Lesson 6

ESP Operation and Maintenance

Goal

To familiarize you with typical operation and maintenance problems associated with ESPs.

Objectives

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

1. Identify typical ESP components which require inspection prior to startup
2. Identify the major steps in ESP startup and shutdown procedures
3. Explain the importance of monitoring each of the following parameters:
   - Voltage/current
   - Opacity
   - Gas temperature
   - Gas flow rate and distribution
   - Gas composition and moisture
4. Describe the function of air-load and gas-load voltage-current curves
5. Identify typical maintenance steps that ensure proper ESP functioning
6. Identify and describe seven common problems that affect ESP performance
7. Describe how evaluating the current, voltage, and spark rate trends from inlet to outlet fields provides information about general resistivity conditions
8. Identify important safety precautions to take when operating ESPs

Introduction

As with any air pollution control system, an ESP must be operated and maintained according to the manufacturer's recommendations. Plant personnel must be properly trained to perform these activities with confidence and efficiency. This lesson reviews some of the key functions that must be completed to keep the ESP operating as it was intended including installation, startup and shutdown procedures, performance monitoring, routine maintenance and record-keeping and problem evaluation.

ESP Installation

Depending on the electrostatic precipitator chosen, production, installation and operation startup may take from a few months to one or two years. In any case, proper installation procedures will save time and money, and will also help in future operation and maintenance (O&M) of the ESP.

Good coordination between the ESP designer (vendor) and the installation and maintenance crews will help keep the ESP running smoothly for years. Occasionally this coordination is overlooked. Because they are so large, ESPs are usually installed by skilled craftsmen who do not work for the ESP vendor, and, therefore, may not be informed of specific installation instructions. Since all design tolerances are critical (especially those affecting discharge and collection electrode alignment), it is imperative that information about the proper installation procedures be transferred from designers to installers.

Some key considerations during installation are:

- Easy access to all potential maintenance areas—fans, motors, hoppers, discharge devices, dampers, flue gas flow rate and temperature monitors, insulators, rappers, T-R sets, and discharge and collection electrodes
- Easy access to all inspection and test areas—stack testing ports and continuous emission monitors (opacity monitors)
- Weather conditions—the ESP must be able to withstand inclement weather such as rain or snow

During installation, the customer purchasing the ESP should be responsible for checking the criteria presented below. The regulatory agency review engineer also should review the process on which the ESP will be installed and verify that these items are being addressed.

1. *Uniform flue gas distribution across the entire unit*. Ductwork, turning vanes, baffle plates, and inlets with perforated diffuser plates all affect flue gas distribution. These items are usually installed in the field and should be checked visually. If improperly installed, they induce high airflow regions that decrease collection efficiency and cause reentrainment of collected dust, especially during rapping cycles.

2. *Complete seal of ESP system from dust pickup to stack outlet.* Air inleakage or outleakage at flanges or collector access points either adds additional airflow to be processed or forces the process gases to bypass the collector. Inleakage to a high-temperature system (hot-side ESP) is extremely damaging, as it creates cold spots which can lead to moisture or acid condensation and possible corrosion. If severe, it can cause the entire process gas temperature to fall below the gas dew point, causing moisture or acid to condense on the hopper walls, the discharge electrode, or collection plates. In addition, air inleakage and moisture condensation can cause caking of fly ash in the hopper, making normal dust removal by the discharge device very difficult. The best way to check for leaks is an inspection of the walls from inside the system during daylight. Light penetration from outside helps to isolate the problem areas.

3. *Proper installation of discharge electrodes and collection plates.* Collection electrodes are usually installed first, and the discharge wires or rigid frames are positioned relative to them. Check each section of electrodes to ensure that the electrodes are plumb, level, and properly aligned.

4. *Proper installation of rappers.* Collection-plate rappers and discharge-electrode rappers should be installed and aligned according to vendor specifications. Check magnetic-impulse rappers to see if they strike the support frame on the collection plates. Check hammer and anvil rappers to see if the hammers strike the anvils squarely. Check vibrator rappers installed on discharge wires to make sure they operate when activated. Rapper frequency and intensity can be adjusted later when the unit is brought on-line.

5. *Proper insulation*. Most ESPs use some type of insulation to keep the flue gas temperature high. This prevents any moisture or acids present in the flue gas from condensing on the hoppers, electrodes, or duct surfaces. Because most ESPs are installed in the field, check that all surfaces and areas of potential heat loss are adequately covered.

6. *Proper installation and operation of discharge devices.* It is important to check the operation of the discharge devices before bringing the ESP on-line to see if they are properly installed. Make sure that the discharge devices are moving in the right direction so they can remove the dust freely from the hopper. A backward-moving screw conveyor can pack dust so tightly that it can bend the screw.

   Overfilled hoppers are common operating problems that can be avoided by proper installation and maintenance of discharge devices. Installed as maintenance tools, dust-level detectors in the hoppers can help alert ESP operators that hoppers are nearly full.

7. *Smoothly running fans*. Check fans for proper rotation, drive component alignments, and vibration. Fans should be securely mounted to a component of sufficient mass to eliminate excessive vibration.

   In addition to the above items, each ESP installation should have its own checklist reflecting the unique construction features of that unit. The installation crew should prepare a checklist before beginning final inspection and initial startup. A prestartup checklist for the initial startup suggested by Peter Bibbo (1982) is shown in Table 6-1.

Table 6-1. Prestartup checklist for electrostatic precipitators

Collecting plates
1. Free of longitudinal and horizontal bows
2. Free of burrs and sharp edges
3. Support system square and level
4. Spacer bars and corner guides free
5. Free of excessive dust buildup
6. Gas leakage baffles in place and not binding

Discharge electrodes
1. No breaks or slack wires
2. Wires free in guides and suspension weight free on pin
3. Rigid frames square and level
4. Rigid electrodes plumb and straight
5. Free of excessive dust buildup and grounds
6. Alignment within design specifications

Hoppers
1. Scaffolding removed
2. Discharge throat and poke holes clear
3. Level detector unobstructed
4. Baffle door and access door closed
5. Heaters, vibrators, and alarms operational

Top housing or insulator compartments
1. Insulators and bushing clear and dry with no carbon tracks
2. All grounding chains in storage brackets
3. Heaters intact, seal-air system controls, alarms, dampers, and filters in place and operational
4. Seal-air fan motor rotation correct, or vent pipes free
5. All access doors closed

Rappers
1. All swing hammers or drop rods in place and free
2. Guide sleeves and bearings intact
3. Control and field wiring properly terminated
4. Indicating lights and instrumentation operational
5. All debris removed from precipitator
6. All personnel out of unit and off clearances
7. All interlocks operational and locked out
   a. No broken or missing keys
   b. Covers on all locks

Transformer-rectifier sets
1. Surge arrestor not cracked or chipped and gap set
2. Liquid level satisfactory
3. High-voltage connections properly made
4. Grounds on: precipitator, output bushings, bus ducts, conduits

Rectifier control units
1. Controls grounded
2. Power supply and alarm wiring properly completed
3. Interlock key in transfer block

Source: Bibbo 1982.

ESP Startup and Shutdown

A specific startup and shutdown procedure should be supplied by the ESP vendor. Improper startup and shutdown can damage the collector. It is imperative for the operator (source) to have a copy of these procedures. Review agency engineers may want to assure that these procedures exist at the sites and that the operators follow the procedures or document reasons for deviations.

Startup

Startup of an electrostatic precipitator is generally a routine operation. It involves heating a number of components such as support insulators and hoppers. If possible, the ESP should not be turned on until the process reaches steady-state conditions. As described in Lesson 5, this is particularly important for ESPs used on cement kilns burning coal as fuel. The internal arcing of the ESP could cause a fire or an explosion. When ESPs are used on oil-burning boilers, the boiler should be started with gas or #2 fuel oil. Heavy oil (#6 fuel oil) is not a good fuel for startup because tarry particulate emissions can coat collection plates and be difficult to remove. If an ESP is used on a coal-fired boiler, the ESP should not be started until coal firing can be verified. This will help prevent combustible gases from accumulating in the unit and causing explosive conditions. A typical startup procedure for an ESP used on a boiler is given in Table 6-2 (Bibbo 1982).

Table 6-2. Typical startup procedures for electrostatic precipitators

Normal Operation
Startup (preoperational checks - at least 2 hours prior to gas load): 1. Complete all maintenance/inspection items. 2. Remove all debris from ESP. 3. Safety interlocks should be operational and all keys accounted for. 4. No personnel should be in ESP. 5. Lock out ESP and insert keys in transfer blocks.
Prestart (at least one hour prior to gas load): 6. Check hoppers. a. Level-indicating system should be operational. b. Ash-handling system operating and sequence check - leave in operational mode. c. Hopper heaters should be on. 7. Check top housing seal-air system. a. Check operation of seal-air fan—leave running. b. Bushing heaters should be on. 8. Check rappers. a. Energize control, run rapid sequence, ensure that all rappers are operational. b. Set cycle time and intensity adjustments, using installed instrumentation—leave rappers operating. 9. Check T-R sets. a. Check half-wave/full-wave operation (half-wave operation is recommended for filtering fly ash when lignite is burned and a cold-side ESP is used.) b. Keys should be in all breakers. c. Test-energize all T-R sets and check local control alarm functions. d. Set power levels and de-energize all T-R controls. e. Lamp and function-test all local and remote alarms.

Continued on next page

Table 6-2. *(continued)* Typical startup procedures for electrostatic precipitators
Normal Operation
Gas load: 10. After gas at temperature of 200°F has entered ESP for 2 hours - a. Energize T-R sets. b. Check for normal operation of T-R control. c. Check all alarm functions in local and remote. d. Within 2 hours, check proper operation of ash removal system. e. De-energize bushing heaters after 2 hours (hopper heaters optional).
Cold start (when it is not possible to admit flue gas at 200°F for 2 hours prior to energizing controls), proceed as follows: 1. Perform steps 1-9 above. Increase rapping intensity 50%. 2. Energize T-R sets, starting with inlet field, setting Powertrac voltage to a point just below sparking. 3. Successively energize successive field as load picks up to maintain opacity, keeping voltage below normal sparking (less than 10 flashes/min on spark indicator). 4. Perform step 10d above. 5. After flue gas at 200°F has entered ESP for 2 hours, perform steps 10b, c, d, and e above. Set normal rapping.

Source: Bibbo 1982.

Shutdown

When an industrial process is shut down temporarily, the ESP system should be de-energized to save energy. The shutdown of the ESP is usually done by reversing the order of the startup steps. Begin with de-energizing the ESP fields starting with the inlet field to maintain appropriate opacity levels from the stack. The rappers should be run for a short time after the ESP is de-energized so that accumulated dust from the collection plates and discharge wires can be removed. All hoppers should be emptied completely before bringing the unit back on line. A typical shutdown and emergency shutdown procedure for ESPs used on industrial sources is given in Table 6-3 (Bibbo 1982).

Table 6-3. Typical shutdown and emergency shutdown procedures for electrostatic precipitators

Typical shutdown

1. When boiler load drops and total ash quantity diminishes:
   a. De-energize ESP by field, starting with inlet field to maintain opacity limit.
   b. De-energize outlet field when all fuel flow ceases and combustion air flow falls below 30% of rated flow.
   c. Leave rappers, ash removal system, seal-air system, and hopper heaters operational.
   d. Four hours after boiler shutdown, de-energize seal-air system and hopper heaters. Secure ash removal system.
   e. Eight hours after boiler shutdown, de-energize rappers.

   Note: Normal shutdown is a convenient time to check operation of alarms.

Emergency shutdown

1. De-energize all T-R sets.
2. Follow steps 1c, d, and e above (shutdown).

Source: Bibbo 1982.

Performance Monitoring

As with the operation of any piece of equipment, performance monitoring and recordkeeping are essential to establishing a good operation and maintenance program. The key to any monitoring program is establishing an adequate baseline of acceptable ranges that is used as a reference point. Then, by monitoring and recording key operating parameters, the operator can identify performance problems, need for maintenance, and operating trends.

Typical parameters that can be monitored include:

- Voltage/current
- Opacity
- Gas temperature
- Gas flow rate and distribution
- Gas composition and moisture

In addition, site-specific data on process operating rates and conditioning system (if used) should also be documented. Operators should not rely on just one parameter as an indicator of performance—trends for a number of parameters gives a clearer picture. Let's briefly look at the ways these parameters affect performance and the techniques used to measure them. Much of this information was extracted from *Operation and Maintenance Manual for Electrostatic Precipitators* (U.S. EPA 1985).

Voltage and Current

Voltage and current values for each T-R set should be recorded; they indicate ESP performance more than any other parameter. Most modern ESPs are equipped with primary voltage and current meters on the low-voltage (a.c.) side of the transformer and secondary voltage and current meters on the high-voltage rectified (d.c.) side of the transformer. When both voltage and current meters are available on the T-R control cabinet, these values can be multiplied to estimate the power input to the ESP. (Note that the primary current reading is multiplied by the primary voltage reading and the secondary current reading is multiplied by the secondary voltage reading). These values (current times voltage) represent the number of watts being drawn by the ESP and is referred to as the corona power input. In addition, whenever a short term spark occurs in a field it can be detected and counted by a spark rate meter. ESPs generally have spark rate meters to aid in the performance evaluation.

The power input on the primary versus the secondary side of the T-R set will differ because of the circuitry and metering of these values. The secondary power outlet (in watts) is always less than the primary power input to the T-R. The ratio of the secondary power to the primary power will range from 0.5 to 0.9 and average from 0.70 to 0.75 (U.S. EPA 1985).

Voltage and current values for each individual T-R set are useful because they inform the operators how effectively each field is operating. However, the trends noted within the entire ESP are more important. T-R set readings for current, voltage, and sparking rates should follow certain patterns from the inlet to the outlet fields. For example, corona power density should increase from inlet to outlet fields as the particulate matter is removed from the gas stream.

The electrical meters on the T-R cabinets are always fluctuating. Normal sparking within the ESP causes these fluctuations in the meter readings. These short term movements of the gauges indicate that the automatic voltage controller is restoring the maximum voltage after shutting down for several milliseconds to quench the spark. When recording values of the electrical data from the T-R meters it is important to note the maximum value that is sustained for at least a fraction of a second.

Opacity

In many situations, ESP operation is evaluated in terms of the **opacity** monitored by a **transmissometer** (opacity monitor) on a *real-time* basis. Under optimum conditions the ESP should be able to operate at some base-level opacity with a minimum of opacity spiking from rapper reentrainment. A facility can have one or more monitors that indicate opacity from various ESP outlet ducts and from the stack.

An opacity monitor compares the amount of light generated and transmitted by the instrument on one side of the gas stream with the quantity measured by the receiver on the other side of the gas stream. The difference, which is caused by absorption, reflection, refraction, and light scattering by the particles in the gas stream, is the opacity of the gas stream. Opacity is expressed as a percent from 0 to 100% and is a function of particle size, concentration, and path length.

Most of the opacity monitors being installed today are **double-pass monitors**; that is, the light beam is passed through the gas stream and reflected back across to a transceiver. This arrangement is advantageous for several reasons:

1. Automatic checking of the zero and span of the monitor is possible when the process is operational.
2. The monitor is more sensitive to slight variations in opacity because the path length is longer.
3. The entire electronics package is located on one side of the stack as a transceiver.

Although **single-pass** transmissometers are available at a lower cost (and sensitivity), the single-pass monitors cannot meet the requirements in EPA Performance Specification 1, Appendix B, 40 CFR 60.

For many sources, dust concentration and opacity correlations can be developed to provide a relative indication of ESP performance. These correlations are very site-specific, but can provide plant and agency personnel with an indication of relative performance for given opacity levels. In addition, site-specific opacity charts can be used to predict deterioration of ESP performance that requires attention by plant personnel. Readings from opacity monitors can also be used to optimize spark rate, voltage/current levels, and rapping cycles, even though the conditions within the ESP are not static. In high-efficiency ESPs, reentrainment may account for 50 to 70% of the total outlet emissions. Therefore, optimization of the rapping pattern may prove more beneficial than trying to optimize the voltage, current and sparking levels. Dust reentrainment from rapping must be observed by using the opacity monitor operating in a real-time or nonintegrating mode because rapping spikes tend to get smoothed out in integrated averages such as the 6-minute average commonly in use. However, the integrated average does provide a good indication of average opacity and emissions.

When parallel ESPs or chambers are used, an opacity monitor is often placed in each outlet duct, as well as on the stack, to measure the opacity of the combined emissions. Although the stack monitor is commonly used to indicate stack opacity (averaging opacities from different ducts can be difficult), the individual duct monitors can be useful in indicating the performance of each ESP or chamber and in troubleshooting. Although this option is often not required and represents an additional expense, it can be very useful, particularly on relatively large ESPs.

New systems, such as the digital microprocessor design, are available in which the opacity monitor data can be used as input for the T-R controller. In this case, the data are used to control power input throughout the ESP to maintain an opacity level preselected by the source. If the opacity increases, the controller increases power input accordingly until the opacity limit, spark limit, current limit, or voltage limit is reached. This system (often sold as an energy saver because it uses only the power required) can save a substantial quantity of energy:

1. On large, high-efficiency ESPs
2. For processes operating at reduced gas loads.

In many cases, however, reduction of ESP power does not significantly alter ESP performance because dust reentrainment and gas sneakage constitute the largest sources of emissions; additional power often does not reduce these emissions significantly. In some observed cases, reducing power by one-half did not change the performance. For units typically operated at 1000 to 1500 watts/1000 acfm, operating the ESPs at power levels of 500 to 750 watts/1000 afcm still provide acceptable collection efficiencies.

Gas Temperature

Monitoring the temperature of the gas stream can provide useful information concerning ESP performance. Temperature is measured using a thermocouple in conjunction with a digital, analog, or strip chart recorder. Temperature is usually measured using a single-point probe or thermocouple. This method has a major limitation in that the probe may be placed at an unrepresentative (stratified) point—one that is not representative of the bulk gas flow. Most ESPs are designed with a minimum of three fields. The gas temperature for each field should be measured at both the inlet and outlet, if possible. Significant temperature changes between the inlet and outlet values may indicate air inleakage problems that should be confirmed by measurement of gas composition.

Changes in gas temperature can have profound effects on ESP performance. The temperature variation can be very small (in some cases as little as 15^{o}F) and yet cause a significant change in ESP power levels and opacity. Although gas temperature variations may have some effect on corona discharge characteristics and physical characteristics of the ESP (corrosion, expansion/contraction), their most important effect is on particle resistivity. For sources with the potential for high resistivity, temperature changes can cause dramatic changes in performance, even when all other parameters seem to be the same. The gas temperature should be checked once per shift for smaller sources and measured continuously on larger sources and on those sources with temperature-sensitive performance.

Temperature measurement can also be a useful tool in finding excessive inleakage or unequal gas flow through the ESP. Both of these conditions can affect localized gas velocity patterns without noticeably affecting the average velocity within the ESP. Yet, localized changes in gas velocities can reduce ESP performance even though the average gas velocity seems adequate.

Gas Flow Rate and Distribution

Gas flow rate determines most of the key design and operating parameters such as specific collection area (ft^2/1000 acfm), gas velocity (ft/sec) and treatment time within the ESP, and specific corona power (watts/1000 acfm). The operator should calculate the flue gas flow rate if the ESP is not operating efficiently. For example, significant variations in oxygen may indicate large swings in the gas flow rate that may decrease ESP performance and indicate the need to routinely determine ESP gas volume. Low SCA values, high velocities, short gas treatment times (5 seconds or less), and much higher oxygen levels at nearly full load conditions are indicators that excess flue gas flow rate may be causing decreased ESP performance.

Presently, most sources do not continuously measure gas velocities or flow rates. Gas velocities are generally only measured during emission compliance testing or when there is a perceived problem. Manual pitot tube traverses are normally used to measure gas velocity (EPA Reference Methods 1 and 2). Because of new technologies and regulations, some of the larger sources are beginning to install continuous flow measurement systems. Multi-point pitot devices, ultrasonic devices, and temperature-based flow devices can be used to continuously measure gas velocity. These devices must be calibrated to the individual stack where they are installed. Most existing facilities currently use indirect indicators to estimate gas flow rate; these include fan operating parameters, production rates or oxygen/carbon dioxide gas concentration levels. However, EPA is now requiring large coal-fired utility boilers to install and certify flow monitors (EPA Acid Rain Program, Part 75 Regulations).

Another important parameter is **gas flow distribution** through the ESP. Ideally, the gas flow should be uniformly distributed throughout the ESP (top to bottom, side to side). Actually, however, gas flow through the ESP is not evenly distributed, and ESP manufacturers settle for what they consider an acceptable variation. Standards recommended by the Industrial Gas Cleaning Institute have been set for gas flow distribution. Based on a velocity sampling routine, 85% of the points should be within 15% of the average velocity and 99% should be within 1.4 times the average velocity. Generally, uneven gas flow through the ESP results in reduced performance because the reduction in collection efficiency in areas of high gas flow is not compensated for by the improved performance in areas of lower flow. Also, improper gas distribution can also affect gas sneakage through the ESP. As stated earlier, good gas distribution can be accomplished by using perforated plates in the inlet plenum and turning vanes in the ductwork.

Measurement of gas flow distribution through the ESP is even less common than measuring flue gas flow rate. Because the flow measurements are obtained in the ESP rather than the ductwork (where total gas volumetric flow rates are usually measured), more sensitive instrumentation is needed for measuring the low gas velocities. The instrument typically specified is a calibrated hot-wire anemometer. The anemometer test is usually performed at some mid-point between the inlet and outlet (usually between two fields). Care must be taken to assure that internal ESP structural members do not interfere with the sampling points.

Gas flow distribution tests are conducted when the process is inoperative, and the ESP and ductwork are relatively cool. This often limits the amount of gas volume that can be drawn through the ESP to less than 50% of the normal operating flow; however, the relative velocities at each point are assumed to remain the same throughout the normal operating range of the ESP. A large number of points are sampled by this technique. The actual number depends upon the ESP design, but 200 to 500 individual readings per ESP are not unusual. By using a good sampling protocol, any severe variations should become readily apparent.

Gas Composition and Moisture

The **chemical composition** of both the particulate matter and flue gas can affect ESP performance. In many applications, key indicators of gas composition are often obtained by using continuous emission monitors. However, particle concentration and composition are determined by using intermittent grab sampling.

The operation of an ESP depends on the concentration of electronegative gases O_2, H_2O, CO and SO_2/SO_3 to generate an effective corona discharge. Often, sources use continuous monitors to measure these gas concentrations to meet regulatory requirements, or in the case of combustion sources to determine excess air levels (CO_2 or O_2).

Evaluating Air-Load/Gas-Load Voltage-Current (V-I) Curves

In addition to the routine panel meter readings, other electrical tests of interest to personnel responsible for evaluating and maintaining ESPs include the air-load and gas-load V-I (voltage-current) tests, which may be conducted on virtually all ESPs. Air-load and gas-load curves are graphs of the voltage (kV) versus the current (mA) values obtained at a set condition (test point). These curves are developed to evaluate ESP performance by comparing the graphs from inlet field to outlet field and over periods in time. Deviation from the normal or previous results can indicate that a problem exists.

Air-Load Curves

Air-load tests are generally conducted on cool, inoperative ESPs through which no gas is flowing. This test should be conducted when the ESP is new, after the first shutdown, and every time off-line maintenance is performed on the ESP. These air-load V-I curves serve as the basis for comparison in the evaluation of ESP maintenance and performance. A typical air-load curve is shown in Figure 6-1.

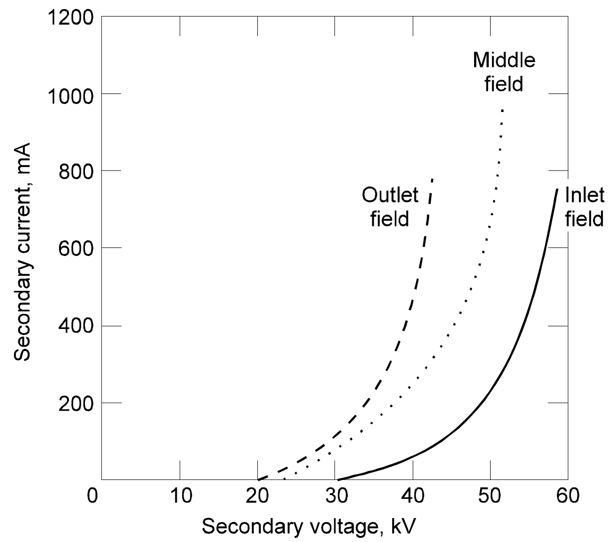

Figure 6-1. Typical air-load voltage and current readings

An air-load V-I curve can be generated with readings from either primary or secondary meters. The following procedures can be used by the ESP operator to develop an air-load curve.

1. Energize a de-energized T-R set on manual control (but with zero voltage and current), and increase the power to the T-R set manually.
2. At corona initiation the meters should suddenly jump and the voltage and near zero current levels should be recorded. It is sometimes difficult to identify this point precisely, so the lowest practical value should be recorded.
3. After corona initiation is achieved, increase the power at predetermined increments [for example, every 50 or 100 milliamps of secondary current or every 10 volts of AC primary voltage (the increment is discretionary)], and record the values for voltage and current.
4. Continue this procedure until one of the following occurs:
   - Sparking
   - Current limit is achieved
   - Voltage limit is achieved
5. Repeat this procedure for each T-R set.

When the air-load tests have been completed for each field, plot each field's voltage/current curves. When ESPs are equipped with identical fields throughout, the curves for each field should be nearly identical. In most cases, the curves also should be similar to those generated when the unit was new, but shifted slightly to the right due to residual dust on the wires (or rigid frames) and plates of older units. These curves should become part of the permanent record of the ESP.

The use of air-load curves enables plant personnel to identify which field(s) may not be performing as designed. Also, comparison of air-load curves from test runs taken just before and after a unit is serviced will confirm whether the maintenance work corrected the problem(s).

One major advantage of air-load tests is that they are performed under nearly identical conditions each time, which means the curves can be compared. One disadvantage is that the internal ESP conditions are not always the same as during normal operation. For example, misalignment of electrodes may appear or disappear when the ESP is cooled (expansion/contraction), and dust buildup may be removed by rapping during ESP shutdown.

Gas-Load Curves

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

The curves generated under gas-load conditions will be similar to air-load curves. Gas-load curves will generally be shifted to the left however, because sparking occurs at lower voltage and current when particles are present. The shape of the curve will be different for each field depending on the presence of particulate matter in the gas stream (see Figure 6-2).

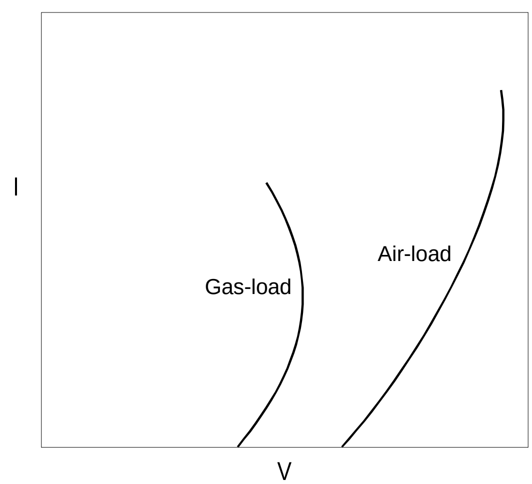

Figure 6-2. Comparison of typical air-load and gas-load V-I curves
Source: EPA 1985

Also, gas-load curves vary from day to day, even minute to minute. Curve positions may change as a result of fluctuations in the following:

- Amount of dust on plates
- Gas flow
- Particulate chemistry loading
- Temperature
- Resistivity

Nonetheless, they still should maintain a characteristic pattern. Gas-load curves are normally used to isolate the cause of a suspected problem rather than being used on a day-to-day basis; however, they can be used daily if necessary.

Routine Maintenance and Recordkeeping

While the overall performance of the ESP is continuously monitored by devices such as voltage meters and transmissometers, the components of the ESP and their operation are periodically inspected by plant personnel as part of a preventive maintenance program. In this way, problems are detected and corrected before they cause a major shutdown of the ESP. Of course, good recordkeeping should be an integral part of any maintenance program.

The frequency of inspection of all ESP components should be established by a formal in-house maintenance procedure. Vendors' recommendations for an inspection schedule should be followed. A listing of typical periodic maintenance procedures for an ESP used to collect fly ash is given in Table 6-4 (Bibbo 1982).

In addition to the daily monitoring of meters and the periodic inspection of ESP components, some operational checks should be performed every shift and the findings should be recorded on a shift data sheet. At the end of every shift, these shift data sheets should be evaluated for maintenance needs. These once-per-shift checkpoints include an inspection of rappers, dust discharge systems, and T-R sets for proper functioning and an indication of which T-R sets are in the "off" position. Rappers that are not functioning should be scheduled for maintenance, particularly if large sections of rappers are out of service. Dust discharge systems should have highest priority for repair; dust should not accumulate in the bottom of the ESP for long periods of time because of the potential for causing severe plate misalignment problems. Hopper heaters can usually be repaired with little difficulty after removing weather protection and insulation. Insulator heaters may be difficult to repair except during short outages. Hopper heaters keep condensation on the insulators to a minimum and help keep the dust warm and free-flowing.

In addition to performing maintenance, keeping records of the actions taken is also important. For example, wire replacement diagrams should be kept. Although an ESP can operate effectively with up to 10% of its wires removed, care must be taken that no more than 5 to 10 wires in any one gas lane are removed. The loss of wires down any one lane can result in a substantial increase in emissions. The only way to adequately track where wires have failed or slipped out of the ESP is with a wire replacement chart. Also, any adjustments to the rapper frequency and intensity should be recorded along with any repairs. These same recordkeeping practices should be followed for any repairs or replacements made on T-R sets, insulator/heaters, alignment, and the dust discharge systems.

Table 6-4. Preventive maintenance checklist for a typical fly ash precipitator

Daily
1. Take and record electrical readings and transmissometer data.
2. Check operation of hoppers and ash removal system.
3. Examine control room ventilation system.
4. Investigate cause of abnormal arcing in T-R enclosures and bus duct.

Weekly
1. Check rapper operation.
2. Check and clean air filter.
3. Inspect control set interiors.

Monthly
1. Check operation of standby top-housing pressurizing fan and thermostat.
2. Check operation of hopper heaters.
3. Check hopper level alarm operation.

Quarterly
1. Check and clean rapper and vibrator switch contacts.
2. Check transmissometer calibration.

Semiannual
1. Clean and lubricate access-door dog bolt and hinges.
2. Clean and lubricate interlock covers.
3. Clean and lubricate test connections.
4. Check exterior for visual signs of deterioration, and abnormal vibration, noise, leaks.
5. Check T-R liquid and surge-arrestor spark gap.

Annual
1. Conduct internal inspection.
2. Clean top housing or insulator compartment and all electrical insulating surfaces.
3. Check and correct defective alignment.
4. Examine and clean all contactors and inspect tightness of all electrical connections.
5. Clean and inspect all gasketed connections.
6. Check and adjust operation of switchgear.
7. Check and tighten rapper insulator connections.
8. Observe and record areas of corrosion.

Situational
1. Record air-load and gas-load readings during and after each outage.
2. Clean and check interior of control sets during each outage of more than 72 hours.
3. Clean all internal bushings during outages of more than 5 days.
4. Inspect condition of all grounding devices during each outage over 72 hours.
5. Clean all shorts and hopper buildups during each outage.
6. Inspect and record amount and location of residual dust deposits on electrodes during each outage of 72 hours or longer.
7. Check all alarms, interlocks, and all other safety devices during each outage.

Source: Bibbo 1982.

Problem Evaluation

Good site specific records of both the design and operating history will enable operating personnel to better evaluate ESP performance. Design parameters built into the ESP include the following: the specific collection area (SCA), number of fields, number of T-R sets, sectionalization, T-R set capacity, design velocity and treatment time, aspect ratio and particle characteristics (resistivity). Design records indicate the specific conditions under which the ESP was designed to operate. A comparison between design records and operating records indicate whether operating parameters have changed significantly from the design conditions. Secondly, maintaining proper operating records establishes good baseline information to bracket normal ranges of operation.

Evaluating ESP operating problems can be difficult and no single parameter can identify all potential problems; a combination of factors should be considered to accurately pinpoint problems. For example, although most ESP problems are reflected in the electrical readings, many different problems produce the same characteristics on the meters. In addition, an initial failure or problem can cause a "domino effect" bringing about even more problems and making it difficult to identify the original cause. Table 6-5 contains a typical troubleshooting cycle (Szabo and Gerstle 1977) that is useful as a general guide.

The EPA (1985) categorized the major performance problems associated with electrostatic precipitators into the following seven areas: resistivity, dust buildup, wire breakage, hopper pluggage, misalignment of ESP components, changes in particle size distribution, and air inleakage. These problems are related to design limitations, operational changes, and/or maintenance procedures. The following discussion about the identification of these problems and their effect on ESP performance is excerpted from the EPA document titled *Operation and Maintenance Manual for Electrostatic Precipitators* (1985).

Problems Related to Resistivity

The resistivity of the collected dust on the collection plate affects the acceptable current density through the dust layer, dust removal from the plates, and indirectly, the corona charging process. High resistivity conditions in utility fly ash applications have received much attention. The optimum resistivity range for ESP operation is relatively narrow; both high and low resistivity cause problems. Excursions outside the optimum resistivity range are particularly a problem when a unit is designed with a modest amount of plate area, sectionalization, and power-input capabilities. At industrial sources where resistivity changes are intermittent, modification of operating procedures may improve performance temporarily. Expensive retrofitting or modifications may be required if the dust resistivity is vastly different than the design range.

High Resistivity

High dust resistivity is a more common problem than low dust resistivity. Particles having high resistivity are unable to release or transfer electrical charge. At the collection plate, the particles neither give up very much of their acquired charge nor easily pass the corona current to the grounded collection plates. High dust resistivity conditions are indicated by low primary and secondary voltages, suppressed secondary currents and high spark rates in all fields. This condition makes it difficult for the T-R controller to function adequately.

Severe sparking can cause excessive charging off-time, spark "blasting" of particulate on the plate, broken wires due to electrical erosion, and reduced average current levels. The reduced current levels generally lead to deteriorated performance. Because the current level is indicative of the charging process, the low current and voltage levels that occur inside an ESP operating with high resistivity dust generally reflect slower charging rates and lower particle migration velocities to the plate. Particle collection is reduced; consequently, the ESP operates as though it were "undersized." If high resistivity is expected to continue, the operating conditions can be modified or conditioning agents can be used to accommodate this problem and thereby improve performance.

High resistivity also tends to promote rapping problems, as the electrical properties of the dust tend to make it very tenacious. High voltage drop through the dust layer and the retention of electrical charge by the particles make the dust difficult to remove because of its strong attraction to the plate. The greater rapping forces usually required to dislodge the dust may also aggravate or cause a rapping reentrainment problem. Important items to remember are (1) difficulty in removing the high-resistivity dust is related to the electrical characteristics, not to the sticky or cohesive nature of the dust; and (2) the ESP must be able to withstand the necessary increased rapping forces without sustaining damage to insulators or plate support systems.

Low Resistivity

Low dust resistivity, although not as common, can be just as detrimental to the performance of an ESP as high resistivity. When particles with low resistivity reach the collection plate, they release much of their acquired charge and pass the corona current quite easily to the grounded collection plate. Without the attractive and repulsive electrical forces that are normally present at normal dust resistivities, the binding forces between the dust and the plate are considerably weakened. Therefore, particle reentrainment is a substantial problem at low resistivity, and ESP performance appears to be very sensitive to contributors of reentrainment, such as poor rapping or poor gas distribution.

Since there is lower resistance to current flow for particles with low resistivity (compared to normal or high), lower operating voltages are required to obtain substantial current flow. Operating voltages and currents are typically close to clean plate conditions, even when there is some dust accumulation on the plate. Low-resistivity conditions, are typically characterized by low operating voltages, high current flow, and low spark rates.

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

Low-resistivity problems typically result from the chemical characteristics of the particulate and not from flue gas temperature. The particulate may be enriched with compounds that are inherently low in resistivity, either due to poor operation of the process or to the inherent nature of the process. Examples of such enrichment include excessive carbon levels in fly ash (due to poor combustion), the presence of naturally occurring alkalis in wood ash, iron oxide in steel-making operations, or the presence of other low-resistivity materials in the dust. Over-conditioning may also occur in some process operations, such as the burning of high-sulfur coals or the presence of high SO_3 levels in the gas stream, which lower the inherent resistivity of the dust. In some instances, large ESPs with SCAs greater than 750 ft^2/1000 acfm have performed poorly because of the failure to fully account for the difficulty involved in collecting a low-resistivity dust. Although some corrective actions for low resistivity are available, they are sometimes more difficult to implement than those for high resistivity.

Typical High, Normal and Low Resistivity Curves

Evaluating the current and spark rate trends from the inlet to the outlet fields provides a means of evaluating the general resistivity conditions. Moderate dust resistivity conditions, under which ESPs work very well, are indicated by low secondary currents in the inlet field and progressively higher values going toward the outlet. Spark rates under moderate resistivity are moderate in the inlet fields and decrease to essentially zero in the outlet field. High resistivity conditions are indicated by low secondary currents in all of the fields coupled with very high spark rates. Conversely, low resistivity has very high currents and low spark rates in all the fields.

Figure 6-3 shows the typical trend lines for moderate (normal) and high resistivity dusts. As the resistivity goes from moderate to high, the currents decrease dramatically in all of the fields. This is due to the suppressing effect caused by the strong electrostatic field created on the dust layer, and to increased electrical sparking. The decrease in currents is most noticeable in the outlet fields which previously had relatively high currents. Spark rates increase dramatically during high resistivity. Often most of the fields will hit the spark rate limits programmed in by the plant operators. Once the spark rate limit is sensed by the automatic voltage controllers, it no longer attempts to drive up the voltage. This causes a reduction in the operating voltages of these fields. The overall impact on the opacity is substantially increased emissions. In some cases, puffing again occurs during rapping. This is due to reduced capability of the precipitator fields to collect the slight quantities of particles released during rapping of high resistivity dust.

Figure 6-4 shows the typical trend lines for moderate (normal) and low resistivity dusts in a four-field ESP. The moderate resistivity dust shows a steady increase of current from the first field to the fourth field, while the secondary current increases rapidly for all fields when the dust exhibits low resistivity. This effect is especially noticeable in the inlet fields which previously had the lowest currents. This increase in current is due simply to the fact that the dust layer’s electrostatic field is too weak to significantly impede the charging field created by the discharged electrodes. At low resistivity, the spark rates are generally very low or zero. The voltages in all of the fields are a little lower than normal since the automatic voltage controllers sense that the power supply is at its current limit; therefore, the controller does not attempt to drive the voltage up any further. While the low resistivity conditions persist, there can be frequent and severe puffs (opacity increase) which occur after each collection plate rapper activates.

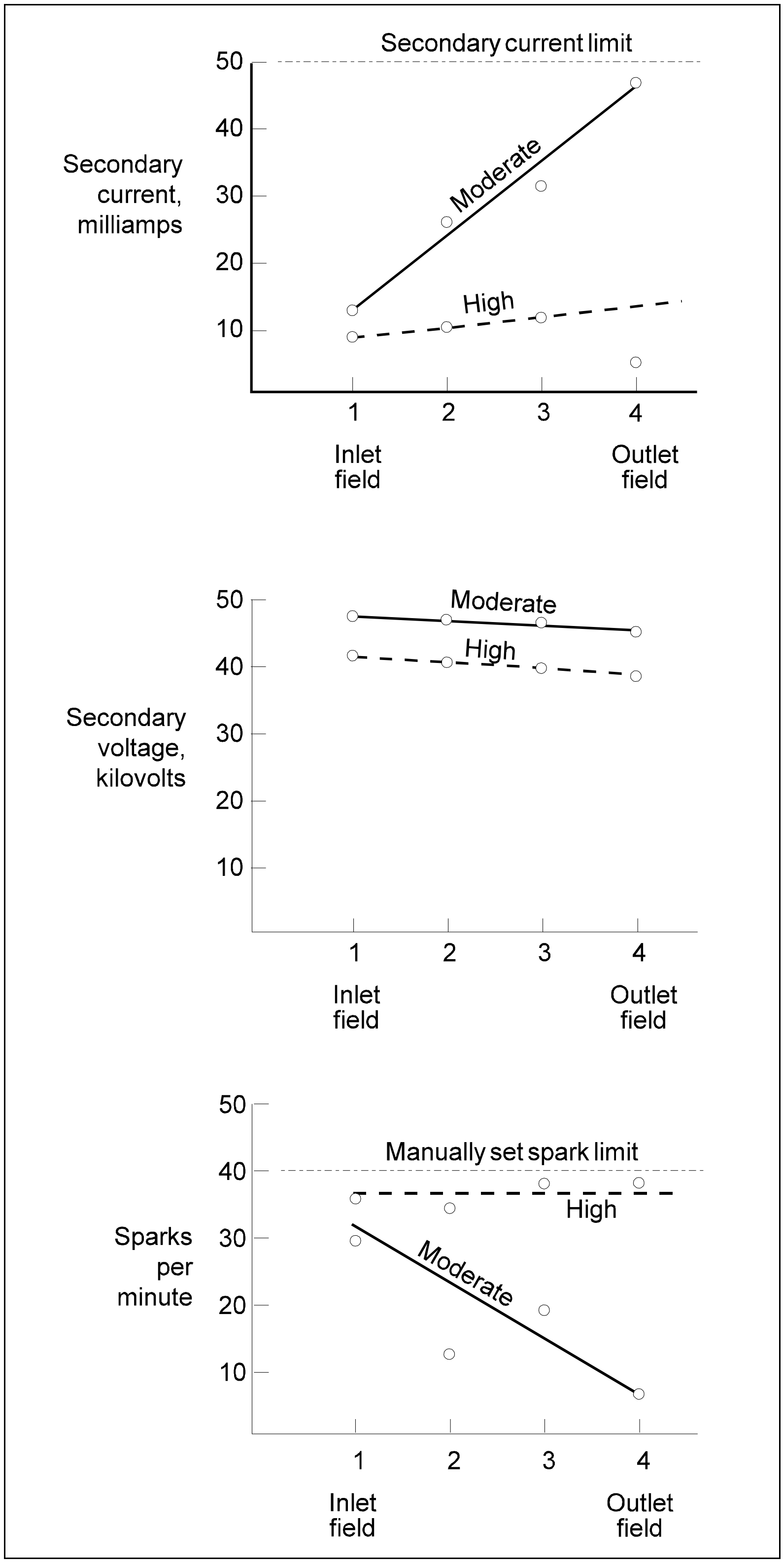

Figure 6-3. Typical T-R set plots - high resistivity versus moderate (normal) resistivity

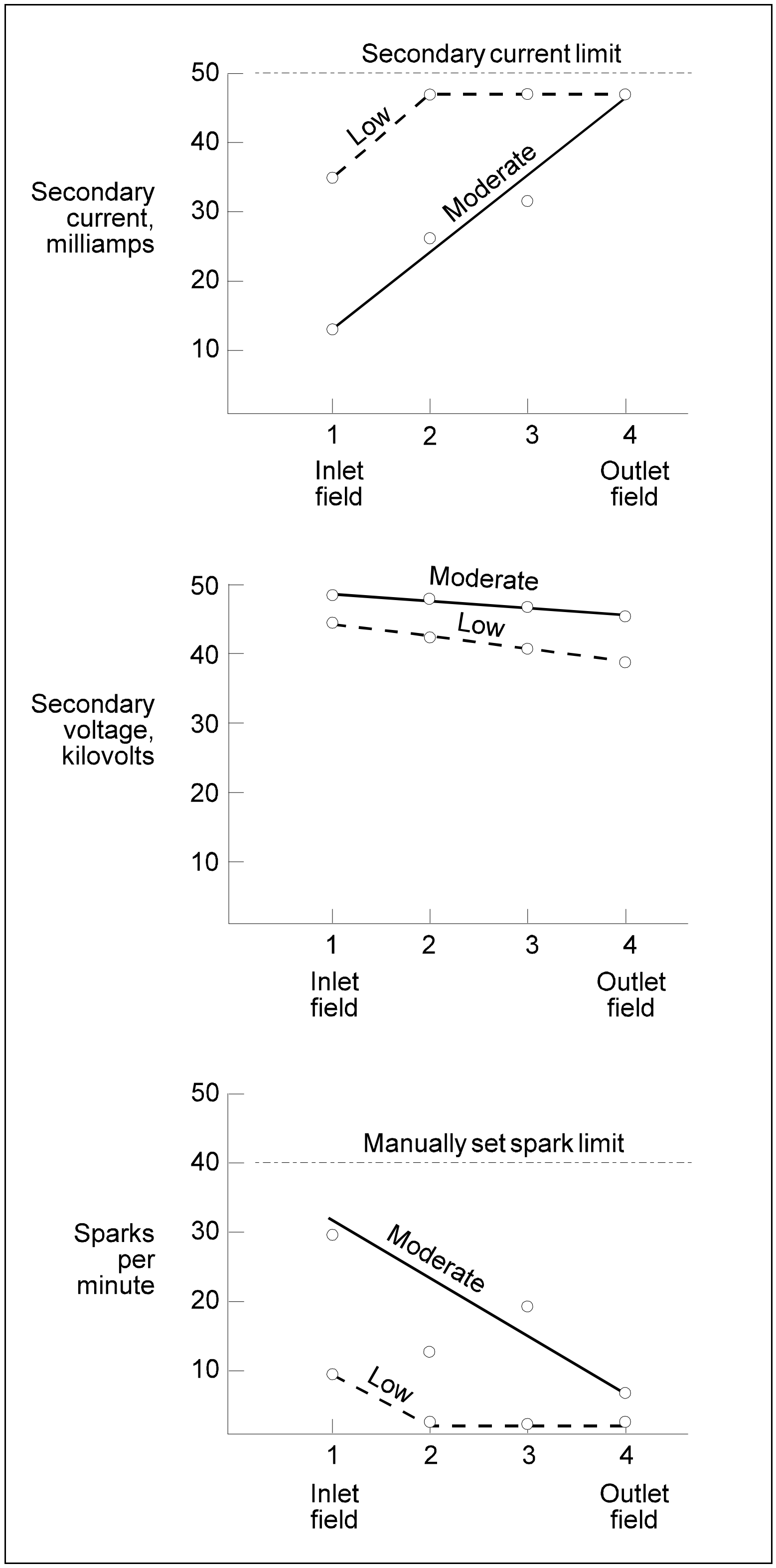

Figure 6-4. Typical T-R set plots - low resistivity versus moderate (normal) resistivity

Using the current, voltage, and spark rate plots is a very good way to use readily available information to evaluate the impossible-to-directly monitor but nevertheless important resistivity conditions. It is possible to differentiate between problems caused by mechanical faults in a single field (such as insulator leakage) and resistivity conditions which inherently affect all of the fields in varying degrees. However, these trend lines are not a perfect analysis tool for evaluating resistivity. A few precipitators never display typical electrical trend lines since they have undersized T-R sets, undersized fields, improperly set automatic voltage controllers, or severe mechanical problems affecting most of the fields.

Dust Accumulation

There are three primary causes of dust accumulation on electrodes:

- Inadequate rapping system
- Sticky dust
- Operation at temperatures below the dew point level

The usual cause for buildup of dust on the collection plates or discharge wires is failure of the rapping system or an inadequate rapping system. The rapping system must provide sufficient force to dislodge the dust without damaging the ESP or causing excessive reentrainment. The failure of one or two isolated rappers does not usually degrade ESP performance significantly. The failure of an entire rapper control system or all the rappers in one field, however, can cause a noticeable decrease in ESP performance, particularly with high-resistivity dust. Therefore, rapper operation should be checked at least once per day, or perhaps even once per shift. A convenient time to make this check is during routine T-R set readings.

Rapper operation may be difficult to check on some ESPs because the time periods between rapper activation can range from 1 to 8 hours on the outlet field. One method of checking rapper operation involves installing a maintenance-check cycle that allows a check of all rappers in 2 to 5 minutes by following a simple rapping pattern. The cycle is activated by plant personnel, who interrupt the normal rapping cycle and note any rappers that fail to operate. After the check cycle, the rappers resume their normal operation. Maintenance of rapper operation is important to optimum ESP performance.

Excessive dust buildup also may result from sticky dusts or operation at gas dew point conditions. In some cases, the dusts may be removed by increasing the temperature, but in many cases the ESP must be entered and washed out. If sticky particulates are expected (such as tars and asphalts), a wet-wall ESP is usually used because problems can occur when large quantities of sticky particles enter a dry ESP.

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

In an operating ESP, differences in the V-I curves can be used to evaluate if a dust buildup problem exists. Buildup of material on the discharge electrodes often means an increase in voltage to maintain a given operating current. The effect of dust buildup on discharge electrodes is usually equivalent to increasing the effective wire diameter. Since the corona starting voltage is strongly a function of wire diameter, the corona starting voltage tends to increase and the whole V-I curve tends to shift to the right (see Figure 6-5). Sparking tends to occur at about the same voltage as it does without dust buildup, unless resistivity is high. This effect on corona starting voltage is usually more pronounced when straight wires are uniformly coated with a heavy dust, and less pronounced on barbed wires and rigid electrodes or when the dust layer is not uniform. Barbed wires and rigid electrodes tend to keep the "points" relatively clean and to maintain a small effective wire diameter and, therefore, a low corona starting voltage. Nevertheless, a higher voltage would still be required to spread the corona discharge over the wire when dust buildup occurs. Thus, buildup on the discharge electrodes would still be characterized by a higher voltage to maintain a given current level.

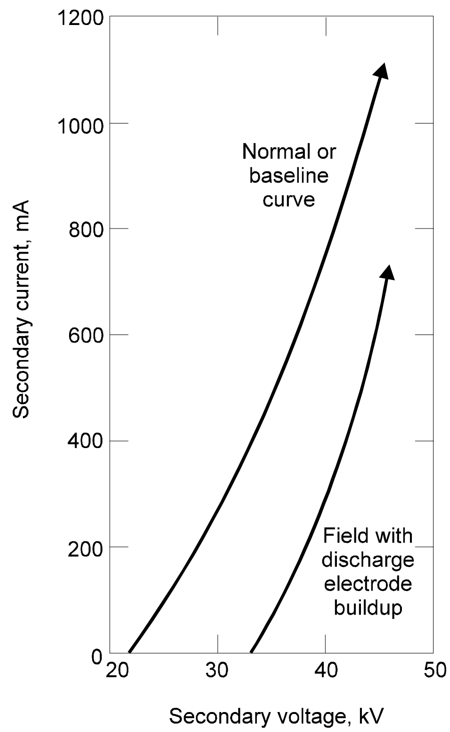

Figure 6-5. V-I curve for a field with excessive wire buildup

Wire Breakage

Some ESPs operate for 10 to 15 years without experiencing a single wire breakage. Whereas others experience severe wire breakage problems causing one or more sections to be out of service nearly every day of operation. Much time and effort have been expended to determine the causes of wire breakage. One of the advantages of rigid-frame and rigid-electrode ESPs is their use of shorter wires or no wires at all. Although most new ESPs have either rigid frames or rigid electrodes, and some weighted-wire systems have been retrofitted to rigid electrodes, the most common ESP in service today is still the weighted-wire.

Wires usually fail in one of three areas: at the top of the wire, at the bottom of the wire, and wherever misalignment or slack wires reduce the clearance between the wire and plate. Wire failure may be due to electrical erosion, mechanical erosion, corrosion, or some combination of these. When wire failures occur, they usually short-out the field where they are located. In some cases, they may short-out an adjacent field as well. Thus, the failure of one wire can cause the loss of particle collection in an entire field or bus section. In some smaller ESP applications, this can represent one-third to one-half of the charging/collecting area and thus substantially limit ESP performance. One of the advantages of higher sectionalization is that wire failure is confined to smaller areas so overall ESP performance does not suffer as much. Some ESPs are designed to meet emission standards with some percentage of the ESP de-energized, whereas others may not have any margin to cover downtime. Because they receive and remove the greatest percentage of particulate matter, inlet fields are usually more important to ESP operation than outlet fields.

Electrical erosion is caused by excessive sparking. Sparking usually occurs at points where there is close clearance within a field due to a warped plate, misaligned guidance frames, or bowed wires. The maximum operating voltage is usually limited by these close tolerance areas because the spark-over voltage depends on the distance between the wire and the plate. The smaller the distance between the wire and plate, the lower the spark-over voltage. Under normal circumstances random sparking does little damage to the ESP. During sparking, most of the power supplied to energize the field is directed to the location of the spark, and the voltage field around the remaining wires collapses. The considerable quantity of energy available during the spark is usually sufficient to vaporize a small quantity of metal. When sparking continues to occur at the same location, the wire usually "necks down" because of electrical erosion until it is unable to withstand the tension and breaks. Misalignment of the discharge electrodes relative to the plates increases the potential for broken wires, decreases the operating voltage and current because of sparking, and decreases the performance potential of that field in the ESP.

Although the breakage of wires at the top and bottom where the wire passes through the field can be aggravated by misalignment, the distortion of the electrical field at the edges of the plate tends to be the cause of breakage. This distortion of the field, which occurs where the wire passes the end of the plate, tends to promote sparking and gradual electrical erosion of the wires.

Design faults and the failure to maintain alignment generally contribute to **mechanical erosion** (or wear) of the wire. In some designs, the lower guide frame guides the wires or their weight hooks (not the weights themselves) into alignment with the plates. When alignment is good, the guide frame or grid allows the wires or weight hooks to float freely within their respective openings. When the position of the wire guide frame shifts, however, the wire or weight hook rubs the wire frame within the particulate-laden gas stream. Failures of this type usually result from a combination of mechanical and electrical erosion. Corrosion may also contribute to this failure. Microsparking action between the guide frame and the wire or weight hook apparently causes the electrical erosion. The same type of failure also can occur in some rigid frame designs where the wires ride in the frame.

Another mechanical failure that sometimes occurs involves **crossed wires**. When replacing a wire, maintenance personnel must make sure that the replacement wire does not cross another wire. Eventually, the resulting wearing action breaks one or both wires. If one of the wires does survive, it is usually worn down enough to promote greater sparking at the point of contact until it finally does break. Any wires that are found to be exceptionally long and slack should be replaced; they should not be crossed with another wire to achieve the desired length.

Corrosion of the wires can also lead to wire failures. Corrosion, an electrochemical reaction, can occur for several reasons, the most common being acid dew point. When the rate of corrosion is slow and generally spread throughout the ESP, it may not lead to a single wire failure for 5 to 10 years. When the rate of corrosion is high because of long periods of operating the ESP below the acid dew point, failures are frequent. In these cases the corrosion problem is more likely to be a localized one (e.g., in places where cooling of the gas stream occurs, such as inleakage points and the walls of the ESP). Corrosion-related wire failures can also be aggravated by startup-shutdown procedures that allow the gas streams to pass through the dew point many times. Facilities have mainly experienced wire breakage problems during the initial process shakedown period when the process operation may not be continuous. Once steady operation has been achieved, wire breakage problems tend to diminish at most plants.

Wire crimping is another cause of wire failure. Crimps usually occur at the top and bottom of the wires where they attach to the upper wire frame or bottle weight; however, a crimp may occur at any point along the wire. Because a crimp creates a residual stress point, all three mechanisms (electrical erosion, mechanical erosion, and corrosion) may be at work in this situation. A crimp can:

1. Distort the electric field along the wire and promote sparking;
2. Mechanically weaken the wire and make it thinner;
3. Subject the wire to a stress corrosion failure (materials under stress tend to corrode more rapidly than those not under stress).

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

Hopper Pluggage

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

The electrical reaction to most plugged hoppers is the same as that for internal misalignment, a loose wire in the ESP, or excessive dust buildup on the plates. Typical symptoms include heavy or "bursty" sparking in the field(s) over the plugged hopper and reduced voltage and current in response to the reduced clearance and higher spark rate. In weighted-wire designs, high dust levels in the hopper may raise the weight and cause slack wires and increased arcing within the ESP. In many cases, this will trip the T-R set off-line because of overcurrent or undervoltage protection circuits. In some situations, the sparking continues even as the dust level exceeds hopper capacity and builds up between the plate and the wire; whereas in others, the voltage continues to decrease as the current increases and little or no sparking occurs. This drain of power away from corona generation renders the field performance virtually useless. The flow of current also can cause the formation of a dust clinker (solidified dust) resulting from the heating of the dust between the wire and plate.

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

Hopper pluggage can be caused by the following:

- Obstructions due to fallen wires and/or bottle weights
- Inadequately sized solids-removal equipment
- Use of hoppers for dust storage
- Inadequate insulation and hopper heating
- Air inleakage through access doors

Most dusts flow best when they are hot, therefore, cooling the dusts can promote a hopper pluggage problem.

Hopper pluggage can begin and perpetuate a cycle of failure in the ESP. For example, there was a case where a severely plugged hopper misaligned both the plates and the wire guide grid in one of the ESP fields. Because the performance of this field had decreased, the ESP was taken off-line and the hopper was cleared. But no one noticed the deteriorated condition of the wire-guide grid. The misalignment had caused the wires and weight hooks to rub the lower guide and erode the metal. When the ESP was brought back on-line, the guide-grid metal eventually wore through. Hopper pluggage increased as weights (and sometimes wires) fell into the hopper, plugging the discharge opening and causing the hopper to fill again and cause more misalignment. The rate of failure continued to increase until it was almost an everyday occurrence. This problem, which has occurred more than once in different applications, demonstrates how one relatively simple problem can lead to more complicated and costly ones.

In most pyramid-shaped hoppers, the rate of buildup lessens as the hopper is filled due to the geometry of the inverted pyramid. Hopper level indicators or alarms should provide some margin of safety so that plant personnel can respond before the hopper is filled. When the dust layer rises to a level where it interferes with the electrical characteristics of the field, less dust is collected and the collection efficiency is reduced. Also, reentrainment of the dust from the hopper can limit how high into the field the dust can go. Although buildups as deep as 4 feet have been observed, they usually are limited to 12 - 18 inches above the bottom of the plates.

Misalignment

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

Changes in Particle Size

Unusually fine particles present a problem under the following circumstances:

1. When the ESP is not designed to handle them
2. When a process change or modification shifts the particle size distribution into the range where ESP performance is poorest.

A shift in particle size distribution tends to alter electrical characteristics and increase the number of particles emitted in the light-scattering size ranges (opacity).

As stated in Lesson 1, there are two principal charging mechanisms: field charging and diffusion charging. Although field charging tends to dominate in the ESP and acts on particles greater than 1 micrometer in diameter, it cannot charge and capture smaller particles. Diffusion charging, on the other hand, works well for particles smaller than 0.1 micrometer in diameter. ESP performance diminishes for particulates in the range of 0.2 - 0.9 micrometer because neither charging mechanism is very effective for particles in this range. These particles are more difficult to charge and once charged, they are easily bumped around by the gas stream, making them difficult to collect. Depending upon the type of source being controlled, the collection efficiency of an ESP can drop from as high as 99.9% on particles sized above 1.0 micrometer or below 0.1 micrometer, to only 85 to 90% on particles in the 0.2 - 0.9 micrometer diameter range. If a significant quantity of particles fall into this size range, the ESP design must be altered to accommodate the fine particles.

When heavy loadings of fine particles enter the ESP, two significant electrical effects can occur: space charge and corona quenching. At moderate resistivities, the space-charge effects normally occur in the inlet or perhaps the second field of ESPs. Because it takes a longer time to charge fine particles and to force them to migrate to the plate, a cloud of negatively charged particles forms in the gas stream. This cloud of charged particles is called a **space charge**. It interferes with the corona generation process and impedes the flow of negatively charged gas ions from the wire to the collection plate. The interference of the space charge with corona generation is called **corona quenching**. When this occurs, the T-R controller responds by increasing the operating voltage to maintain current flow and corona generation. The increase in voltage usually causes increased spark rates, which may in turn signal the controller to reduce the voltage and current in an attempt to maintain a reasonable spark rate. Under moderate resistivity conditions, the fine dust particles are usually collected by the time they reach the third field of the ESP which explains the disappearance of the space charge in these later fields. The T-R controller responds to the cleaner gas in these later fields by decreasing the voltage level, but the current levels will increase markedly. When quantities of fine particles being processed by the ESP increase, the space charging effect may progress further into the ESP.

Air Inleakage

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

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

Inleakage is also accompanied by an increase in gas volume. In some processes, a certain amount of inleakage is expected. For example, application of Lungstrom regenerative air heaters on power boilers or recovery boilers is normally accompanied by an increase in flue gas oxygen. For utility boilers the increase may be from 4.5% oxygen at the inlet to 6.5% at the boiler outlet. For other boilers the percentage increase may be smaller when measured by the O_2 content, but 20 to 40% increases in gas volumes are typical and the ESP must be sized accordingly. Excessive gas volume due to air inleakage, however, can cause an increase in emissions due to higher velocities through the ESP and greater reentrainment of particulate matter. For example, at a kraft recovery boiler, an ESP that was designed for a superficial velocity of just under 6 ft/s was operating at over 12 ft/s to handle an increased firing rate, increased excess air, and inleakage downstream of the boiler. Because the velocities were so high through the ESP, the captured material was blown off the plate and the source was unable to meet emission standards.

Table 6-5 summarizes the problems associated with electrostatic precipitators, along with corrective actions and preventive measures.

Table 6-5. Summary of problems associated with electrostatic precipitators				
Malfunction	**Cause**	**Effect on electrostatic precipitator efficiency**[1]	**Corrective action**	**Preventive measures**
1. Poor electrode alignment	1. Poor design 2. Ash buildup on frame hoppers 3. Poor gas flow	Can drastically affect performance and lower efficiency	Realign electrodes Correct gas flow	Check hoppers frequently for proper operation
2. Broken electrodes	1. Wire not rapped clean, causes an arc which embroglios and burns through the wire 2. Clinkered wire. Causes: a. Poor flow area, distribution through unit is uneven b. Excess free carbon due to excess air above combustion requirements or fan capacity insufficient for demand required c. Wires not properly centered d. Ash buildup, resulting in bent frame, same as (c) e. Clinker bridges the plates and wire shorts out f. Ash buildup, pushes bottle weight up causing sag in the wire g. "J" hooks have improper clearances to the hanging wire h. Bottle weight hangs up during cooling causing a buckled wire i. Ash buildup on bottle weight to the frame forms a clinker and burns off the wire	Reduction in efficiency due to reduced power input, bus section unavailability	Replace electrode	Boiler problems; check space between recording steam and air flow pens, pressure gauges, fouled screen tubes Inspect hoppers; check electrodes frequently for wear; inspect rappers frequently
3. Distorted or skewed electrode plates	1. Ash buildup in hoppers 2. Gas flow irregularities 3. High temperatures	Reduced efficiency	Repair or replace plates Correct gas flow	Check hoppers frequently for proper operation; check electrode plates during outages
4. Vibrating or swinging electrodes	1. Uneven gas flow 2. Broken electrodes	Decrease in efficiency due to reduced power input	Repair electrode	Check electrodes frequently for wear

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Table 6-5. *(continued)*
Summary of problems associated with electrostatic precipitators

Malfunction	Cause	Effect on electrostatic precipitator efficiency[1]	Corrective action	Preventive measures
5. Inadequate level of power input (voltage too low)	1. High dust resistivity 2. Excessive ash on electrodes 3. Unusually fine particle size 4. Inadequate power supply 5. Inadequate sectionalization 6. Improper rectifier and control operation 7. Misalignment of electrodes	Reduction in efficiency	Clean electrodes; gas conditioning or alterations in temperature to reduce resistivity; increase sectionalization	Check range of voltages frequently to make sure they are correct; check in-situ resistivity measurements
6. Back corona	1. Ash accumulated on electrodes causes excessive sparking requiring reduction in voltage charge	Reduction in efficiency	Same as above	Same as above
7. Broken or cracked insulator or flower pot bushing leakage	1. Ash buildup during operation causes leakage to ground 2. Moisture gathered during shutdown or low-load operation	Reduction in efficiency	Clean or replace insulators and bushings	Check frequently; clean and dry as needed; check for adequate pressurization of top housing
8. Air inleakage through hoppers	1. From dust conveyor	Lower efficiency; dust reentrained through electrostatic precipitator	Seal leaks	Identify early by increase in ash concentration at bottom of exit to electrostatic precipitator
9. Air inleakage through electrostatic precipitator shell	1. Flange expansion	Same as above; also causes intense sparking	Seal leaks	Check for large flue gas temperature drop across the ESP
10. Gas bypass around electrostatic precipitator • dead passage above plates • around high tension frame	1. Poor design; improper isolation of active portion of electrostatic precipitator	Only few percent drop in efficiency unless severe	Baffling to direct gas into active electrostatic precipitator section	Identify early by measurement of gas flow in suspected areas
11. Corrosion	1. 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

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Table 6-5. *(continued)*
Summary of problems associated with electrostatic precipitators

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

[1]The effects of precipitation problems can be discussed only on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems.
Sources: Szabo and Gerstle 1977, and Englebrecht 1980.

Safety

Persons who will be operating and maintaining an ESP must be well trained on all safety aspects to avoid injury. One person at the plant should be assigned the responsibility of constantly checking safety standards and equipment and to train or procure safety training for all those who will work with the ESP. A suggested list of important safety precautions is listed in Table 6-6 (Bibbo 1982).

Table 6-6. Important safety precautions

Wiring and controls

1. Prior to startup, double-check that field wiring between controls and devices (T-R sets, rapper prime motors, etc.) is correct, complete, and properly labeled.
2. Never touch exposed internal parts of control system. Operation of the transformer-rectifier controls involves the use of dangerous high voltage. Although all practical safety control measures have been incorporated into this equipment, always take responsible precautions when operating it.
3. Never use fingers or metal screwdrivers to adjust uninsulated control devices.

Access

1. Use a positive method to ensure that personnel are out of the precipitator, flues, or controls prior to energization. Never violate established plant clearance practices.
2. Never bypass the safety key interlock system. Destroy any extra keys. Always keep lock caps in place. Use powdered graphite only to lubricate lock system parts; never use oil or grease. Never tamper with a key interlock.
3. Use grounding chains whenever entering the precipitator, T-R switch enclosure, or bus ducts. The precipitator can hold a high static charge, up to 15 kV, after it is de-energized. The only safe ground is one that can be seen.
4. Never open a hopper door unless the dust level is positively below the door. Do not trust the level alarm. Check from the upper access in the precipitator. Hot dust can flow like water and severely burn or kill a person standing below the door. Wear protective clothing.
5. Be on firm footing prior to entering the precipitator. Clear all trip hazards. Use the back of the hand to test for high metal temperatures.
6. Avoid ozone inhalation. Ozone is created any time the discharge electrodes are energized. Wear an air-line mask when entering the precipitator, flues, or stack when ozone may be present. Do not use filters, cartridge, or canister respirators.
7. Never poke hoppers with an uninsulated metal bar. Keep safety and danger signs in place. Clean, bright signs are obeyed more than deteriorated signs.

Fire/explosion

1. In case of boiler malfunction that could permit volatile gases and/or heavy carbon carryover to enter the precipitator, immediately shut down all transformer-rectifier sets. Volatile gases and carbon carryover could be ignited by sparks in the precipitator, causing fire or explosion, damaging precipitator internals.
2. If high levels of carbon are known to exist on the collecting surface or in the hoppers, *do not open precipitator access doors until the precipitator has cooled below 52°C (125°F)*. Spontaneous combustion of the hot dust may be caused by the inrush of air.
3. If a fire is suspected in the hoppers, empty the affected hopper. If unable to empty the hopper immediately, shut down the transformer-rectifier sets above the hopper until it is empty. Use no other method to empty the hopper. Never use water or steam to control this type of fire. These agents can release hydrogen, increasing the possibility of explosion.

Source: Bibbo 1982.

Summary

Successful longtime operation of an ESP ultimately depends on effective inspection, startup and shutdown and operation and maintenance procedures. Regardless of how well the ESP is designed, if these procedures are not developed and routinely followed the ESP will deteriorate resulting in a decrease of its particulate emission removal efficiency.

The lesson discusses the importance of monitoring key operating parameters including voltage and current readings of each T-R set, opacity, flue gas flow rate and flue gas composition and moisture levels. We also covered how evaluating current, voltage and spark rate trends can help provide information on dust resistivity conditions. A change in dust resistivity can drastically alter the performance of the ESP and will likely lead to emission compliance problems if not rectified.

Suggested Reading

Bibbo, P. P. 1982. Electrostatic precipitators. In L. Theodore and A. Buonicore (Eds.), *Air Pollution Control Equipment-Selection, Design, Operation and Maintenance* (pp.3-44). Englewood Cliffs, NJ: Prentice Hall.

Englebrecht, H. L. 1980. Mechanical and electrical aspects of electrostatic precipitator O&M. In R. A. Young and F. L. Cross (Eds.), *Operation and Maintenance for Air Particulate Control Equipment* (pp. 283-354). Ann Arbor, MI: Ann Arbor Science.

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Review Exercise

1. Air inleakage at flanges or collector access points in high-temperature systems (hot-side ESPs) may:
   a. Allow dust to settle out quickly into hoppers
   b. Cause acids and moisture to condense on internal components of the ESP
   c. Increase the overall collection efficiency of the unit
2. Gas streams of high temperature should be maintained above the:
   a. Ignition temperature
   b. Gas dew point
   c. Concentration limit
3. Since most ESPs are installed in the field, it is important to check that all surfaces and areas of potential heat loss are adequately covered with:
   a. Paint
   b. Plastic coating
   c. Insulation
   d. Aluminum siding
4. Before the ESP is started, the installation crew should prepare and use a____________________.
5. Which of the following ESP components should be checked before starting the collector?
   a. Hoppers and discharge devices
   b. Rappers
   c. Discharge and collection electrodes
   d. All of the above
6. Two very important parameters monitored by meters on T-R sets and used to evaluate ESP performance are ____________________ and____________________.
7. True or False? Individual T-R set values for voltage and current are important; however, the trends for voltage and current noted within an entire ESP are more valuable in assessing performance.
8. As particulate matter is removed from the gas stream, the ____________________ should increase from the inlet to the outlet fields.
   a. Opacity
   b. Current density
   c. Rapper intensity
   d. Amperage

9. An opacity monitor (transmissometer) measures:
   a. Particle weight
   b. Particle size
   c. Light differential
   d. Primary current

10. True or False? Opacity monitors are useful tools to aid in optimization of spark rate, power levels and rapping cycles in ESPs.

11. True or False? Changes in flue gas temperature generally have little or no effect on particle resistivity.

12. Operating parameters such as specific collection area, superficial velocity, and treatment time are dependent on the ____________________ ____________________ ____________________.

13. True or False? Because of their open design, gas flow distribution through ESPs are generally very evenly distributed.

14. ____________________ tests are generally conducted on cool, inoperative ESPs through which no gas is flowing.
    a. Air Load V-I Curve
    b. Gas Load V-I Curve
    c. Compliance
    d. All of the above

15. True or False? When ESPs are equipped with identical fields, the air-load curves for each field should be very similar.

16. Air Load V-I curves for a given ESP field will generally shift to the ____________________ if plates are dirty compared to previous tests.
    a. Left
    b. Right
    c. a and b, above

17. Gas-load curves are similar to air-load curves except the gas-load curves are shifted to the ____________________ compared to the air-load curves.
    a. Left
    b. Right

18. True or False? Gas-load curves generally are identical for a given ESP field on a day-to-day basis.

19. True or False? High dust resistivity is characterized by the tendency toward high spark rates at low current levels.

20. Excessive dust buildup on the collecting plates or discharge wires can be caused by failure of the:
    a. Primary and secondary voltage
    b. Rapping system
    c. Back corona
    d. All the above
21. Wire failure can be caused by:
    a. Electrical erosion
    b. Mechanical erosion
    c. Corrosion
    d. All of the above
22. True or False? Unlike baghouses, ESPs are not affected by operating temperatures falling below the acid or moisture dew point.
23. True or False? In general, a well-designed ESP can operate effectively with a small percentage (less than 10) of its wires out-of-service.
24. True or False? Dust discharge hopper pluggage is not a major concern for ESPs.

Review Exercise Answers

1. **b. Cause acids and moisture to condense on internal components of the ESP**
   Air inleakage at flanges or collector access points in high-temperature systems (hot-side ESPs) may cause acids and moisture to condense on internal components of the ESP.

2. **b. Gas dew point**
   Gas streams of high temperature should be maintained above the gas dew point. When the temperature falls below the gas dew point, moisture or acid can condense on ESP components and possibly cause corrosion.

3. **c. Insulation**
   Since most ESPs are installed in the field, it is important to check that all surfaces and areas of potential heat loss are adequately covered with insulation.

4. **Checklist**
   Before the ESP is started, the installation crew should prepare and use a checklist.

5. **d. All of the above**
   The following are some ESP components that should be checked before starting the collector:
   - Hoppers and discharge devices
   - Rappers
   - Discharge and collection electrodes

6. **Voltage**
   Current
   Two very important parameters monitored by meters on T-R sets and used to evaluate ESP performance are voltage and current.

7. **True**
   Individual T-R set values for voltage and current are important; however, the trends for voltage and current noted within an entire ESP are more valuable in assessing performance. T-R set readings for current, voltage, and sparking should follow certain patterns from the inlet to the outlet fields.

8. **b. Current density**
   As particulate matter is removed from the gas stream, the current density should increase from the inlet to the outlet fields. The dust concentration in the inlet sections will suppress the current. Increased current density is needed in the outlet sections where there is a greater percentage of very small particles.

9. **c. Light differential**
   An opacity monitor (transmissometer) measures light differential. An opacity monitor compares the amount of light generated and transmitted by the instrument on one side of the gas stream with the quantity measured on the other side of the gas stream.

10. **True**
    Opacity monitors are useful tools to aid in optimization of spark rate, power levels and rapping cycles in ESPs.

11. **False**
    Changes in flue gas temperature have an important effect on particle resistivity. In fact, while gas temperature variations may have some effect on corona discharge characteristics and physical characteristics of the ESP (corrosion, expansion/contraction), their most important effect is on particle resistivity. See Figure 3-1.

12. **Gas flow rate**
    Operating parameters such as specific collection area, superficial velocity, and treatment time are dependent on the gas flow rate.

13. **False**
    Actually, gas flow through the ESP is not evenly distributed. ESP manufacturers settle for what they consider to be an acceptable variation.

14. **a. Air Load V-I Curve**
    Air-Load V-I Curve tests are generally conducted on cool, inoperative ESPs through which no gas is flowing.

15. **True**
    When ESPs are equipped with identical fields, the air-load curves for each field should be very similar.

16. **b. Right**
    Air Load V-I curves for a given ESP field will generally shift to the right if plates are dirty compared to previous tests. Dirty plates suppress the current. It takes a higher voltage to generate the same amount of current as with a "clean plate" condition.

17. **a. Left**
    Gas-load curves are similar to air-load curves except the gas-load curves are shifted to the left compared to the air-load curves. Gas-load curves are generated while the unit is on-line. The curves are generally shifted to the left because sparking occurs at lower voltage and current when particles are present.

18. **False**
    Gas-load curves for a given ESP field generally vary on a day-to-day basis. Curve positions can change due to fluctuations in the amount of dust on the plates, gas flow, particulate loadings, temperature, and resistivity.

19. **True**
    High dust resistivity is characterized by the tendency toward high spark rates at low current levels.

20. **b. Rapping system**
    Excessive dust buildup on the collecting plates or discharge wires can be caused by failure of the rapping system.

21. **d. All of the above**
    Wire failure can be caused by the following:
    - Electrical erosion
    - Mechanical erosion
    - Corrosion.

22. **False**
    Like baghouses, ESPs are affected by operating temperatures falling below the acid or moisture dew point. At temperatures below the acid or moisture dew point, acid or moisture can condense on ESP components and cause corrosion.

23. **True**
    In general, a well-designed ESP can operate effectively with a small percentage (less than 10) of its wires out-of-service.

24. **False**
    Dust discharge hopper pluggage is a major concern for ESPs. Hopper pluggage can permanently damage an ESP.

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