure

Suspension insulators support and isolate the high-voltage parts of an ESP. As mentioned earlier, inadequate pressurization of the top housing of the insulators can cause ash deposits or moisture condensation on the bushings, which may cause electrical breakdown at the typical operating potential of 45 kV d.c.

Corrective or preventive measures include inspection of fans that ventilate the top housing and availability of a spare fan for emergencies. Frequent cleaning and checking for damage of the fans by vibration is also necessary to ensure trouble-free operation.

Inadequate Electrical Energization

Since an ESP operates on the basis of electric field and electric charge, electrical energization must be adequate to charge the particles, maintain the electric field, and hold the collected dust to the collection plates.

Among several possible causes of failure to achieve the required level of power input to the ESP, the following are most common:[1]

- High dust resistivity
- Excessive dust accumulation on the electrodes
- Unusually fine particle size
- Inadequate sectionalization
- Improper rectifier and control operation
- Misalignment of electrodes
- Inadequate power supply range

If a precipitator is operating at a spark-rate-limited condition but current and voltage are low, the problem can commonly be traced to high-resistivity dust, electrode misalignment, or uneven corona resulting from buildup on the discharge electrode.

The effects of high resistivity were discussed in more detail in Section 2, in terms of conditions specific to utility industry, where resistivity presents the greatest problem.

Because of the importance of resistivity in the precipitation process, a first step in troubleshooting should be in situ resistivity measurements. High resistivity (more than 10^{10} ohm-cm) may be causing the abnormally low currents. If resistivity is not high, other potential causes should be investigated.

Failures in ESP controls can prevent the system from achieving the level of power required for normal operation. Following are the most common malfunctions in controls:

1) Power failure in the primary system

2) Transformer or rectifier failure in secondary system caused by:

   a. insulation breakdown in transformer
   b. arcing in transformer between high-voltage switch contacts
   c. leaks or shorts in high-voltage structure
   d. contamination of the insulating field

The most effective measure for correction of control failures is a good maintenance program in which the controls are checked periodically for proper operation. A daily log of instruments that register current, voltage, and spark rate can also indicate potential problems.

SURVEYS OF PRECIPITATOR MALFUNCTIONS

Two surveys are cited to support the preceding information on precipitators, one by the Industrial Gas Cleaning Institute (IGCI)[3] and the other by the TC-1 Committee of the Air Pollution Control Association (APCA).[4] Both surveys give similar results.

The IGCI survey lists the following problems, in order of frequency and severity:

- Discharge electrode failure
- Rapper malfunction
- Insulator failure
- Dust buildup (causing electrical shorts)
- Hopper plugging
- Transformer rectifier malfunctions

The APCA survey covers four major industries: electrical utilities, cement, paper, and metallurgical. The equipment reported on had been in service ranging from 3 months to 50 years, with an average service life of 7 to 10 years.

Responses from 174 users indicate the following problem areas in order of importance and cost:

Discharge electrodes	30.5%
Dust removal systems	25.1
Rappers or vibrators	21.4
Collecting plates	14.8
Insulators	5.8

The TC-1 Committee notes that manufacturers are making design improvements in discharge electrodes, the largest source of problems. They also cite the importance of the design, operation, and maintenance of dust removal systems, noting the industry that reported the highest incidence degree of hopper plugging.

The committee concludes that although problems do occur with precipitator equipment, most users are satisfied with the ESP as a functioning unit. They suggest close cooperation between user and supplier, coupled with exchange of information among the user industries to facilitate development of an ESP that meets the needs of all users.

REFERENCES - APPENDIX B

1. Electrostatic Precipitator Manual. The McIlvaine Co. 1976.

2. Hesketh, H.E., and F.L. Cross, Jr. (ed.) Handbook for the Operation and Maintenance of Air Pollution Control Equipment. Technomic Publishing Co. Westport, Connecticut. 1975.

3. Engelbrecht, H.L. Plant Engineer's Guide to Electrostatic Precipitator Inspection and Maintenance. Plant Engineering. April 1976, pp. 193-196.

4. Bump, Robert L. Electrostatic Precipitator Maintenance Survey. TC-1 Committee of the Air Pollution Control Association. 1974.

APPENDIX C

CHECKLISTS FOR INSPECTION OF ESP'S

TABLE C-1. PREINSPECTION CHECKLIST FOR FLY ASH ELECTROSTATIC PRECIPITATORS

A. FACILITY IDENTIFICATION

Facility Name: ____________________

Facility Address: ____________________

Person to Contact: ____________________

Date Information Gathered: ____________________

Source Code No.: ____________________

B. DATE INFORMATION GATHERED:

C. SITE DATA

1. UTM Coordinates: ____________________

2. Elevation Above Mean Sea Level, ft: ____________________

3. Soil Data - Bearing Value: ____________________

   Piling Necessary: ____________________

4. Attach Drawings:

   a) Plot Plan

   b) Equipment Layout and Elevation

   c) Aerial Photographs of Site Including Power Plant, Coal Storage and Ash Disposal Area

(continued)

TABLE C-1. (continued).

	Boiler number				
	1	2	3	4	5
D. **BOILER DATA**					
1. Service: Base Load Standby, Floating, Peak					
2. Total Hours Operation (19)					
3. Average Capacity Factor (19)					
4. Served by Stack No.					
5. Boiler Manufacturer					
6. Year Boiler Placed in Service					
7. Estimated Remaining Life of Unit					
8. Rated Generating Capacity, MW					
Coal					
Oil					
Gas					
9. Design Fuel Consumption:					
Coal, 10^6 tons/yr					
Oil, 10^6 gal/yr					
Gas, 10^6 ft^3/yr					

Notes:

(continued)

TABLE C-1. (continued).

	Boiler number				
	1	2	3	4	5
10. Actual Fuel Consumption					
Coal, 10^6 tons/yr					
Oil, 10^6 gal/yr					
Gas, 10^6 ft^3/yr					
11. Wet or Dry Bottom					
12. Excess Air, %					
13. Fly Ash Reinjection (Yes or No)					
14. Stack Ht Above Grade, ft					
15. I.D. of Stack at Top, in.					

E. <u>COAL DATA</u>

1. Coal Seam, Mine, Location

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

Notes:

(continued)

TABLE C-1. (continued).

2. Quantity Used by Seam and or Mine

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

3. Analysis

   GHV, Btu/lb ______________________________

   S, % ______________________________

   Ash, % ______________________________

   Moisture, % ______________________________

F. <u>FUEL OIL DATA</u>

1. Type ______________________________

2. S Content, % ______________________________

3. Ash Content, % ______________________________

4. Specific Gravity ______________________________

5. GHV, Btu/gal ______________________________

Notes:

(continued)

TABLE C-1. (continued).

	Boiler number 1	2	3	4	5
G. FLUE GAS CLEANING EQUIPMENT					
1. Mechanical Collectors					
Manufacturer					
Type					
Efficiency: Design Actual, %					
Mass Emission Rate:					
gr/acf					
lb/h					
lb/10^6 Btu					
2. Electrostatic Precipitator					
Manufacturer					
Type					
Design/Actual Efficiency, %					
Design Sulfur Range, %					
Design Ash Content, %					
Design Heating Value					

Notes:

(continued)

TABLE C-1. (continued).

	Boiler number 1	2	3	4	5
2. Electrostatic Precipitator (continued)					
Mass Emission Rate					
gr/acf					
lb/h					
lb/10^6 Btu					
No. of Fields					
No. of T-R Sets					
No. of Independent Bus Section					
Total Plate Area, ft^2					
Flue Gas Temperature @ Inlet ESP @ 100% Load, °F					
H. I.D. FAN DATA					
1. Maximum Static Head, in H_2O					
2. Working Static Head, in H_2O					
3. Design Flue Gas Rate, acfm					
@ 100% Load					
@ 75% Load					
@ 50% Load					

Notes:

(continued)

TABLE C-1. (continued).

	Boiler number 1	2	3	4	5
4. Design Stack Gas Exit Temperature, °F					
@ 100% Load					
@ 75% Load					
@ 50% Load					
5. Exit Gas Stack Velocity, ft/s					
@ 100% Load					
@ 75% Load					
@ 50% Load					
6. Exhaust Duct Dimensions @ Stack, ft					
7. Elevation of Tie-in Point to Stack, ft					

I ASH DISPOSAL

1. Fly Ash: Total Collected, tons/yr ______

   Disposal Method ______

   Disposal Cost, $/ton ______

Notes:

(continued)

TABLE C-1. (continued).

2. Bottom Ash: Total Collected, tons/yr ____________________

Disposal Method ____________________

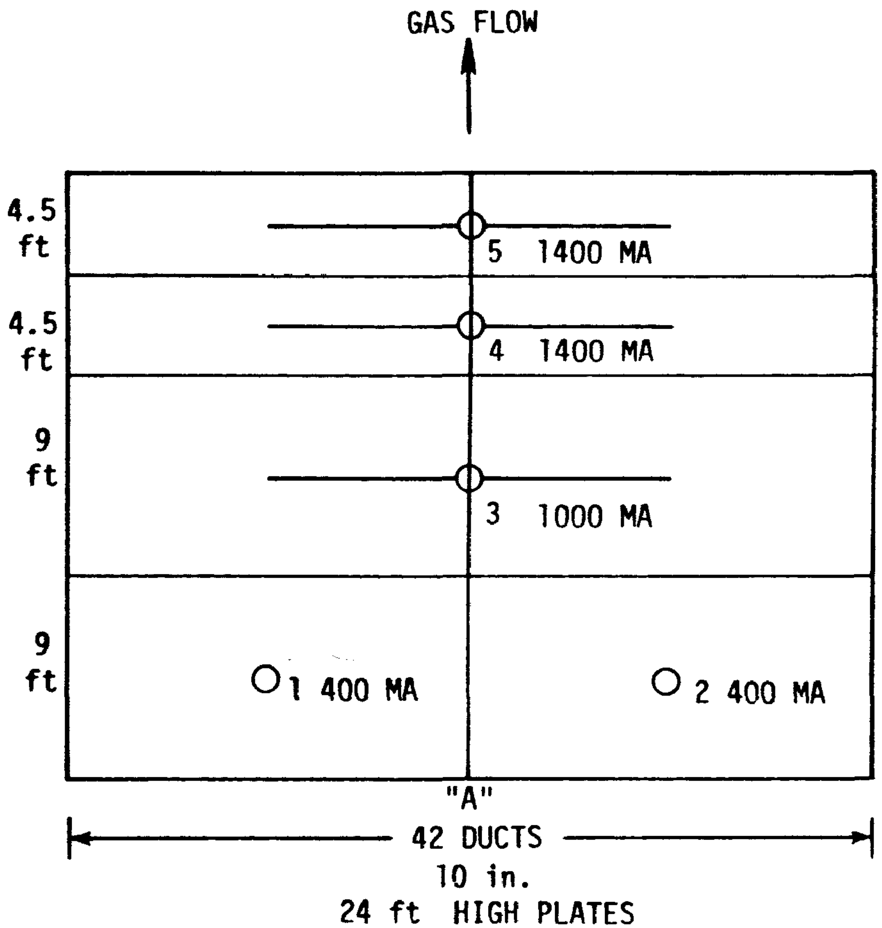
Disposal Cost, $/ton ____________________

J. SCHEDULED MAINTENANCE SHUTDOWN-MAJOR (ATTACH PROJECTED SCHEDULE)

Notes:

PREINSPECTION DATA SHEET - ATTACHMENT 1
BLOCK DIAGRAM OF FACILITY

PREINSPECTION DATA SHEET - ATTACHMENT 2
BLOCK DIAGRAM AND POWER SUPPLY DATA FOR EXISTING ESP'S
Example:
(Include design primary amps, primary volts, secondary milliamps, and secondary kilo-volt-amp ratings for each T-R set.)



	T-R set ratings			
T-R set no.	Primary amps	Primary volts	D.C. kilovolts	D.C. milliamps
A 1	75	420	55	400
A 2	75	420	55	400
A 3	238	420	50	1000
A 4	238	420	50	1400
A 5	261	420	55	1400

TOTAL 4 PPTRS AS ABOVE A, B, C, D - MANUFACTURER - W.P.

TABLE C-2. INSPECTION CHECKLIST FOR ELECTROSTATIC PRECIPITATORS

A. FACILITY IDENTIFICATION

Facility Name: ______________________________

Facility Address: ______________________________

Person to Contact: ______________________________

Inspection Date: ______________________________

Source Code No.: ______________________________

	Boiler number				
	1	2	3	4	5
B. PRE-ENTRY DATA					
1. Stack Plume Equivalent Opacity, %					
2. Opacity Regulation, %					
3. Smoke Color (white, grey, black, brown, reddish brown, bluish white, yellowish brown)					

(continued)

TABLE C-2. (continued).

C. ELECTRICAL ENERGIZATION ARRANGEMENT AND CONTROL SET READINGS FOR ESP NO.

Location	T-R set no.	Primary voltage, V		Primary current, A		ESP voltage, V		ESP current, A		Spark rate, sparks/min	
		Present	Design	Present	Design	Present	Design	Present	Design	Present	Design

(continued)

TABLE C-2. (continued).

	Boiler number				
	1	2	3	4	5
D. <u>ESP CONTROL ROOM</u>*					
1. Ventilation					
2. Control Sets Condition					
E. <u>ESP TOP HOUSING</u>*					
1. Condition of Insulators					
2. Rapper/Vibrator Operation					
3. T-R Sets Condition					
F. <u>ESP EXTERIOR</u>					
1. Corrosion Problems?					
2. Condition of Transition Ducts					
3. Fugitive Emissions?					
G. <u>ASH HANDLING</u>					
1. Interval Between Hopper Evacuations, h					
2. Level Alarm Operation*					
3. Evacuation and Removal Procedure*					
4. General Housekeeping*					

* Indicate as satisfactory or unsatisfactory.

(continued)

TABLE C-2. (continued).

H. BOILER ROOM CONTROL READINGS

	Boiler number				
	1	2	3	4	5
1. Gas Flow - Inlet to ESP, acfm					
2. Flue Gas Temperature, °F					
3. Pressure Readings					
a. Before ESP, in. H_2O					
b. After ESP, in. H_2O					
4. Excess Air, %					
5. Moisture Content, %					
6. Flue Gas Analysis					
CO_2, %					
O_2, %					
7. Steam Flow, psi					
8. Steam Temp., °F					
9. Soot Blowing Schedule					
10. Pressure Drop Through Air Preheaters, in. H_2O					

(continued)

TABLE C-2. (continued).

	Boiler number 1	2	3	4	5
11. FD Fan Current, Amperes					
Rated					
Present					
12. ID Fan Current, Amperes					
Rated					
Present					
I. <u>PLANT RECORDKEEPING</u>*					
1. Calibration of Instruments					
2. ESP Control Readings					
3. Boiler Control Room					
4. Auxiliary Equipment Maintenance					
5. Preventive Maintenance and Inspection of ESP's					
6. ESP and Process Malfunctions					

* Indicate as satisfactory or unsatisfactory.

(continued)

TABLE C-2. (continued).

J. COMMENTS ON THE INSPECTION: