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CHAPTER 1 - ELECTROSTATIC PRECIPITATOR TECHNICAL REVIEW

This chapter is a comprehensive technical review of electrostatic precipitator fundamentals and designs for various types of ESPs and the components which comprise an ESP, including:

- ***Discharge Electrodes***
- ***Collecting Electrodes***
- ***Rappers***
- ***Hoppers***
- ***High Voltage Support Systems***
- ***Hot-side ESPs***
- ***Sodium Depletion and Back Corona***
- ***Wet ESPs***
- ***ESP Doors***

A Flat Plate Collecting Electrode
(Courtesy of BHA)

1.1 Electrostatic Precipitator Fundamentals

Basic Theory of Electrostatic Precipitation

The basic concepts of electrostatic precipitation are presented to help the reader understand how an ESP operates and what affects its performance. It is not important to understand the rigorous mathematical derivation of the equations that govern the operation of an ESP, it is important to understand the basic principles.

Traditional Theory

The electrostatic precipitation process consists of three distinct parts:

- Charging of the particles
- Collection of the charged particles
- Removal of the collected dust or material particles from the electrodes

Theoretical equations can be applied to the first two precipitation process parts above. There are

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many equations that are used to describe the efficiency of an ESP. The most commonly used equation is the Deutsch-Anderson equation. Although the equation neglects a number of practical and empirical considerations, it is effective to illustrate the effect of important parameters on ESP efficiency. In its simplest form, the Deutsch-Anderson equation defines the particulate loss (penetration) from an ESP as given in the Equation below. Because of the negative (-) sign in the exponent, increasing the exponent decreases losses. Thus, higher the migration velocity and larger collecting area equate to higher efficiency and less loss. Since volume (Q) is in the denominator, a higher volume means lower efficiency and more loss.

$$P = e^{-(A\,W/Q)}$$

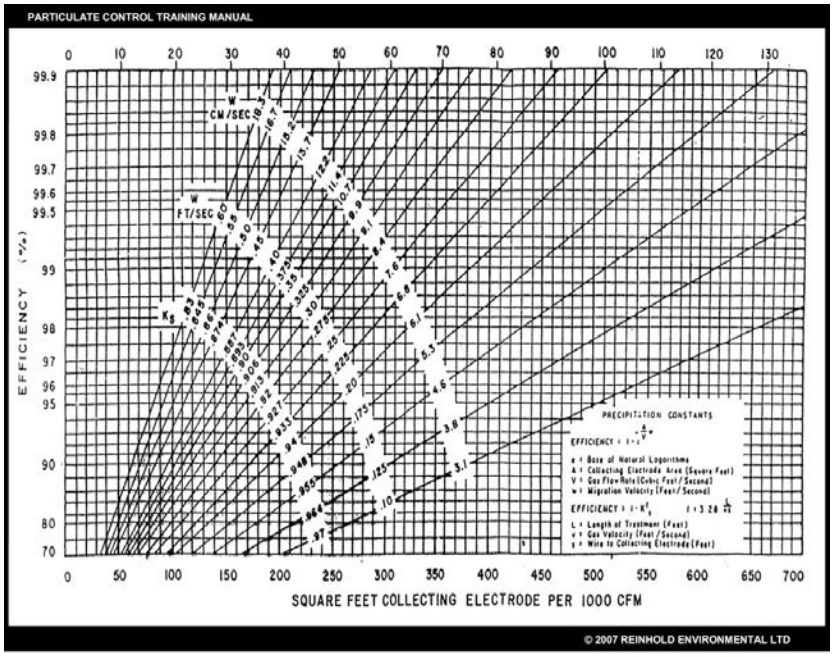
where

- P = penetration (loss)
- e = base of the natural logarithm = 2.71828
- A = effective collecting surface area
- W = particulate migration velocity
- Q = gas volume

This equation can be represented graphically as shown in **Figure:**

Graphical representation of the Deustch-Anderson equation

This basic equation has been used for many years, but did not seem to predict the efficiency of modern high efficiency precipitators. The Deutsch-Anderson equation has been modified from its original in many ways, but the most common is to replace the quantity (AW/Q) with (AWk/Q)k , where Wk is the modified migration velocity and the superscript k is a variable factor. For fly ash ESPs, the value of k is generally accepted as 0.5, and ranges from 0.4 to 0.6.



Graphical Representation of the Deutsch-Anderson Equation

The migration velocity (W) represents the speed of movement of the charged particulate towards the collecting surface under the influence of an electric field. The migration velocity is given in the Equation below.

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$W = k\ a\ Eo\ Ep$

where
- a = particle radius
- k = proportionality constant related to gas viscosity and physical geometry
- Eo = electric field strength in which the particles are charged (proportional to peak operating voltage)
- Ep = electric field strength in which the particles are collected (proportional to average operating voltage)

This equation clearly shows the "squaring" effect that electric field (and thus operating voltage) has on precipitator efficiency. It also emphasizes the effect particle size has on collection efficiency. Finer particles have lower migration velocities, and therefore, are more difficult to collect. Another way to write the equation for the loss of particles through an ESP is given in the Equation below.

$P = e^{-(WL/RV)}$

where
- L = total collecting length in the direction of gas flow
- R = nominal space between discharge and collecting electrodes
- V = gas flow velocity

The quantity L/V is the treatment time (T) of the particles. Intuitively, a longer the treatment time relates to higher efficiency and lower losses. Thus, a longer treatment length or lower gas velocity are more favorable to ESP performance. These theoretical equations do not consider the non-ideal effects such as:

- Non-uniform gas velocity or temperature distribution
- Gas sneakage around the active precipitation zone (i.e. between the sidewall and the last collecting plate)
- Hopper sweepage (i.e. gas sweeping into the hopper and re-entraining collected ash)
- Electrode scouring (i.e. gas flowing past the electrodes and re-entrains collected ash)
- Rapping re-entrainment

Some of these will be discussed in other sections of this manual. Re-entrainment is addressed in the next section.

Re-Entrainment

A large portion of the losses from a high efficiency ESP is from some form of re-entrainment. The following is a brief discussion on another way of looking at ESP losses that shows the importance of reentrainment losses. Once the dust has been precipitated onto and agglomerated on the collecting electrodes, it falls down into the hoppers. This may happen with the assistance of mechanical rapping or by the weight of the collected dust alone. While falling, it is inevitable

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that some fraction F of the dust is re-entrained into the gas stream. This re-entrainment adds to the penetration, or loss of dust, through the ESP. This part of the penetration also has an exponential relationship and may be represented by the following Equation

$$Pr = e^{-(L/FV)} = e^{-(T/F)}$$

where T is treatment time L/V, described above.

The total effective penetration (Pe) can now be written as

$$Pe = P + Pr$$

where P is defined as the theoretical penetration above.

Tests with full-scale, dry type ESPs show that the effective penetration (Pe) is much greater than the theoretical penetration (P).

This indicates that the effective penetration is controlled by the re-entrainment penetration (Pr) and that the effective penetration is the re-entrainment penetration $e \sim Pr$.

Thus, although it is important to have an ESP that is sized appropriately, steps should be taken to reduce re-entrainment of the dust.

1.2 Discharge Electrode Designs

Introduction

The discharge electrode is one of the key components in an ESP. The discharge electrode has two functions:

- to generate a corona to charge gas ions which collide with and charge the dust particles, and
- to generate an electrostatic field to drive the particles to the collecting electrode.

Applying a negative high voltage to the discharge electrode relative to the electrically positive grounded collecting electrode generally produces these processes. The discharge electrode must have a small radius surface or sharp point to generate the strong electric field necessary to produce the corona. Theory of particle charging and collection is discussed elsewhere in this manual. This section discusses the types of discharge electrodes shown in **Figure:**

Typical Discharge Electrodes

and their characteristics.

Several important characteristics of a good discharge electrode are

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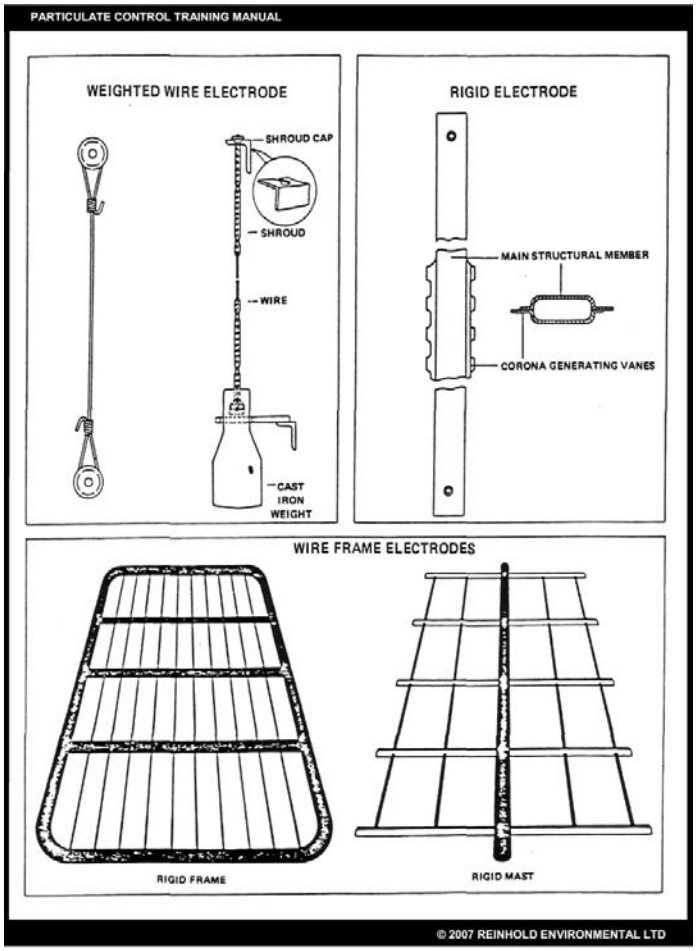
- Cost effectiveness
- Ease of installation
- Ability to be aligned and to maintain the alignment
- Ability to be rapped
- Reliability
- Performance



Typical Discharge Electrodes

Obviously, it is important that the discharge electrodes be cost effective. The manufacturer cannot sell, and the purchaser will not buy it, if the cost of the electrode makes the ESP non-competitive. Ease of installation is also a cost factor, whether the manufacturer has a turnkey project or whether the purchaser hires a separate contractor to construct the ESP. Proper electrode alignment is important for good ESP performance. Alignment requirements at the initial installation and the ability to maintain that alignment over the life of the ESP, is important.

Although most of the particles are collected on the collecting electrodes, i.e. the collecting plates, a significant amount of particulate collects on the discharge electrodes. The ability of the discharge electrode to be rapped to remove the accumulated particulate is important. Reliability of the discharge electrode and its resistance to breakage is important in long-term maintainability and minimal maintenance costs. The keys to good electrode performance of a discharge electrode are in its electrical characteristics, its electrical charging system and its physical arrangement in the ESP box.

The design of the discharge electrode determines its effectiveness in achieving its purposes, and thus, the efficiency of the ESP. Discharge electrode designs have evolved since the initial application of ESPs to industrial processes in the early 1900s. Three common types of discharge electrodes are discussed is **Figure:**

Typical Discharge Electrodes

- Weighted wires (WW)
- Rigid frames (RF) including Mast electrodes
- Rigid discharge electrodes (RDE)

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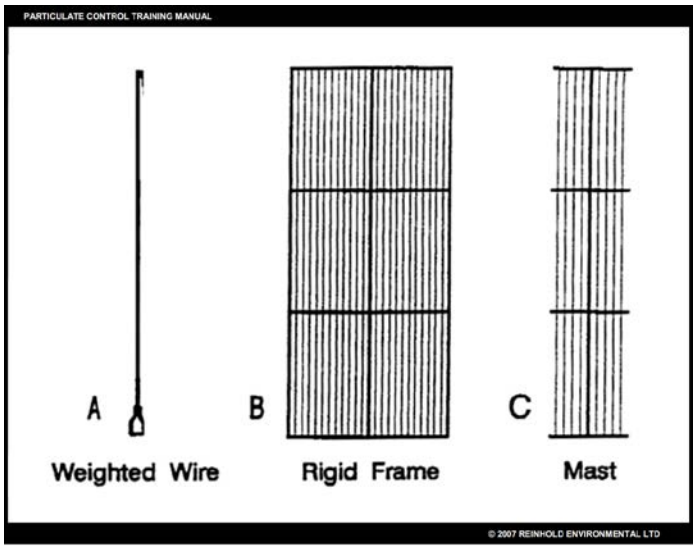
Weighted Wire

The weighted wire discharge electrode is the simplest of the three. A series of thin wires, typically 0.1 inches (2.5mm) in diameter, are hung from a high voltage support frame. The wires are tensioned by a weight at the bottom, as the name implies. The electrode arrangement is shown in the **Figure:**

Discharge Electrode Types - View A

where two wires are aligned with one collecting plate section. This will be discussed in a later section. Sometimes a barbed wire, similar to that used to contain animals, is used in place of the round wire, where higher corona generation is required.

The WW was the predominant discharge electrode used by US suppliers of ESPs until the 1980s. The WW electrode is cost effective in the short term, easy to install and align, cleans relatively easily, and performs well. The reliability of the weighted wire has been poor. The long wires fatigue due to sparking and vibration, and fail. The broken wire then shorts out the electrical field, making it inoperable. Sometimes the broken wire also shorts out adjacent electrical sections of the ESP. Strict quality control in manufacturing is essential to prevent pre-mature failure.



Discharge Electrode Types

Rigid Frame Electrode/Mast Electrode

The rigid frame (RF) discharge electrode is designed to overcome some of the reliability problems of the WW electrodes. As the name implies, a rigid pipe frame is suspended between collecting electrodes. The pipe extends around the perimeter of the frame with intermediate horizontal and vertical cross members as needed for strength. The pipes generally do not generate a discharge corona. The discharge members, usually wires, are then suspended between the horizontal cross members. This design is shown in **Figure:**

Discharge Electrode Types - View B

A variation of the rigid frame design is the mast design, where a single pipe mast is used with horizontal cross pipes only. The perimeter vertical pipes are eliminated. This design is shown in **Figure:**

Discharge Electrode Types - View C.

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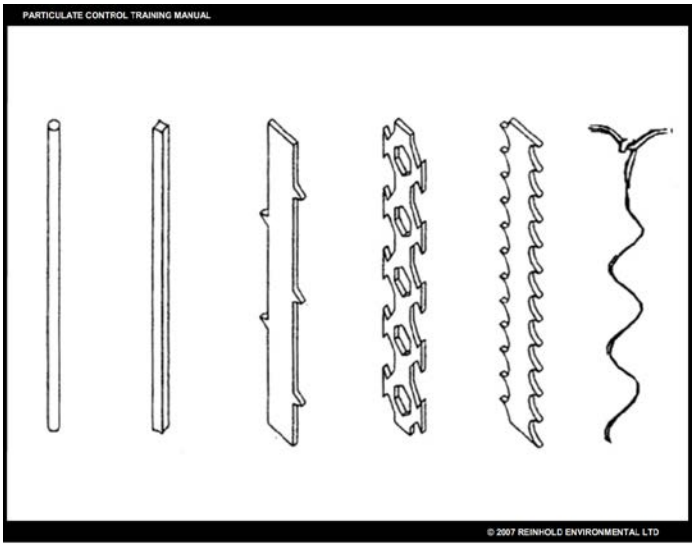
The wires used in rigid frame and mast discharge electrodes vary widely, depending on the ESP supplier and the application. These wires can be round, square, barbed, or spiral, as shown in **Figure:**

Typical Discharge Wires.



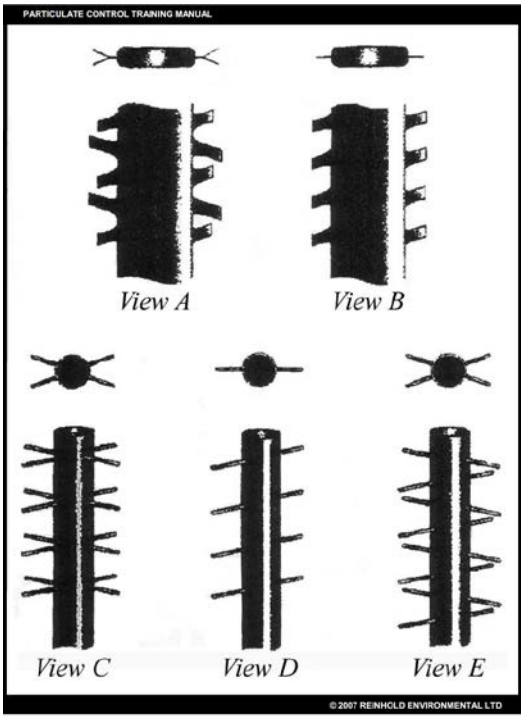
Typical Discharge Wires

European ESP suppliers typically use the RF design, even today. The RF is more expensive to manufacture and erect than weighted wires, but its reliability is superior. The relatively short length of the discharge wire (5-10 feet) makes them less likely to break. If they do break they will only short out one electrical section. These electrodes rap well, but require more intense rapping because of the mass of the electrodes relative to weighted wires. These electrodes provide better reliability than weighted wire electrodes. The short sections of wire strung between the horizontal cross pipes provide higher reliability by reducing the potential of wire breakage and the resultant shorting of electrical fields.

Rigid Discharge Electrode

The rigid discharge electrode (RDE) term has been used to refer to both the rigid frame and mast type of discharge electrode described previously. For purposes of this section, the RDE is defined as a truly rigid, unitized electrode that combines the mechanical strength and discharge component in one single electrode. The most common of these is referred to as a "pipe and spike", as shown in the last figure in this section, **Figure:**

Typical Rigid Discharge Electrodes - View C.



Rigid Discharge Electrodes

As the name implies, a single tube or pipe is used as the mechanical and structural member. Attached to the pipe are discharge spikes, usually nails or needles with sharp points to generate the corona discharge. These spikes may be perpendicular to the body of the RDE or

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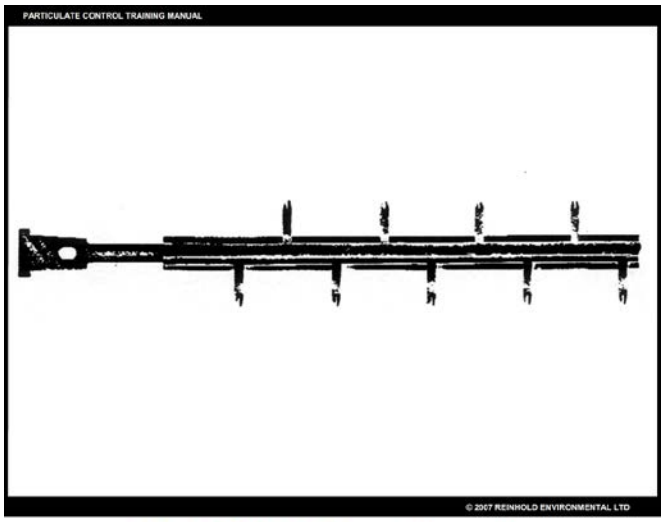
they can be at various angles as shown in **Figure:**

Rigid Discharge Electrodes - Views C, D and E



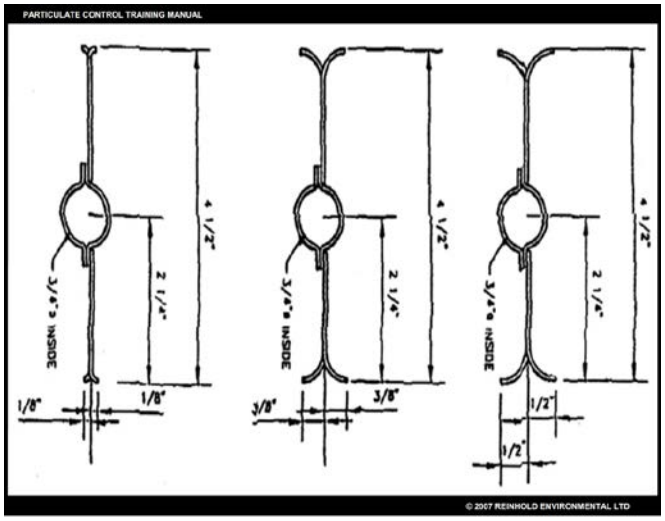
Typical Rigid Discharge Electrode

Other RDE designs are shown in **Figure:**

Rigid Discharge Electrodes - Views A and B

and the remaining three figures in this section, where the body of the electrode is roll formed and/or fabricated. The discharge spikes may be simple nails or tabs, or they may be complex spikes, as these figures show.

RDEs are very reliable. They are not likely to break, but they are not unbreakable. There are cases of electrode failure due to corrosion or electrical erosion. Installation of RDEs is often easier than RFs, and they can be rapped effectively. Alignment problems can occur if the electrodes are not manufactured properly. Strict quality control in the manufacturing process is absolutely necessary.



Typical Rigid Discharge Electrodes - 1

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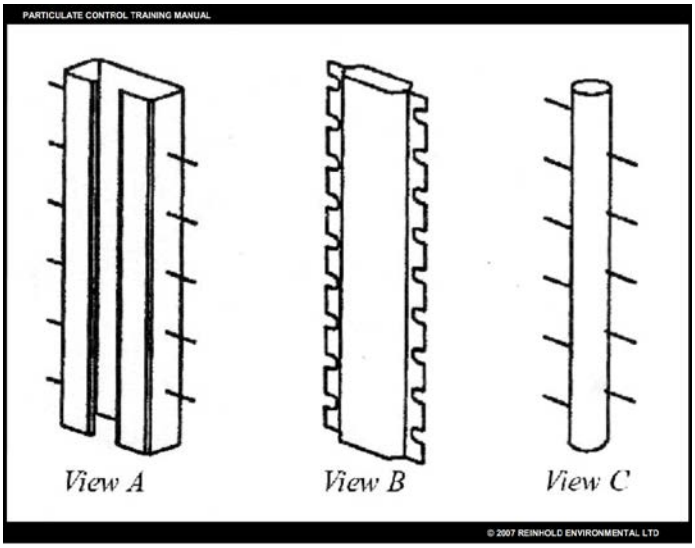
Although developed initially by a European ESP supplier, the European suppliers do not generally use RDEs. The RF ESP became more popular in the US in the 1970's because of its reliability over weighted wire ESPs. The U.S. suppliers needed a more reliable electrode to be competitive with the RF electrode and turned to the RDE design. The RDEs were used in the same way as the weighted wires, with one RDE replacing two wires.

Often plate-to-wire spacing will need to be increased to accommodate RDEs replacing WW, and TR sets could need to be upgraded.



Typical Rigid Discharge Electrodes - 2

1.3 Collecting Electrode Designs

Collecting electrodes must work in conjunction with their associated discharge electrodes. In its simplest form, the collecting electrode is a flat plate. Because of the large size of the collecting electrodes in an industrial ESP, a flat plate does not have the structural or mechanical strength necessary to maintain proper alignment. This has lead to many variations of collecting electrode designs, each with its own characteristics.

Several important characteristics of a good collecting electrode are

- Cost effectiveness
- Ease of installation
- Ability to be aligned and to maintain the alignment
- Ability to be rapped
- Reliability

A Flat Plate Collecting Electrode
(Courtesy of BHA)

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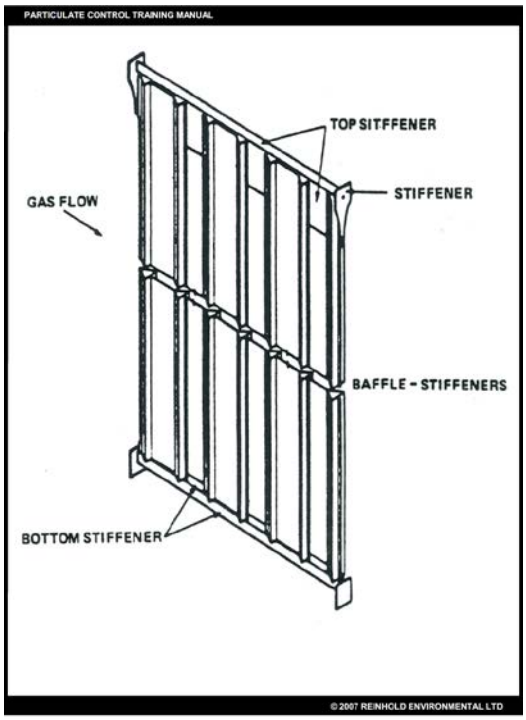
- Performance

Obviously, it is important that the collecting electrodes be cost effective. The manufacturer cannot sell and the purchaser will not buy it if the cost of the electrode makes the ESP non-competitive. Ease of installation is also a cost factor, whether the manufacturer has a turnkey project or whether the purchaser hires a separate contractor to construct the ESP. Proper electrode alignment is important for good ESP performance. Alignment requirements at the initial installation and the ability to maintain that alignment over the life of the ESP are important.

Manufacturing of Flat Plate Collecting Electrode
(Courtesy of BHA)

Although some of the particles are collected on the discharge electrodes, most of particulate collects on the collecting electrodes (i.e. the collecting plate), as the name implies. The ability of the collecting electrode to be rapped to remove the accumulated particulate is important in maintaining good ESP efficiency. Reliability of the collecting electrode and its resistance to fatigue and failure is important in long-term maintainability and minimal maintenance costs. The key to good electrode performance of a collecting electrode is in its electrical characteristics in concert with the selected discharge electrode.



Typical Shop Assembled Collecting Electrode

Collecting electrodes can be divided into two categories:

- Shop assembled electrodes
- Field assembles electrodes

Each of these will be discussed below.

With small precipitators, collecting electrodes could easily be shop assembled for easier installation. As ESPs grew in size to meet more stringent environmental regulations, it became more difficult to shop assemble collecting plates, but this method is still used. These shop-assembled plates can be fabricated in several ways. In its simplest form stiffeners are welded to a flat plate to make the plate more rigid. The stiffeners can

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have a variety of shapes, depending on the suppliers' preferences and manufacturing capabilities. The welding has to be done carefully. Too much weld will distort the plate. Too little weld and the stiffeners will come off due to vibrational stresses during rapping. Collecting electrode fabricators have many techniques available to properly weld the plate and stiffeners therefore this is not considered a problem. Some typical fabricated flat plate collecting electrodes are shown in Figures:

A Flat Plate Collecting Electrode

Manufacturing of Flat Plate Collecting Electrode

and

Typical Shop Assembled Collecting Electrode.

Some shop-assembled plates are fabricated from individual strips, that are typically roll formed. These strips may be anywhere from 16 inches to 36 inches (400-900 mm) wide. Generally the roll formed strip has the stiffener rolled into it to eliminate the need for welding. These individual strips are then assembled by welding or crimping the strips together. A typical electrode fabricated from individual strips is shown in **Figure:**

Assembly of roll formed collecting electrode strips into an interlocked collecting electrode module.

The shop assembled collecting electrodes were popular with US ESP suppliers. European suppliers traditionally have offered field assembled collecting electrodes. These field-assembled electrodes are made from individual collecting strips, similar to those used in shop assembled collecting electrodes. They may vary in width from 16 to 36 inches (400-900 mm). The strip may be assembled so that they are separated, overlapping or interlocking, depending on the profile of the plate. For rigidity and for maintaining proper alignment, interlocking strips can be superior, particularly for tall field heights. Those strips that are not rolled to interlock generally will have some type of interlocking clip used during installation. See **Figure:**

Assembly of Roll Formed Collecting Electrode Strips into an Interlocked Collecting Electrode Module

Typical Field Assembled Collecting Electrode

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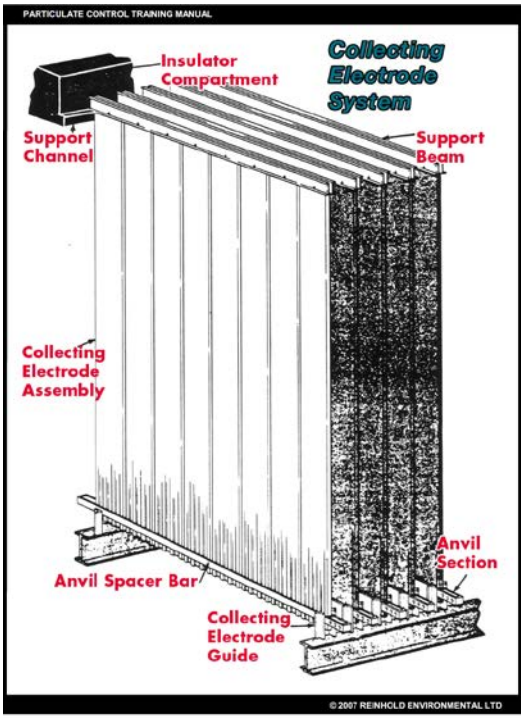
for an example.

There are many different profiles for the collecting electrode. The profile is determined by four factors.

- Structural and mechanical integrity
- Electrical characteristics in association with the discharge electrode
- Rapping characteristics
- Aerodynamics

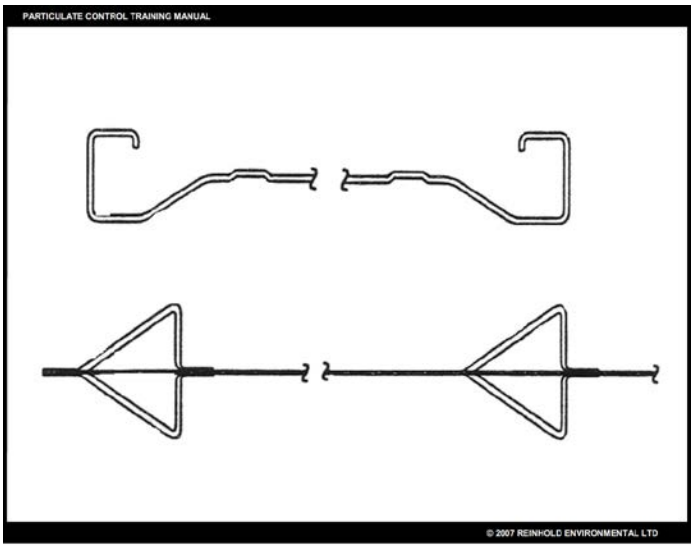


Typical Field Assembled Collecting Electrode

The issue of structural and mechanical integrity has already been mentioned above. Small and large ribs can be rolled into the strips to provide adequate resistance to deformation during operation at high temperatures or during handling. The ability to simply and easily hang the plate or strip is a part of this issue.

There are many electrical characteristics to consider in the shape of the collecting plate.

- Uniformity of electric field between the discharge electrode and collecting electrode
- Avoidance of sharp edges or protrusions
- Uniformity of corona current on the collecting surface



Unitized Plate Designs-Top View
(Courtesy of BHA)

All three of the above items assure the highest possible operating voltage and minimize the potential for premature sparking. The issue of uniformity of corona current has two other considerations. First, corona current flowing through the dust layer helps to hold the dust to the collecting electrode. A uniform corona current will uniformly hold the duct to the collecting electrode and minimize dust reentrainment from gas flow across the collecting electrode. Second, in the case of high resistivity particulate, current flow through the ash layer leads to back corona, which is devastating to ESP efficiency. Uniformity of corona current is critical to minimizing back corona formation.

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The rapping characteristics of the collecting electrode are important in properly removing the collected particulate from the surface of the electrode. We should seek a design that requires minimum acceleration forces to dislodge the dust from the plate to overcome the holding forces of the current flow through it. Uniformity of rapping acceleration will remove collected dust uniformly. Excessive rapping acceleration will result in larger re-entrainment of the dust back into the gas stream.

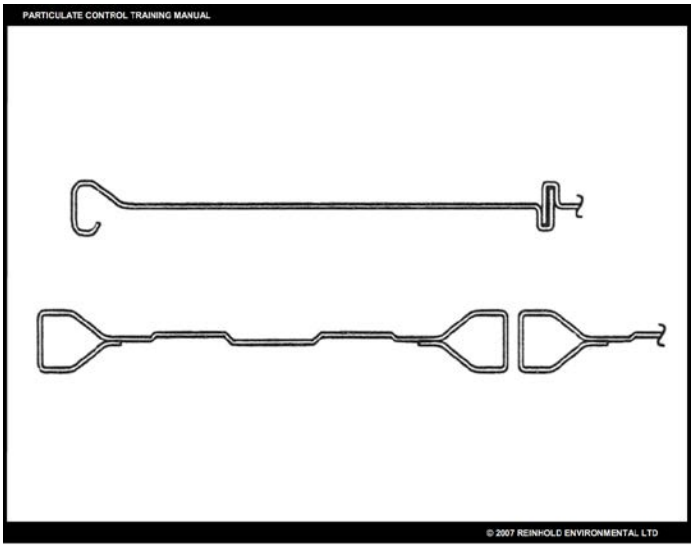
The issue of re-entrainment brings us to the discussion of the aerodynamics of the collecting plate. Re-entrainment can occur in two ways. First, the gas flowing past the collecting electrode can scour off the collected dust directly. Second, when rapping the dust can be thrown into the gas stream to be re-entrained. The profile of the collecting electrode and placement of stiffening ribs can be used to shield the collected ash from re-entrainment by scouring or by rapping re-entrainment.

With all of the above issues to consider, ESP suppliers have developed a wide range of collecting electrode profiles. Some of the more common collecting electrode profiles are shown in Figures:

Unitized Plate Designs

and

Strip Plate Designs.



Strip Plate Designs-Top View
(Courtesy of BHA)

The collecting electrode material and thickness can vary greatly, but generally do not. Collecting electrode thickness usually varies between 20 gauge and 16 gauge. (Note: 16 ga = 0.067 inches (1.7mm); 18 ga = 0.046 inches (1.17mm); 20 ga = 0.034 inches (0.86mm)) Eighteen gauge is almost an industry standard. Collecting electrode material is usually mild steel. For roll formed collecting electrodes, steel must be selected that is appropriate for rolling. Sometimes corrosion resistant materials such as stainless steel are used. Stainless steel or fiberglass is used where corrosion is a major issue, such as wet ESPs.

In the installation of collecting plate spacers, provision must be made for differential expansion so that plates are never placed in compression. Compression can permanently deform or bend the plate, making good alignment impossible to attain.

The weaknesses in collecting electrode performance seldom arise from the concept of the design. They are most often found in the erection and manufacture of the plates. The most common defect resides in the plate spacers, usually at the bottom of the plate, but at times there are

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intermediate spacers.

These spacers must not be rigidly attached to the plates or the casing. They must permit each plate to move independently from the other and from the casing. Any rigid fastening has the potential for applying forces, which will deform the plates. These faults normally occur because of construction errors.

The only frequent design error seen is in the cold side precipitators, where insufficient differential expansion between plates and casing are made to accommodate the 500°F temperature differential, which occurs with an air heater stall. The plates heat up and expand rapidly while the casing is slow to heat up and expand.

Other problems occur with the connections between strips in panel plates. These problems usually occur due to construction execution, not design. Some of these "cup" like devices are too flimsy.

Mainly in manufacturing, two defects happen frequently. The first is simple. The welding on various parts of the plate suspension is not of the quality required by the specifications and the rigorous service. QA inspection of these areas is essential.

The second defect in manufacturing is much more subtle. The blank for rolling an 18 inch (450 mm) panel is typically 24 inches (600 mm) wide. Instead of ordering 24 inch stock from the mill, the fabricator orders 72 inch wide stock and slits it into three 24 inch wide rolls. In rolling sheet, the rolls of the cold (or hot) mill deflect causing a crown of a few mils (0.003 inches) in the center. The center or crown section is symmetrical but the two side sections are asymmetrical. Depending on the mill, in some cases these side sections, after passing through the roll form machines, have internal stresses, which ultimately result in twisted plate panels. Collecting plates should be rolled from crown coils only.

Finally, the historic progression of plates has included reinforced concrete slab plates (graded resistance, grounded through rebars, cleaned by scraper chains), rod curtain plates, perforated plates, pocket plates, corregated plates, expanded metal plates flat fabricated plates, opzel plates and panel plates. Plates have been made of various metals (lead, steel, stainless, aluminum), wood, transite, concrete, plastic, hard rubber and yes - water. The same principal - keep them aligned - applies to all.

1.4 Rapper Designs for Collecting and Discharge Electrodes

Introduction

As discussed in an earlier section, the third process in electrostatic precipitation is the removal of

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the collected particles. Electrode rappers are used to dislodge the collected particles from the electrodes to get them into the hoppers. From there, ash removal systems remove the particulate from the ESP. This section is devoted to discussion of the electrode rapper systems.

There are many types of rappers used in ESPs. Some of the more common ones are listed below and will be discussed in this section.

- Vibrators
- Electromechanical rappers
- Drop or tumbling hammers
- Pneumatics rappers
- Acoustic horns

Hammers

The European rigid frame (RF) ESP designs typically use drop or tumbling hammer rapping for both the discharge and collecting electrodes. Tumbling hammer rappers are almost always used for collecting plates, and are sometimes used for discharge electrodes. They can be located inside the ESP casing in the flue gas stream or outside the casing on top.

The tumbling hammers are generally attached to a rotating shaft. These hammers typically vary between 12 and 25 pounds (5.5-11 kg), so they can produce significant rapping forces. High rapping forces are necessary for more tenacious dusts and for larger ESP electrical sections or fields. European ESP designs typically have larger electrical sections or fields that require the more intense rapping from hammers.

Generally for RF ESPs, there is one hammer per rigid (pipe) frame or collecting curtain assembly. For the discharge electrode an anvil is incorporated into the frame. The frame is often reinforced at the rapping point. The individual collecting strips are generally fastened together at the bottom with a rapper bar. An impact anvil is generally incorporated into the rapper bar. One hammer generally impacts one anvil or rapper bar, which transmit the rapping forces to the electrodes. A Typical collecting plate tumbling hammer rapping system is shown in **Figure:**

Tumbling Hammers

Tumbling Hammers.

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Some US suppliers also use tumbling hammer rapping to rap RDEs. The hammers impact anvils on the RDE support members. **Figure:**

Drop Rod Discharge Rapping System and Tumbling Hammer Rapping System

shows this arrangement.

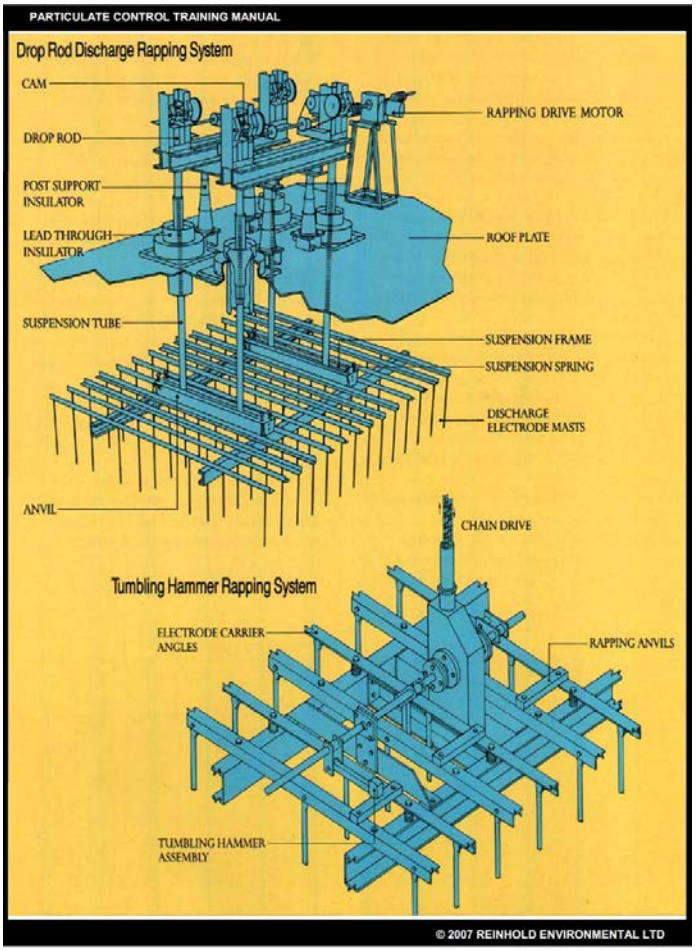
The main advantage of the tumbling hammer type rappers is their simplicity and when properly designed, ruggedness and freedom from maintenance. If not designed properly, the moving components inside the ESP (for tumbling hammers located inside the box, exposed to flue gas) will wear due to the friction and abrasion of the dust. In time, these components will need to be replaced to maintain effective rapping. Hammer anvils and connecting rods may be fabricated, cast or forged. Experience has indicated that:

- Forged parts are superior
- Fabricated are often satisfactory
- Castings can be inferior

The key to reasonably long life is careful design with low bearing pressures, hammer-to-anvil alignment and ample bearing clearances to minimize wear.

Timing is infinitely adjustable but intensity can only be changed by changing hammer weight and/or with great difficulty, hammer throw. Frequency of rapping is limited to adjusting the speed of rotation and/or the energization duration of the drives.

Drop hammer rapping systems, as the name implies, simply lift and drop a hammer through some adjustable angle. The hammers are attached to a rapper shaft around which they rotate, but the shaft typically does not rotate more than 90 degrees. There are many variations of drop hammer rapping systems, two of which are shown in Figures:



Drop Rod Discharge Rapping System and Tumbling Hammer Rapping System

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Drop Rod Discharge Rapping System and Tumbling Hammer Rapping System

and

Discharge Electrode Drop Rod Rapper.

Discharge Electrode Drop Rod Rapper

In discharge electrode or high voltage rapping some manufacturers have used lift and drop hammers using mechanisms to translate the rotary motion of the motor to a reciprocating motion. These mechanisms are prone to misalignment and wear and in many cases are not as satisfactory as tumbling hammer designs. Many have been converted to tumbling hammers.

With European style precipitators, there have been few cases of under rapping where the rule of one hammer per collecting plate and one hammer per pipe frame have been followed. In some cases however, shortsighted economics have resulted in the application of one hammer for two or three collecting plates or pipe frames and the results were, as you would expect, poor rapping and heavy ash buildups. Also, the use of cast or fabricated hammers instead of forged hammers has resulted in some failures leaving individual plates and wire frames without any rapping.

Improper bearings, couplings, rapper shafts, and undersized gear motors have also caused rapper system failures.

Magnetic Impulse Gravity Impact Rapper
(Migi TM Rapper)

Electromagnetic Rappers

There are two major types of electromechanical rappers. The most common has many names, but is referred to here as the gravity impact rapper. Gravity impact rappers are a generic classification of rappers that use electromagnetic forces to lift a weight and then allow it to impact an anvil by gravity. The term MIGI® (Magnetic Impulse Gravity Impact) rapper is often used as a generic name, but is actually a registered trademark name of Research-

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Cottrell. There are many variations of this rapper, but they all require the energization of an electrical coil to produce an electromagnetic field that pulls the cylindrical weight or plunger up into the coil. The coil is then de-energized and the cylindrical weight drops and impacts the rapping anvil.

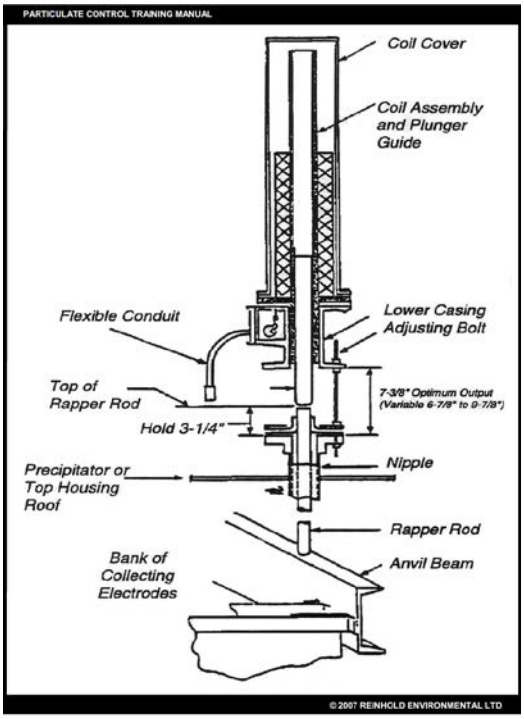
Typical magnetic impulse gravity impact rappers are shown in Figures:

Magnetic Impulse Gravity Impact Rapper

and

Magnetic Impulse Rapper.

These are commonly used by US ESP suppliers for rapping both discharge and collecting electrodes. These rappers have two main advantages. First, they are located outside the ESP casing. Although the electromagnetic coils are very reliable, a failed coil can be replaced while the unit is in operation. Second, the intensity of the rap is adjustable. Rapping can be easily increased when dealing with tenacious dusts, but can be decreased for light, fluffy dusts. This avoids over rapping that can lead to increased rapping re-entrainment and reduced rapper component life.



Magnetic Impulse Rapper
(Courtesy of BHA)

The intensity of the impact can be varied in two ways. First, the weight of the cylinder can be varied. Although not an industry standard, the cylinders are typically ten or twenty pounds. Second, the lift height can be varied. The lift height can be adjusted by varying the energization time of the coil. There is a limit to the lift height determined by the design of the coil, the cylinder weight, and the energization time. A typical maximum lift height is 12 inches (300mm).

Rapping frequency is also easily adjusted using the same rapper control that adjusts rapping intensity. This provides great flexibility in setting a rapping sequence that can minimize rapping re-entrainment and optimize ESP efficiency. Another type of the impact rapper is the MI (magnetic impact) rapper, which uses the electromagnetic forces to cause the impact, rather than gravity. The plunger is held up by a spring. When the coil is energized, the cylinder is pulled downward to impact the anvil. When the coil is deenergized the spring returns the coil to the upper rest position. This rapper is shown in **Figure:**

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Spring Opposed Magnetic Impact Rapper.

Spring Opposed Magnetic Impact Rapper
(MI Rapper)

This rapper was prone to spring failures and failures of the rapper housing and is not commonly used today.

The cylindrical weight of the electromechanical rapper generally strikes an anvil that then transmits the energy to a support member and then to the electrode. The design of these components is critical in getting the rapping forces to the discharge and collecting electrodes.

The main advantage of the magnetic rappers is their flexibility. They can be adjusted for intensity as well as for timing. Rapping energy can be precisely tailored to the conditions of the moment. Extremely versatile solidstate controllers can use feedback signals from the rectifier controls to constantly adjust rapper timing and intensity to provide optimum rapping.

Failures of magnetic rapper systems can often be found in the system for transmission of the impact to the collecting plates and wire frames. These systems involve bolts, shop weldments, castings, and forgings, as well as shafts and rapper bars. In most cases, field welding as well as field bolting is required. Quality control of these field activities is difficult to enforce since the work is often done in cramped and difficult areas.

The development of the new tapered shaft and socket designs to eliminate field welding has greatly improved the reliability of these systems. Use of these designs is recommended to eliminate rapper component failures or on rebuilds or major modifications.

Many precipitators of the American design have been insufficiently rapped. Experience indicates that one magnetic rapper mechanism is required for each 1200 to 1500 ft2 (110-140 m2) of collecting electrode surface (count both sides of plate). One discharge electrode rapper is required for each 1800 to 2200 linear feet (550-670 m) of discharge electrode for weighted wire or rigid frame designs and about half of that for RDE designs.

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Vibrators

Vibrators provide a low intensity continuous or intermittent vibration to the electrodes. They are effective in cases of light particulate loading, smaller ESPs, and applications where the particulate is not tenacious in sticking to the electrodes. Many years ago, vibrators were commonly supplied by U.S. ESP manufacturers to clean weighted wire discharge electrodes and collecting plates. There are many still in operation and working well. Larger ESPs with taller fields have virtually eliminated use of vibrators for most ESP applications.

Figure:

Vibrator

shows an installation of vibrators.

The vibrators are generally mounted to a structural support member, either a high voltage frame for discharge electrodes or a collecting electrode support beam. The rapping force must be transmitted through anvil rods and support members to the discharge and collecting electrodes.

One objection to large numbers of electric vibrators is that they need frequent adjustment to remain effective.

Pneumatic Rappers

Pneumatic rappers take two forms:

- Pneumatic vibrator with a 2.5 to 3.0 inch (60-75 mm) cylinder. The vibration frequency is dependent on air pressure. Activation is typically with a solenoid valve, with the use of Teflon liners. Lubrication is no longer required.
- Single or multiple impact rapper driven by compressed air through a solenoid valve. Intensity depends on air pressure.

In both cases, reducing valves are used to regulate pressure.

Pneumatic Rapper
(Courtesy of BHA)

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Presently these devices are little used since:

- Compressed air is expensive
- Freeze protection is often needed in colder climates
- Good air quality is imperative

The weakness in these systems is usually the solenoid valve, which is subject to failure. See **Figure:**

Pneumatic Rapper.

Sonic Horns for Rapping Discharge Wires or RDEs (75 Hz to 150 Hz)

Acoustic Horns

Acoustic or sonic horns are primarily used to augment the mechanical rapping systems described above (although recent installations have seen them used as the primary rapping devices). Acoustic horns use the sound energy to vibrate the collected material from the electrode. The horns use approximately 100-140 dB of sound energy at low frequencies of 20-200 Hz. An acoustic horn installation is shown in **Figure:**

Sonic Horns for Rapping Discharge Wires or RDEs.

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RESISTANCE TO:	Natural Rubber	Hypalon	Neoprene	E.P.D.M.	Viton
Aliphatic Hydrocarbons	Poor	Good	Good	Poor	Excellent
Aromatic Hydrocarbons	Poor	Fair	Fair	Poor	Excellent
Oxygenated (ketone, etc.)	Fair	Poor	Poor	Good	Poor
Lacquer Solvents	Poor	Poor	Poor	Poor	Poor
Swelling in lubricating oil	Poor	Very Good	Good	Poor	Excellent
Oil and gasoline	Poor	Good	Good	Poor	Excellent
Animal and vegetable oils	Fair	Good	Good	Good	Excellent
Water absorption (hydrolitic stability)	Excellent	Excellent	Good	Excellent	Excellent
Oxidations	Good	Excellent	Excellent	Excellent	Excellent
Ozone	Fair	Excellent	Excellent	Excellent	Excellent
Sunlight aging	Poor	Excellent	Excellent	Excellent	Excellent
Heat aging (upper limit coat service)	85° C (185° F)	135° C (275° F)	95° C (203° F)	145° C (293° F)	205° C (401° F)
Flame*	Poor	Good	Excellent	Poor	Excellent
Heat	Good	Excellent	Excellent	Excellent	Excellent
Cold	Excellent	Good	Good	Excellent	Good

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Properties of Boot Seal Materials
(Courtesy of BHA)

Rapper Components and Boot Seals

Rapper components, including alumina and fiberglass rapper shafts, adapter sleeves and anvil shoes are shown in the previous figures. Sometimes if the rapper sleeves are too small, corrosion and particulate builds up in the sleeve and binds the rapper shaft. As a result the roof is rapped rather than the plates.

Boot seals assist in maintaining

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proper alignment of the rapper shaft without damping rapper force. They also form a positive seal between the shaft and guide nipple to prevent leakage of gases and corrosion of the rapper shaft. Worn rapper seals can be difficult to replace requiring the dismantling of the rapper assembly. **Figure:**

Properties of Boot Seal Materials

itemizes the properties of boot seal materials (courtesy of BHA).

Rapping Acceleration

The effectiveness of rapping depends on a combination of many factors including:

- Electrode geometry
- Electrode suspension
- Rapper system components
- Type of impact or rapper
- Impact energy

The effectiveness of the rapping is often determined by the acceleration imparted to the electrodes and the uniformity of that acceleration. Acceleration is generally measured and related to the force of gravity or "g's". The minimum rapping acceleration needed to dislodge the dust is dependent on the application, and the value is debatable. Typical specification of minimum acceleration is 50g for discharge electrodes and 100 g for collecting electrodes. The most important direction of acceleration is also debatable. European suppliers typically report accelerations in the plane of the electrode, while US suppliers report accelerations normal (perpendicular) to the electrode.

Rapping forces can be too great. Excessive rapping forces will throw the collected particles into the gas stream and increase rapping re-entrainment. Excessive rapping intensity can also cause high stresses in the electrodes, which can lead to fatigue and failure.

Rapper System Insulators

All discharge electrode or high voltage rapper systems involve the use of isolating insulators to transmit the impact or rotation of the rapper motive power to the high voltage system. These insulators are subject to failure if they get wet or dirty. These electrical failures can be prevented by providing a supply of clean, dry and hot purge air.

These insulators are also subject to mechanical failure if they are overstressed or have manufacturing defects. If they are not tightly fastened in their mountings, they are subject to chipping and flaking on their ends. They can take tremendous compressive forces, but break easily if flexed, so alignment is critical.

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Some of the new resin impregnated fiberglass insulators are useful in eliminating these problems if temperature limitations are observed. High alumina ceramic insulators are more durable than porcelain insulators.

Also the tapered end designs eliminate the problems due to loose end fittings. Welding on these impact parts is critical. For correct installation, special welding rod and careful pre-heat and post-heat procedures must be used.

Reliability and Effectiveness

Many of the older precipitators have vibrators on the discharge electrodes and collecting plates. The use of vibratory cleaning on weighted wire systems is widespread. The oscillating energy that vibrators produce has been shown to be effective. However, solenoid rappers have universally replaced vibrators on discharge systems that have been converted to rigid discharge electrodes (RDEs).

Although effective in some applications, all types of vibrators have been shown to be destructive. Both to the systems they are designed to clean and to themselves. High frequency oscillation of the components inside the precipitator in combination with the suspended highly abrasive fly ash in the gas stream, causes certain wear. Externally, vibrators of the electric type need frequent adjustment of the anvil gaps to remain effective.

The two major types of impact rappers are the tumbling or swinging hammers typical on precipitators of European design, which are motor driven, and the magnetic impact or magnetic impulse gravity impact rappers

The main advantage of the tumbling hammer type rappers is their simplicity. Rapping intensity is controlled by the weight of the hammers and the length of the hammer mounting arm. The frequency of rapping can be changed by adjusting the speed of the rotating shafts and the dwell period between the shaft operation. The adjustment for intensity, however, is not easily done, as it requires changing the hammers. This rapping system is subject to abrasive wear as the rotating mechanism is in a very hostile environment. The rapping mechanism and the rapper impact points are the highest maintenance areas on most precipitators with this style of rapping. The root causes of excessive wear include excessive duty cycle (on/off time), misalignment, and the unavoidable exposure to fly ash. Inlet fields generally experience more wear due to a greater volume and coarseness of the ash. Also, it is likely that the duty cycle is greater in those areas.

Some high-tension rapping uses lift and drop hammers with mechanisms to translate the rotary motion of the motor to a reciprocating motion. These mechanisms are prone to isalignment and wear and in many cases are not as satisfactory as tumbling hammer designs.

The main advantage of the solenoid rappers is their flexibility. Rapping energy can be precisely tailored to the conditions of the moment. Rapper frequency and intensity are easily regulated by an electrical control system. The spring opposed magnetic rappers has a spring type plunger. The rapper is energized monetarily and the spring plunger is raised by a solenoid-type coil. The

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spring pushes the plunger back down striking a rod. The solenoid mechanisms are generally superior to the spring opposed magnetic impulse type rappers.

Rapper Maintenance

Maintenance for rappers and vibrators can be very important in all precipitators. Some of the critical areas include:

- A periodic check and adjustment of the anvil gaps of the electric vibrators are recommended on a yearly basis.
- Check for the binding of the rapper shafts that extend through the precipitator shell. This condition is apparent by observing the plumbness of the rapper.
- Discharge electrode or high voltage rapper systems using isolating insulators to transmit the impact or rotation of the motive power to the high voltage system, should be inspected periodically. These insulators are subject to failure if they get wet or dirty. They are subject to mechanical failure if they are overstressed. If they are not tightly fastened in their mountings they are subject to chipping or flaking on their ends.
- Check the packing gland, or boot enclosure, that provides a gas seal between the rapper shaft and the shell. Corrosion can initiate substantial damage to the shaft at this point.
- The internal junction between the rapper shaft and frame being rapped should be inspected periodically to detect whether the connection is intact.
- Check the springs or coils in the spring-opposed type of impact rapper. High rapping intensities can cause spring failures. Failures in the coils may occur at the wire leads.
- Check to make sure the plunger or hammer, and strike pad are aligned. If the two parts are not aligned correctly, then some deformation of the metal will take place.

Rapper Optimizing

Resistivity and the timing between raps can have an adverse effect on re-entrainment. There are certain concepts in rapping techniques that tend to either add to or minimize the re-entrainment losses. These concepts include:

- Always use the internal inspection and other visual means to help attain the lowest rapping intensity as possible.
- Always attempt to match the rapping to the dust characteristics or resistivity. For example, low resistivity ash requires soft rapping, moderate resistivity ash requires a harder impact, and high resistivity ash requires even greater rapping impacts.

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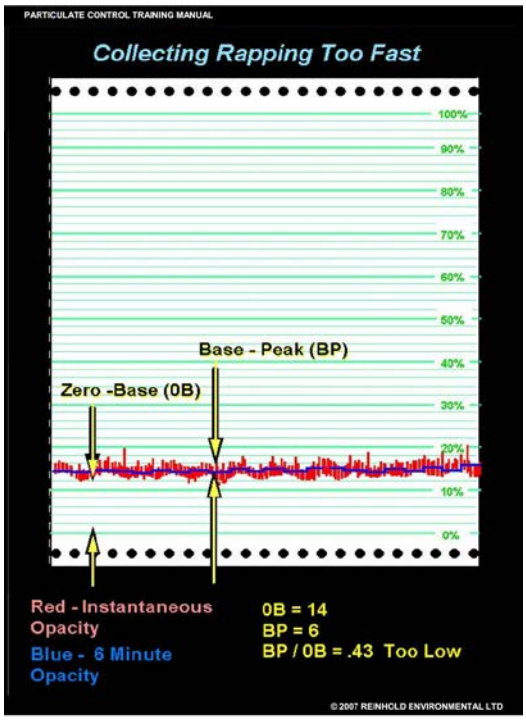
- The inlet field need not be over-rapped because it handles the bulk of material. Be aware that puffs out of the stack, or other signs of re-entrainment, are not unique to the outlet fields.
- Rapping loss is not usually uniform across the precipitator. When re-entrainment losses are observed, investigations into possible problems with gas distribution are recommended.
- When re-entrainment losses are severe, lengthen the time between raps on the collecting surfaces in the direction of inlet to outlet.
- Rappers should normally operate across one field before the cycle moves on to the next field.
- The use of opacity spikes on a chart to ascertain the effects of rapping reentrainment is a good evaluation tool. The instantaneous readout response of an opacity chart can help determine if and what rappers are causing re-entrainment.
- See Figures:

Collecting Rapping Too Fast

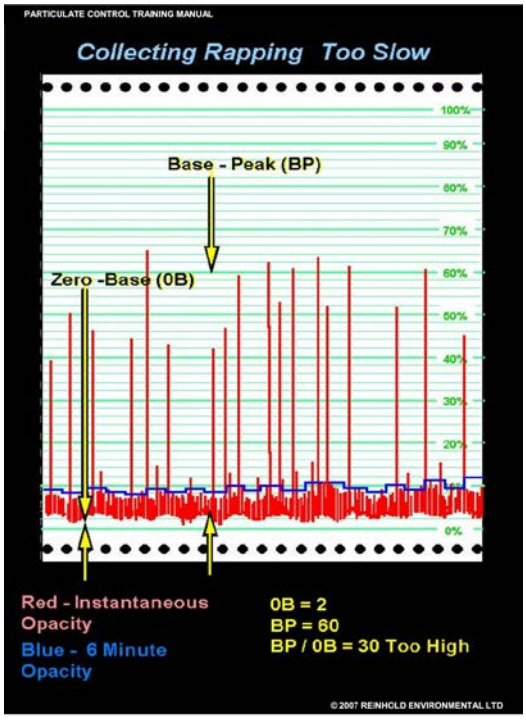
Collecting Rapping Too Slow

and

Normal Opacity Trace.



Collecting Rapping Too Fast



Collecting Rapping Too Slow

Determining the Condition of the Existing Rapping Equipment

The general condition of the rappers, vibrators, hammer systems, or acoustic horns should also be determined periodically. The inspection period depends on the historical reliability of the particular unit. This determination should include a functional test by manually sequencing (also called a rapper "walkdown") through each group or row while an observer notes any abnormalities. Additionally, in the case of solenoid rappers, the intensity should be verified by actual measurement rather than relying on the sound of impact alone.

Proper transmission of rapping force should also be periodically checked. This could possibly be done by observing rapping while standing inside a de-

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energized, off-line, dirty precipitator. Or in extreme cases, an accelerometer profile can be done to plot the energy distribution within the system.

Programming Rapping Systems

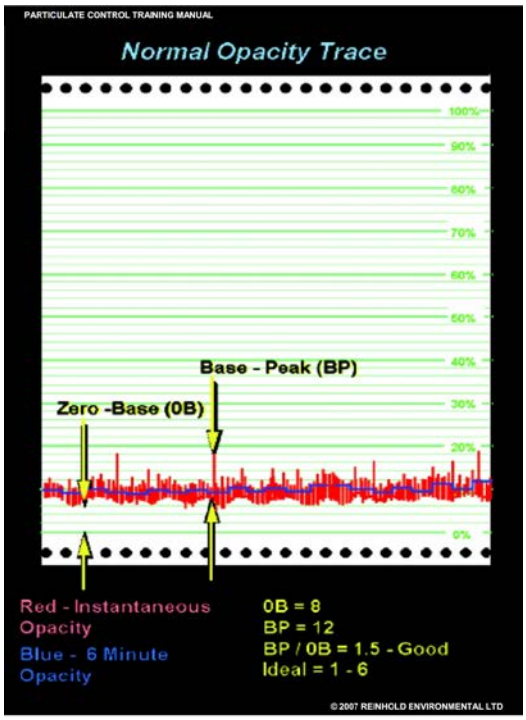
When programming rapping systems, the starting point should be intensity. In the case of solenoid-type rappers, this refers to slug weight, stroke length and in some models, spring strength. In the case of vibrators or acoustic horns, this refers to applied voltage, or air pressure. In the case of mechanical rappers, this refers to hammer weight and swing arc.

Generally, some of the above variables are not easily changed such as spring and hammer weights and also arc, although most others are indeed variable and should be fully exploited to produce the most optimum results. The determination of minimum intensity for the collecting system is best done using a series of alternating adjustments and inspections. The objective should be to find the minimum shear force necessary to dislodge the dustcake at the extremities of the system.

For some top rapped systems that have exceedingly tall collecting plates, the required rapping energy can be quite high. In these cases, a compromise must often be reached between over cleaning the upper portions of the system in deference to providing a minimum level of cleaning at the bottom.

Intensity requirements will usually decrease in the direction of gas flow. Along with shear forces (linear to the plate), some percent of normal forces (perpendicular to the plate) are developed. Normal forces tend to disperse the dustcake, a condition that should be kept to a minimum in the outlet sections. Often it is necessary to vary intensity across gas flow. This is usually necessary when unbalanced gas velocities are present. When this condition exists the opacity profile may appear like the one illustrated in **Figure:**

Normal Opacity Trace.



Normal Opacity Trace

Once the minimum intensity has been determined, further optimization is gained through frequency and on time. A good starting point for the rapping optimization program is rapping intervals of about five minutes for the inlet, 10 to 15 for the second field, 30 to 45 for the third, and 1 to 2 hours for the outlet, for a four field ESP. The inlet two fields should be roughly established and then the outlets should be fine tuned. About a week of operation should allow the new conditions to become fully established. In very long, high efficiency

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precipitators the extreme outlet field may be rapped only once in 12 hours.

By using experimentation, an opacity profile similar to the one shown in **Figure:**

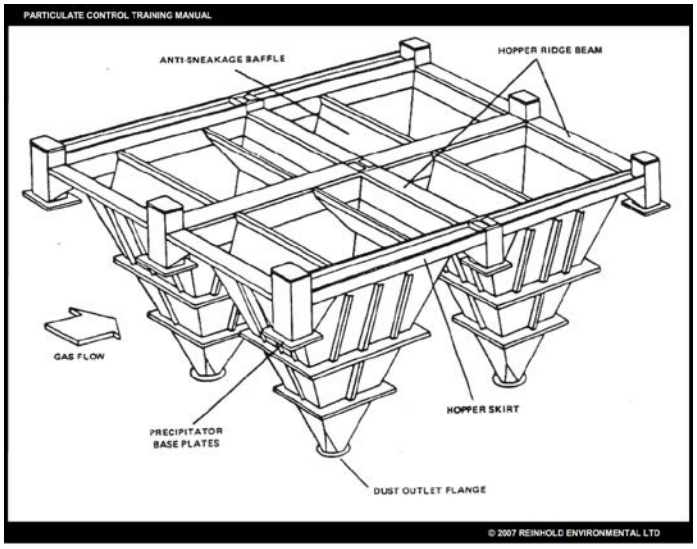
Normal Opacity Trace

should be achieved. Other figures show the term "Opacity Aspect Ratio". This is a tool used to correlate rapping, instantaneous opacity and six-minute opacity. The "Opacity Aspect Ratio" uses the factors of zero-to-base opacity and base opacity-to-peak opacity for indicating best overall emissions. The values shown are typical for standard precipitator/duct configurations for cold side applications. Adjustments must be made when longer or shorter distances between the opacity monitor and the precipitator exist.

1.5 Hopper Designs

Hoppers can be the source of considerable operating trouble in both precipitators and fabric filters. Most problems occur due to the failure of the hopper to discharge the collected fly ash properly. The other major problem is due to a buildup of fly ash on hopper internal parts or on peaks where hoppers join at the top into the high voltage elements or bottom bag entrances for inside bags and fouling of lower surfaces in outside bags. **Figure:**

Typical Hopper Construction



Typical Hopper Construction

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depicts a typical hopper construction.

The hopper valley angle should be a minimum of 55 degrees. Sixty degrees is better.

The interior of the hopper should be smooth with no horizontal surfaces. Hopper struts are acceptable but they should be bars with the long axis vertical.

Hoppers with removable or hinged doors in the hopper baffles are to be discouraged. Put external access doors on both sides of the hopper. Doors must be tightly sealed. Leakage will cause re-entrainment.

Hopper insulation should be of sufficient thickness to keep the ash hot, and insulation should be properly lagged. Careful attention should be paid to insulation details where the precipitator casing including bottom end frames, support bottom baffles side frames, and partition frames, join the hopper and the precipitator or fabric filter support structure. Careful attention should also be paid to insulation and lagging details at the hopper throat and hopper valve.

Hopper heating systems and enclosure of the hopper area with siding are recommended. Heaters are usually used on the bottom one-third of the hopper. Heater circuits should be equipped with ammeters so failed heaters can be detected (see **Figure:**

Hopper Design with Heating

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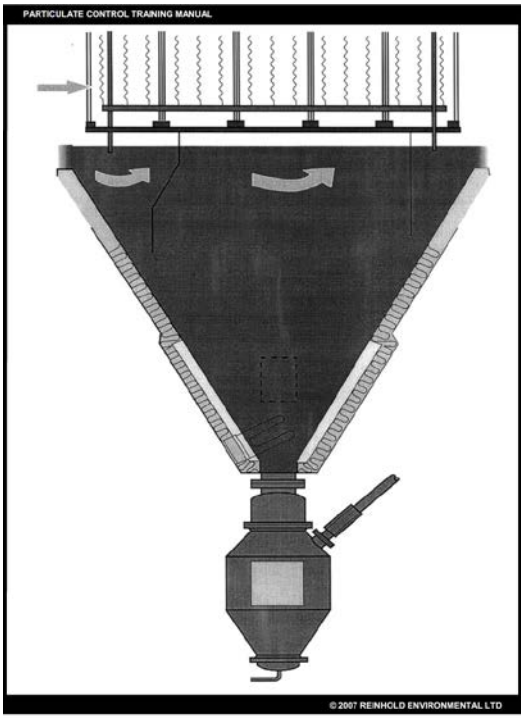

Hopper Design with Heating

The installation of poke holes in hopper throats is often helpful as are strike plates and anvils at the bottom of the hopper.

Hopper rappers are also helpful, but they must be interlocked to prevent their use with the hopper valve closed.

Hopper level indicators are also useful if they are reliable. They must be located low enough on the hopper to give ample warning, between the one-half and two-thirds point in elevation. Much success has been found with nuclear or capacitance type probes.

Over the years many types of hopper level measurement devices have been used with varying degrees of success. Various mechanical and air back pressure equipment was often used.

Today there has been good success with nuclear radiation and detector systems, capacitance

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probes, and radio frequency probes. When properly installed and maintained, they give reliable and satisfactory performance.

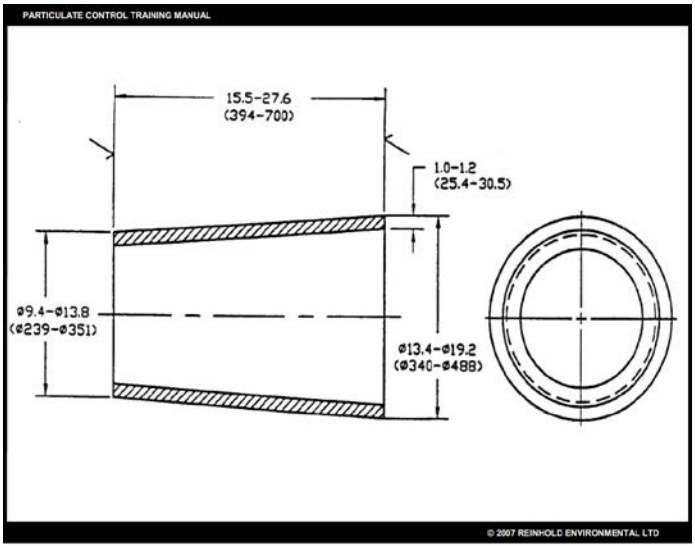
Hopper baffles should be securely fastened to hopper walls so they cannot break free and plug the hoppers by falling over.

Refinement such as rounded corner hoppers and stainless steel sheet liners in hoppers have been found unnecessary except in special situations.

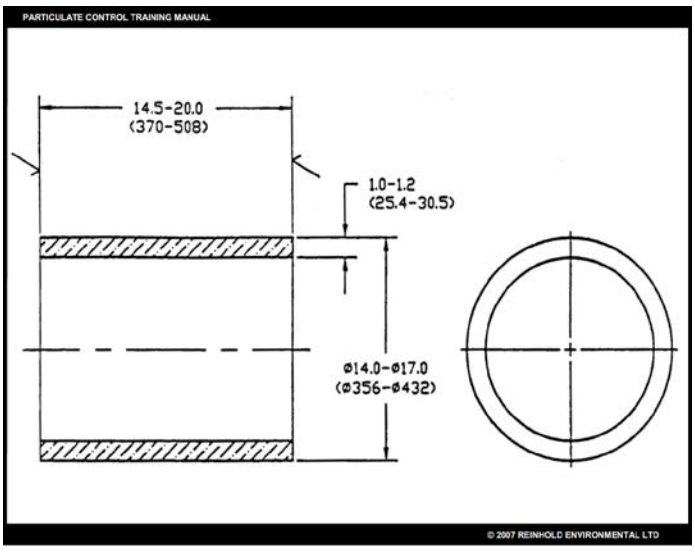
Make sure hopper valves are tight and do not leak. Air leakage, especially with pressure type ash removal systems, can cause severe re-entrainment and loss of performance. It will also shorten fabric life.

Careful attention must be paid to insure there are no flat spots or discontinuities where adjacent hoppers join. Dust buildup here can ground precipitator sections or cause short fabric life.

Since bottom sections of hoppers may be below the dew point, metal thickness measurements should be made in these areas to detect corrosion.



Support Insulator, conical, alumina, typical sized available



Support Insulator, cylindrical, alumina, typical sizes available

1.6 High Voltage Support System Technical Review

High Voltage Support Systems

The purpose of the high voltage (HV) support system is to support and isolate the electrostatic precipitator high voltage system from the grounded parts of the precipitator. In addition to the isolation system withstanding the high voltage imposed, it must be square and plumb so that the alignment of the high voltage system with regard to the grounded elements can be maintained through the

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life of the unit.

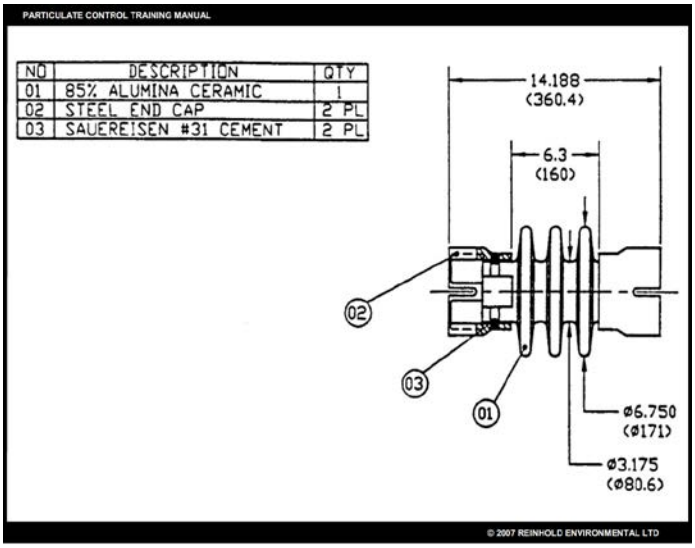
The key elements in this system are the high voltage support insulators since a failure of these elements will not only ground a portion of the precipitator but may do permanent damage to the alignment.

High voltage electrodes and their system frames can be designed for two-point, three-point or four-point support. Three-point support is uncommon.

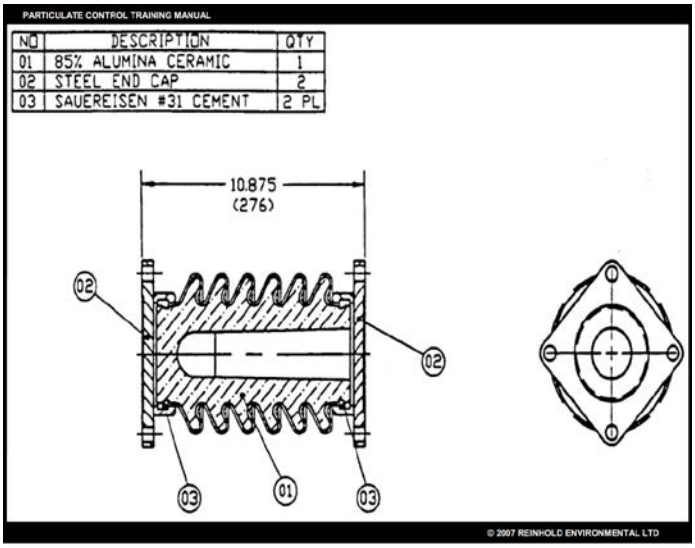
The typical support insulator may be a tapered hollow truncated cone or a straight hollow spool. Material used is generally 85% alumina, fused silica or electrical grade porcelain.

Some typical insulators used in ESPs are shown in the twelve figures in this section. These designs are by no means all-inclusive. Currently, over 125 different ESP insulator designs can be supplied by ceramic manufacturers.

In some older designs, porcelain or zirconium oxide post insulators with complicated buss beam and hanger pipe arrangements wereused, but these have mostly disappeared. Except for specialized designs, they have been rebuilt to the present standard design.



Rotating Rapper Insulator Assembly, Deep Shed Style



Six Shed Pedestal Insulator Assembly, Drip Shed Style

Insulators are subject to temperature limitations due to electrical leakage, which increases with temperature. The best is 85% alumina, satisfactory for 600° F (316° C). The poorest is porcelain with a limitation of about 325° F (163° C).

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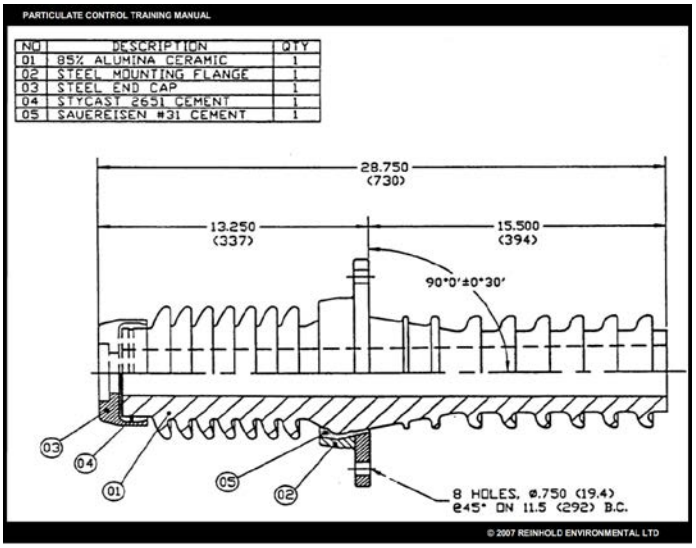
The length or insulating path of the insulator is determined by the voltage, which is applied, as is the diameter.

Great care must be taken in the design of the gaskets and metal parts associated with the insulator on both the grounded and high voltage ends as well as in between. Small radiuses, sharp corners and points are to be avoided since these generate local corona discharges cause electrical breakdown of the gas and the insulator material. Positive corona (ground side) is the most destructive.

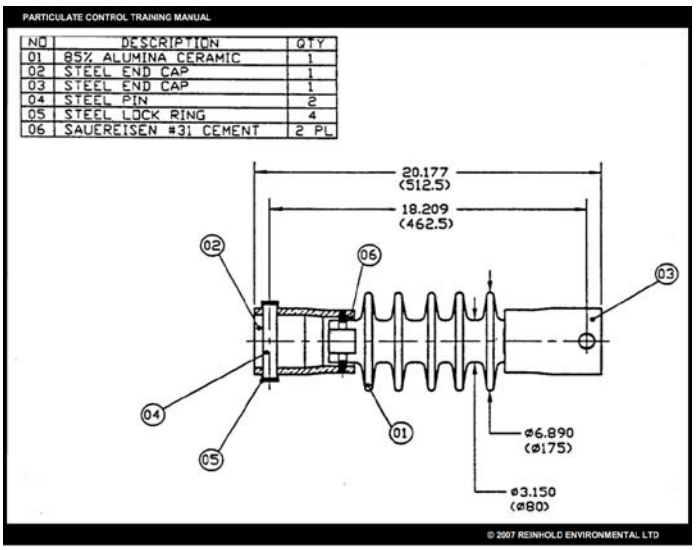


Suspension-inlet Bushing Insulator Assembly, Drip Shed Style

Other insulators in the system such as rapper isolating insulators, wall bushings, anti-sway insulators and high voltage bus support insulators require similar care in design.

Generally, electrical clearances in all parts of the precipitator should be 1.4 to 1.5 times the intra-electrode space (the space between discharge electrodes and collecting electrodes at their closest point).

The discharge electrode support system must be designed to support the dead weight of the system plus the accumulated dust on the discharge electrodes and frame plus earthquake load and the dynamic load imposed by the high tension rapping system.



Rotating Rapper Insulator Assembly, Deep Shed Style

The support insulators should be heated and ventilated to prevent loss of electrical resistance due to moisture and fly ash deposits.

The support system must be designed to accommodate the delivery of rapping energy to the discharge electrodes and their support frames. The most satisfactory method of accomplishing this is through rapper bars or shaft driven hammers, which deliver the rapping energy direct to the HV rapper anvil, independent of the high-tension supports. The least satisfactory method involves designs, which deliver energy to the HV supports without the use of independent rapper anvils.

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Rapper isolating insulators, properly designed with tapered shafts, generally are more satisfactory than bolted or other mechanical designs.

At every opportunity, high tension support systems should be checked for plumbness and squareness and for broken or worn bolted or welded connections.

It should be noted that the use of wider electrode spacing such as 12 inch (300 mm) or 16 inch (400mm) have raised operating voltage and require design review of insulator amid electrical clearances other than in the intra-electrode space.

In inspecting the precipitator, it is necessary to examine the roof and roof beams on the underside of the roof, which hold up the HV support insulator and the high-tension system. Corrosion damage and failure at this point due to a failed insulator heating and ventilating system has caused costly damage.

Purge Air Systems

In many cases, hot filtered atmospheric air is introduced to insulator compartments or top insulator housing to keep insulators clean and warm. The purpose is to prevent electrical leakage and resulting failure of support and rapper insulators, high voltage bushings and bus bar standoff insulators.

Most American designs let heated filtered air pass through the insulator cap at a flow rate of 50-100 actual ft3/min. (100-200 m3/hr) per support insulator to clean the inside of the support insulator bushing. Some European designs seal these insulator support bushings and do not purge.

Experience has indicated that the use of purge air does often benefit operation. It is especially important when the precipitator is in cycling duty or is shut down frequently. Purge air should be injected when the precipitator is out of service to prevent problems on startup.

Often duplicate systems are installed with one operating and one standby. Temperature should be controlled to insure above dew point conditions and electric heater metered to detect heater failure. In general, targeting a purge air temperature at a value 25° to 30° F (14°-17° C) above the dew point in the precipitator will prevent problems in all cases since the diluting effect of the purge air will also reduce the dew point in the area of the insulator. The challenge is to make sure the insulator is hot and dry at startup when most insulator failures occur. Start the purge air system far enough in advance to avoid all problems.

Filters must be maintained periodically.

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High Voltage Insulators

Introduction

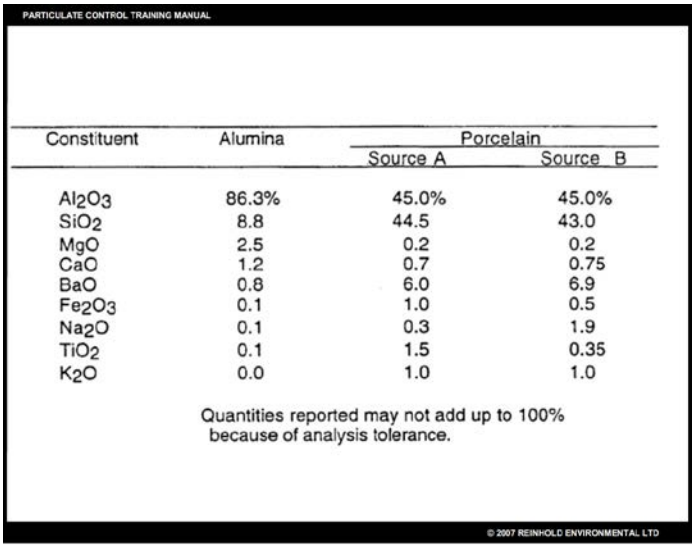
The removal of particulates and mists from gas streams involves the generation of corona by discharge electrodes. Full-wave rectified 60 Hz voltage of 35 to 70 kV, average, is applied to the discharge electrodes. Both the power supply and the discharge electrodes must be isolated from electrical ground.

The isolation is accomplished by components constructed of a dielectric material that can withstand the electrical and mechanical stresses encountered in this service. These components are generally referred to as ESP insulators.

The design and selection of ESP insulators requires evaluation of four criteria:

- Material of construction
- Function
- Service conditions, operating environment
- Design, i.e. configuration and size

Material of Construction



Typical Compositions of EP Insulator Materials
(Courtesy of CoorsTek)

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Dielectric materials that are suitable for ESP insulators comprises a relatively short list. Most are ceramics, i.e. alumina, standard electrical porcelain, special (high-strength) electrical porcelain, and fused silica. Another material, a composite of an organic resin and fiberglass, has limited application.

Of the ceramics, the use of fused silica has been minor and is dwindling, mainly because it is prone to mechanical damage. Two major materials dominate the ESP insulator field, alumina and porcelain.

The grade of alumina used in ESP insulators has a nominal content of 85% Al2O3 and is classified as C-780, high alumina ceramics, by the European IEC.

Porcelains are identified as C-100 materials and are classified as alkaline alumino-silicates. Grade C-130, aluminous porcelain, high strength, has generally replaced the earlier use of standard electrical porcelain in ESP insulators.

Therefore, the following discussion will deal with alumina and grade C-130 porcelain.

Figure:

Typical Compositions of EP Insulator Materials

lists the composition of a typical alumina and two porcelains. The test samples were taken from ESP insulators obtained from the field.

Figure:

Physical Properties of ESP Insulator Materials

PHYSICAL PROPERTIES - EP INSULATOR MATERIALS

Property	Units of Measure	Alumina	Porcelain Source A	Porcelain Source B
Specific Gravity	g/cc	3.47	2.60	2.62
Flexural Strength @ 25°C, 4 pt.	MPa (kpsi)	262 (38)	116 (16.8)	87 (12.6)
Volume Resistivity	ohm-cm			
	25°C	$>10^{14}$	$>10^{14}$	$>10^{14}$
	200°C	2×10^{12}	2.5×10^{11}	5×10^{11}
	300°C	9×10^{10}	6×10^{9}	5×10^{9}
	400°C	3×10^{9}	2.5×10^{8}	3×10^{8}

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Physical Properties of EP Insulator Materials
(Courtesy of CoorsTek)

Type	Replacements For:	Material	Dimensions
Anti-Sway	Belco	Porcelain	Convoluted 6.5"Dia x 18"H
	Joy Western	Alumina	2"Dia x 21.125"Long
	PrecipTech/MPC	Alumina	Blade, 3" x 17.5"Long
	Research-Cottrell	Alumina	Blade, 3" x 17.5"Long
	Research-Cottrell	Teflon	Blade, 2.875" x 17.5"Long
	Universal	Alumina	2"Dia x 24"Long
	Universal	Alumina	1.875"Dia x 24"Long
Rapper/Vibrator	Belco	Porcelain	Convoluted 7"Dia x 14"H
	Belco	Porcelain	Convoluted 6.5"Dia x 18"H
	Belco	Porcelain	Convoluted 9"OD x 15"H
	Buell/GE	Alumina	3"Dia x 30"Long
	Enelco/Koppers	Fiberglass	2"Dia x 48"Long, tapered ends
	Enelco/Koppers, Research-Cottrell	Fiberglass	2"Dia x 40"Long, tapered ends
	Joy Western	Alumina	2"Dia x 21.125"Long
	Research-Cottrell	Alumina	3.94"Dia x 30"Long
	Research-Cottrell	Porcelain	3.94"Dia x 30"Long
	Research-Cottrell	Alumina	2"Dia x 30"Long, tapered ends
	Research-Cottrell	Fiberglass	2"Dia x 30"Long, tapered ends
	Universal	Alumina	2"Dia x 36"Long, tapered ends
	Universal	Fiberglass	2"Dia x 36"Long, tapered ends
Post/Stand-Off	Enelco/Koppers	Porcelain	Convoluted 6"OD x 10.5"H
	Joy Western	Porcelain	Convoluted 6"OD x 10.875"H
	Research-Cottrell	Porcelain	Convoluted 5"OD x 11"H
Support	Research-Cottrell	Porcelain	Pin-type 12"OD x 9.75"H
	Buell/GE	Alumina	12"OD x 9.75"ID x 23.5"H
	Enelco/Koppers, UOP	Alumina	14"OD x 12"ID x 24"H
	Enelco/Koppers, UOP	Porcelain	14"OD x 12"ID x 24"H
	Joy Western	Porcelain	Convoluted 6"OD x 10.875"H
	Research-Cottrell	Alumina	16.5"OD x 14"ID x 31"H
	Research-Cottrell, Belco	Alumina	16.5"OD x 14"ID x 20"H
	Research-Cottrell	Porcelain	16.5"OD x 14"ID x 31"H
	Research-Cottrell, Belco	Porcelain	16.75"OD x 14"ID x 20"H
	Wheelabrator	Alumina	Conical 10.5" x 14.75" x 20"H
Wall Bushing	Joy Western	Porcelain	Convoluted 14"OD x 20" Long
	Research-Cottrell	Porcelain	Convoluted 3.625"OD x 26"H

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Replacement Components for Insulators
(Courtesy of BHA)

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lists some physical property values of the same ESP insulator materials shown in the first table.

ESP insulators require a material of construction that exhibits a combination of good mechanical and electrical properties. Otherrequirements include corrosion resistance, thermal-shock resistance, and zero absorption of gases and liquids.

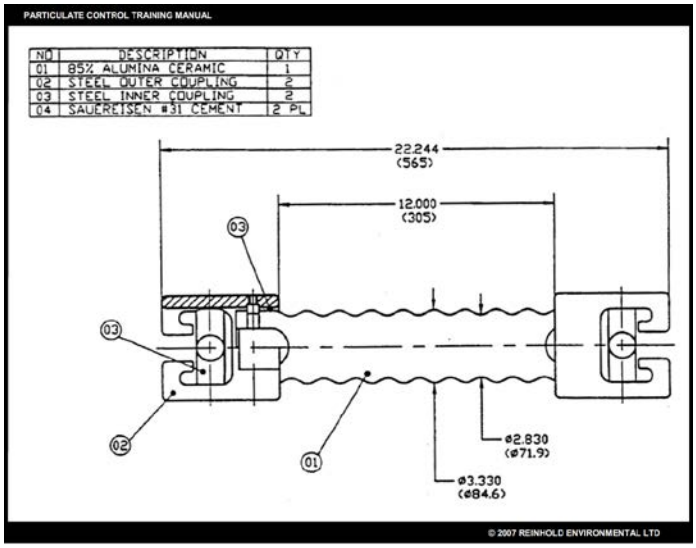
Figure:

Replacement Components for Insulators

lists many of the replacement components for original Insulators.

Function

Typical functions of ESP insulators include discharge electrode support, discharge electrode rapping, feed-through of power supply for discharge electrodes, and anti-sway for discharge electrodes.



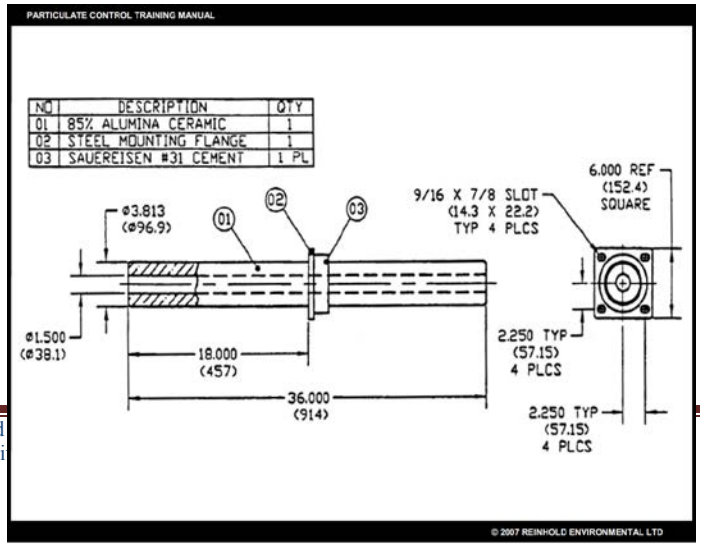
Rotating Rapper Insulator Assembly, Shallow Shed Style

Support insulators carry the weight of the discharge electrode internals; therefore, mechanical strength is important. Styles include cylinders, truncated cones, pedestals, and hybrid suspension-inlet insulators.

Rapping insulators are available for two different systems: electromagnetic (solenoid) and mechanical. Solenoid rapper systems use insulator rods. Mechanical rapper system insulators function either in a rotating drive or in a liftrelease mode.

Feed-through insulators (inlet bushings) are used to handle the power supply to the penthouse or enclosure for the support insulators.

Anti-sway insulators are installed inside the ESP box to stabilize the discharge electrode internals.



Feed-through Insulator Assembly

Service Conditions, Operating Environment

Obviously, the first condition to be addressed is operating voltage. Of almost

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equal importance is temperature. Mechanical stress must also be considered.

Finally, the operating environment must be known and accounted for in the design and selection of ESP insulators. Is the system dry or wet? And if the ESP is to be operated dry, could condensation wet the insulator surfaces? Costly repairs and downtime can be avoided if these service conditions are defined so that the proper ESP insulators can be selected for the job.

Dry ESP's operate within a range of 300° to 840° F (150°- 450° C) so insulators must withstand these temperatures for extended periods of time, generally up to 20 years.

Wet ESPs operate in lower temperature ranges but pose special requirements to prevent electrical creep and flashover. Almost without exception, shedded designs are recommended for wet duty. This will be discussed in more detail later.

Operating environment entails the nature of the particulate and gas that the ESP is handling. The term "particulate" commonly is used to refer to dry particles. Wet ESPs handle mists and gases.

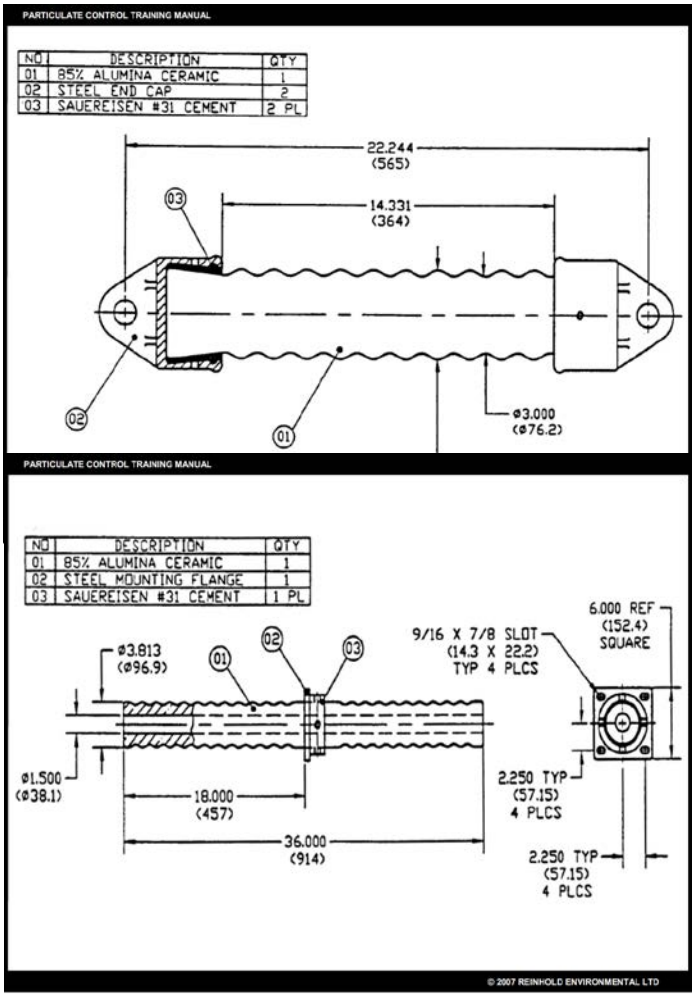
The most important property of a dry particulate is its electrical resistivity. High resistivities favor ESP insulators with straight surfaces, which are generally more economical. Low resistivities and wet service both may require shedded surfaces to break up or dissipate the electrical charge.

Design (Configuration and Size)

The fourth and final criterion involves actual design and sizing. Three factors must be evaluated:

- Adequate cross-section to withstand electrical puncture
- Adequate electrical clearance around the insulator
- Adequate creep distance to avoid power leakage and/or flashover to ground.

Puncture is the breakdown of the dielectric material when electrical stress exceeds the material's resistance to electrical stress. High volume resistivity and high dielectric strength permit more economical designs with thinner walls. A



Feed-through Insulator Assembly, Shallow Shed Type

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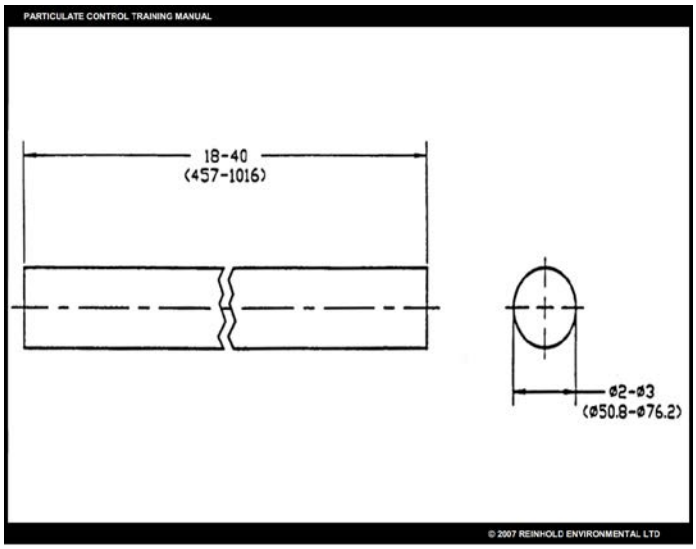
safe guideline in ESP insulator design is that 0.5 inches (12.7 mm) of alumina ceramic will resist puncture at typical ESP operating voltages.

Adequate electrical clearance between power and ground depends on the gas surrounding the insulator. Calculations of electrical clearances are best done by the electrical designers of ESPs. Obviously, the higher the operating voltage, the larger the required electrical clearance. Distances generally fall in the range of 5 inches (127 mm) to 7.5 inches (190 mm).

By far the most important consideration in the sizing of an ESP insulator is the electrical creep over the surface of the insulator between power and ground. The condition of the insulator surface is critical. Will the surface be kept dry or is condensation possible? The resistivity of any material fouling the insulator surface must be known.

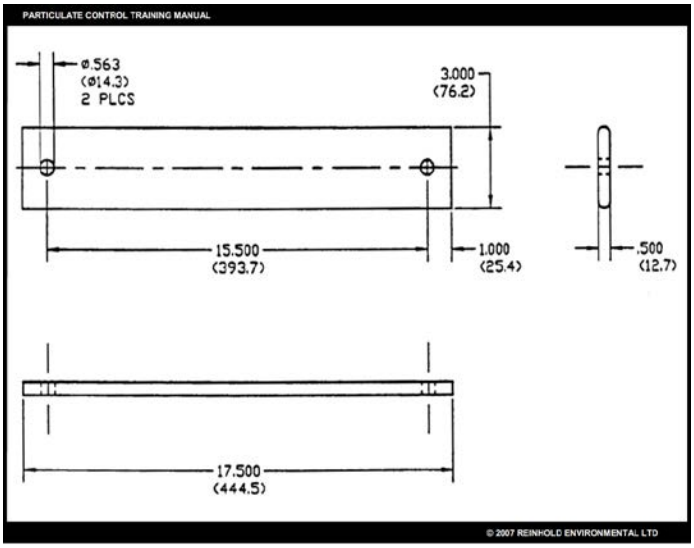
Operating experience indicates that 0.3 to 0.4 inches (7.6 - 10.1 mm)/kV is adequate creep distance in a dry environment and moderate to high resistivity particulate, i.e. > 106ohm-cm. Under these conditions, economical straight surfaced insulators are recommended.



Rod Insulator, Solenoid Rapping and Anti-sway, Alumina
Typical Sizes Available

As mentioned in the previous section, low resistivity particulates and/or wetting by condensation of mist and/or vapor generally require shedded (convoluted) surfaces to increase electrical creep and dissipate charges.

When sheds are required, three styles are available for ESP insulators-ripple or shallow, deep straight, and drip sheds. Selection of the optimum shed style will depend on the service and should be discussed with the insulator manufacturer.



Anti-sway Insulator Bar,
Alumina

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1.7 Hot Side ESP Technical Review

Hot Side ESP Designs

The hot side electrostatic precipitator was designed to circumvent the high fly ash resistivity problem inherent with the use of cold (~300°F/150°C) side precipitators collecting fly ash from low sulfur coals.

In the smaller sized units (under 200 MW) the design is very similar to cold side units except for the use of high temperature insulators (alumina) and heavier heat insulation. In sizes above 200 MW special measures must be taken to accommodate the heat expansion.

Suitable bearings must be used for high temperatures. The Teflon slide plates used in cold side precipitators are not suitable. The best material is graphite impregnated cast iron. Conservative bearing pressure must be used for design.

Because of the temperature differentials, which develop between the support structure and the precipitator casing, stub columns are normally used, fastened to the casing columns. The slide plates are installed between the stub column base plate and the support structure. The heat insulation details in this area must be carefully designed.

Flues cantilevered off the precipitator inlet and outlet flanges are not as satisfactory as using expansion joints on the inlet and outlet faces. Remember that fly ash fall out in the bottom of the inlet and outlet nozzles will have a high insulation value. This can cause temperature differentials of several hundred degrees between the steel of the flue bottom and the steel of the sides and top of these flues. The differential expansion imposing stresses on both flues and precipitators has caused serious problems such as buckling and rupture of both flues and precipitator bottom end frames.

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The same type of problems occur between the roof and top end frames and the top insulator housing. An expansion provision must be made to accommodate this differential expansion.

The heat insulation for the precipitator must be well designed to at least 4 to 6 inches thick and be suitable for long service at 700° to 800 °F (370°- 425° C). Ordinary mineral wool is not satisfactory since the plastic binder deteriorates with time at these temperatures. Installations not properly insulated can exhibit a temperature differential of 50° F (28° C) from inlet to outlet. This has a serious effect on ash resistivity as well as unit heat rate.

The electrical insulators should be of 85% alumina.

The expansion provision for the collecting plates must be adequate for high differential expansion between the collecting plates and the casing. When hot gas is turned into the precipitator, the collecting plates immersed in this gas heat up almost instantly. The side frames may take several hours to reach the gas temperature. The collecting plate bottom spacers should be designed to accommodate a 2.5 to 3.0 inch (60-75 mm) differential expansion downward of the plates, relative to the casing. Placing the plates in compression either vertical or horizontal will certainly deform them and ruin electrical clearances.

We have seen many hot precipitators collecting plates ruined by insufficient provision for differential expansion in the vertical direction and a few cases where the design of the collecting plate supports imposed restrictions on horizontal expansion.

The preferred material for hot precipitator construction for many years was a low alloy, high strength steel marketed under the trade names: "Corten", "Mayori R" and "Jal 10" by various steel companies. This material was supposed to have higher strength and more creep resistance than mild steel at hot precipitator operating temperatures.

Unfortunately, it was determined that prolonged exposure (10-15 years) of these steels to hot precipitator temperatures (700°-800°F / 370°-425°C) caused a change in the crystal structure of these materials seriously weakening the steel and making it prone to stress cracking, especially in the areas of seam welds. This problem mandates close inspection of seam welds during maintenance inspections.

Finally, the structural members over the flue opening are designated as top end frames. In most designs they are the collecting plate supports for the first and last fields, as the roof beams are plate supports for the intermediate fields.

Unlike roof beams, the top end frames are eccentrically loaded since they only support plates on one side. In addition these members are subject to suction loads, wind loads and roof snow loads and live loads, all eccentric.

Because of this, plus the use of low alloy steels noted above, these members are subject, after long (10-15 years) service, to creep. The longer the span, the greater is the problem. These members tend to roll toward the center of the chamber and deflect downwards.

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When this happens, the bottoms of the collecting plates in the middle of the field move toward the supporting bottom baffles and may impinge on them. If this happens, the bottom chords of the plates are placed in horizontal compression and bow normal to gas flow.

If this is detected early, it is simple to re-plumb these center plates by tightening the appropriate plate hanger bolts. If not detected, it will bend the plates and permanently destroy alignment.

Hot side precipitators require much more intensive inspections to keep them performing than do cold side precipitators.

Hot Side Precipitator Problems

Early History.

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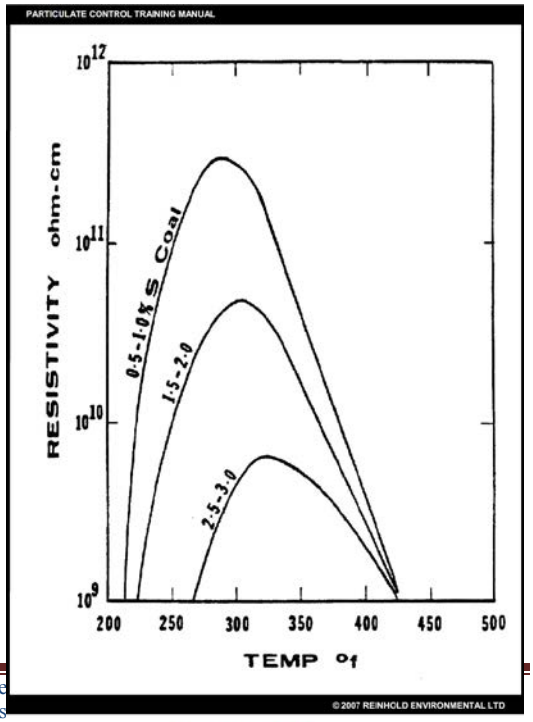
In the late 1950s and early 1960s the electric power industry embarked on an unprecedented growth period, which extended for some 25 years into the mid 1970s. Faced with unprecedented power demands, electric utilities turned to the plentiful supply of coal to produce the needed energy. The traditional coal fields of West Virginia, Pennsylvania, Kentucky, and Illinois produced high sulfur steam coal and could certainly supply the fuel needs, which at that time (50s and 60s) were concentrated east of the Mississippi. As the power demand spread westward, utilities began to look at the vast resources in the West.

In the late 50s when units of 300-500 MW were being designed, mechanical collectors gave way almost totally to electrostatic precipitators. This was largely due to the physical difficulty in fitting enough mechanical collectors in the space, high maintenance costs, high pressure drops, and the much higher efficiencies being offered by precipitators. In much earlier precipitator installations, it had become known that collection of fly ash by electrostatic precipitation became more difficult as the sulfur content of the coal decreased. U.S. companies as well as overseas companies became concerned about the problem and arrived at concepts concerning the effects of ash resistivity, its measurement, and in a crude way, its prediction. From this, the role of sulfur trioxide and its interaction with water vapor content and temperature became clarified.

The emergence in the U.S. of the possibilities of large-scale power production based on low sulfur fuels stimulated aggressive development and marketing of ESPs to cope with fly ash from low sulfur coals. This effort was targeted not only at the expanding power production in the east, but especially at the limitless, low sulfur coal production capacity in the Powder River Basin, Montana, Colorado, New Mexico, and the lignites of Texas and North Dakota. The marketers rapidly passed the technology, and new companies entered the field. The market for particulate pollution control equipment for the power industry virtually exploded, and there actually was real concern and some predictions that production capacity for precipitators could not meet demand. Pollution control had become a "hot" industry, producing all the excesses, such growth generates.

Hot Side Precipitator Concept.

The hot side precipitator was launched as a product to circumvent the electrical resistivity problems associated with fly ash generated in the burning of low sulfur coals. It had long been known that the electrical conductivity of fly ash occurrs through two mechanisms, surface conduction and volume conduction. Surface conduction occurs due to the adsorption of sulfur trioxide, water and sulfuric acid on the surface of the fly ash particles and decreases with increasing temperature; alkali metal oxides are important influences here. Volume conduction occurs when current flows through the particles and increases with increasing temperature. The combination of these



Resistivity Curve

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two conductivity mechanisms produces the traditional resistivity vs. temperature curve (See **Figure:**

Resistivity Curve

). Unfortunately, this concept did not turn out to be valid in all cases.

How it actually is!

Examination of early resistivity curves for fly ash leads one to believe that if a precipitator is operated above a certain temperature, typically 600° to 700° F (315°-370° C), the electrical resistivity is low enough to permit high current densities and good precipitator performance. This is true whether resistivity measurements are made in the laboratory or in situ, since such measurements are made in a short time. Until the physics of volume conduction were understood, the development with time of typical high resistivity symptoms in a precipitator, such as heavy sparking and ultimately back corona, were inexplicable. The concept of a thin layer of fly ash on the collecting plates, whose resistance increases with time because of the depletion of current carriers, was a long time in coming. Resistivity had always been thought of as a constant value at a given temperature and gas composition. It was difficult to accept the concept of resistivity changing (increasing in nearly all cases) with the passage of time, but this is really what happened.

The reason that this concept escaped us for so long was of course the various mechanical and physical difficulties, real and imagined, which were thought to be plausible explanations for the behavior of the hot side units on fly ash from Western fuels. Much time and money were spent on treating the symptom in trying to correct the problem.

Early Hot Side Installations.

The first hot side precipitator was placed in operation at a Jones and Laughlin Steel Mill in Aliquippa, PA in January 1965 for treatment of 200,000 ACFM of gas at 630° F (332° C). It was followed closely by start up in June 1967 of the Ravenwood 30 unit for treatment of 4,300,000 ACFM of gas at 700° F (370° C). These early units were rapidly followed by installations at numerous other plants and by 1974, 81 hot side units had been sold, of which there were 40 in operation. It is significant that most of these units were operating on eastern low sulfur coals. No serious problems had surfaced by this time, and the consensus was that the hot side precipitator was the answer for successful collection of fly ash when burning low sulfur coals.

Serious operating problems had not yet surfaced, as some did even with eastern low sulfur coals. We were yet to hear of problems from the West, but they were in the making. Today, there are approximately 150 hot side ESPs in operation. About 56 of these are on units burning Western low sulfur coals where the most serious operating problems have occurred. At least 30 of these units on the Western coals have experienced problems of varying degrees.

The Development of Troubles - Structural Designs.

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Early hot side precipitator designs were based upon cold precipitator design practices. These design practices did not adequately provide for thermal expansion in the larger, higher temperature units. These design errors were not necessarily limited to "early" units - depending on who the vendor was. Some of the later hot side designs still did not have slide bearings provided in the original design.

In one specific case there were four boxes, each one over 100 ft wide and no slide bearings provided! In this case, the outboard supports were badly deformed. In all such cases, including the first major hot side unit, Ravenwood 30, which went into operation in 1967, there has been severe expansion problems caused by lack of attention to structural design at elevated temperatures.

The results have been ruptures in sidewall casings, roof plates, insulator housings, nozzles and hopper crotches, permitting large quantities of air in-leakage and, in some instances, large amounts of water leakage. Internal cross bracings have even been bent as much as 8-12 ft (2.4-3.7m) out of its normal plane to where it impringed on the trailing edge of collector plates and caused severe deformation of the plates. Inadequate expansion provisions have, in many cases, caused bowed and warped collecting plates and slack discharge electrodes, which resulted in unacceptable alignment, severe sparking, reduced power input, and non-compliance. Rather than correct the root cause of the expansion problem, Band-Aid approaches, such as tying all plates together across rapping sections and to sidewalls, have been taken. This attempt to control expansion by "Brute force" simply magnifies the expansion problem once the unit is heated up, reducing rapping effectiveness, and causing further performance deterioration.

Following the Ravenwood unit in 1967, the next major installations were Public Service of New Mexico at San Juan and Public Service of Colorado at Comanche Station, both starting up in August 1973. Both developed expansion problems resulting in ruptures in flues and casings. San Juan shut down for a prolong period due to a boiler explosion, but Comanche Station continued to operate with severe air in-leakage. Poor performance was attributed to this inleakage, gas distribution problems, and binding of internals due to differential expansion, as well as a much higher than expected operating temperature.

All the while, these thermal expansion and structural problems were being dealt with (some effectively and some not so effectively) the total attention to them was masking the "Western Coal Syndrome" problem.

Western Coal Syndrome.

The first unit to operate on Wyoming coal fly ash was the 15 MW George Neal Unit #1, in 1972. Unfortunately, this was a cyclone boiler, not too well suited to this type of coal, having very high combustible content in the fly ash (25-30%). This unit was relatively small and did not have expansion problems. The high carbon content of the ash was deemed to be the major problem of poor performance, requiring much attention and work; and here again the resistivity difficulty peculiar to the Western Coal Syndrome was completely obscured. Another factor contributing to the masking of the Western Coal Syndrome or resistivity problem was the emergence of a long succession of hot precipitator successes in the east.

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Now, however, in the West, Comanche's physical problems had been corrected; Columbia 1 and Hayden 1 were in service; and, with the startup of Navajo 1, Comanche 2, and Deely 1, it was becoming apparent that something else other than expansion and structural problems was causing performance deterioration. The pattern was similar in all cases. Performance would start out at reasonable levels and after a period of time would deteriorate, some to borderline levels and others totally out of compliance.

As units got larger and more and more Western coal came into use, more problems appeared. Nebraska City, George Neal 4, Gerald Gentleman, and Council Bluffs 3 came into service on ash from Powder River fuels and Hayden 2 on Colorado fuel. Another disturbing factor was the appearance of the "Western Disease" or something similar at Lansing Smith on the Gulf Coast. Problems on all these units went on concurrently, with major attention still directed to physical problems such as differential expansion, induced distortion of internals, gas distribution, and air in-leakage caused by casing and flue ruptures.

Various researchers and investigators zeroed in on the ratios in the fly ash of sodium, potassium, iron, lime, and magnesia in various combinations. Correlations of these various ratios with resistivities and other parameters were advanced by Grondhov, Selle, Bickelhaupt, and others.

High Silica and Alumina Ash.

At two of the stations mentioned above, Hayden and Lansing Smith, the ash is characterized by a high combined content of silica and alumina, totaling 75-80%, with lime at 10% for Lansing Smith and 5% for Hayden. In both of these cases the addition of 15-20 ppm of ammonia gas produced marked improvement in performance, and at Hayden compliance was achieved on a sustained basis. Addition of ammonia to typical Powder River Basin ash did nothing.

Sodium Depletion Identified.

The premiere discovery was, however, in the continuing work of Bickelhaupt at Southern Research, who early established the sodium ion as the overwhelming contributor to the conductivity of ash at higher temperatures. This, coupled with his realization that at the immediate plate surface there was a finite supply of sodium atoms, led to a plausible explanation of the Western Syndrome. Further work confirmed the mechanisms, which were occurring, and the scientific puzzle was unraveled. Today, it is known as the Sodium Depletion Effect, and the longterm effect on resistivity can now be computed.

Sodium Depletion Treatment.

Obvious solutions to low sodium, high lime ash have been to artificially increase the sodium content of the ash. This has been attempted in the following ways:

1) Spraying a sodium salt solution into the hot flue gas after the economizer (Columbia 1)

2) Blowing a pulverized dry sodium salt into the flue gas following the economizer (Comanche)

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3) Blending high sodium ash fuel with low sodium ash fuel or switching to high sodium ash fuel (Parrish)

4) Adding sodium salt to the coal conveyor (Deely, Neal 4, and Council Bluffs)

Methods 1 and 2 proved to be cumbersome, resulting in poor distribution of the sodium and excessive fall out in the flues. Methods 3 and 4 proved to be easier to accomplish but not subject to close control, i.e., quick response to changes in load or fuel. In addition, the introduction of sodium to the furnace has in many cases caused extensive fireside deposits in convection superheater and reheater surfaces and especially on economizer surfaces. This has necessitated the addition of extra soot blowers and/or frequent load restrictions and outages for boiler cleaning, including the use of dynamite both off line and on line. When the sodium is increased to a level to prevent the development of a depleted layer on the collecting plates, fouling of boiler surfaces and excessive ash build up in precipitators have occurred. If a lesser amount of sodium is added, then we have forced unit outages in order to clean the precipitators by washing, sand or grain blasting, or by mechanical means of scraping or hammering on a frequent basis.

The above problems were all well known to City Public Services of San Antonio at Deely 1 and 2, where, prior to their decision to convert the units to cold side operation, they were taking the units off line in excess of 6 times a year for washing the ESPs. As indicated earlier, costs incurred by outages this frequent can far exceed the original cost of the ESPs.

Thus, while the scientific problem was solved, its reduction to practical countermeasures for the mitigation of sodium depletion has proven a marginal solution at best and unacceptable for the long term in many cases.

Recap of Persistent Hot Side Problems.

In the review and inspection of many operating hot side precipitators, the following problems, which recur frequently, were noted:

1) Higher than design temperature, in some cases by up to 150° F (83° C) due to:

- Insufficient heat transfer surface in superheater, reheater and economizer.
- Fouling of heat transfer surfaces due to fireside deposits (attributable to addition of sodium in many cases) and inability to clean these surfaces with soot blowers. This has cased deformation and near failure of internal structural members and has required replacement and reinforcement of such members in many cases.

2) Operation at higher than design temperature has caused deformation and bending of the relatively thin collecting electrodes of the roll formed panel type due to creep after prolonged operation at higher temperature.

3) The use of mild steel for anticipated design temperatures has required costly modifications. Had it been known that operating temperatures would exceed design temperatures by as much as

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150° F (83° C), materials with better strength/temperature properties might have been selected.

4) Selection of improper materials for slide plates and bearing surfaces and restriction of sliding movement.

5) Lack of adequate expansion provisions results are:

- Casing and flue ruptures
- Collecting plate warping and bowing
- Slack discharge electrodes
- Terrible alignment
- Air and water in-leakage
- Performance deterioration
- Non-compliance

6) Sodium depletion resistivity: The lion's share of units burning Western coals have been plagued with this problem, resulting in:

- Performance deterioration
- Frequent outages for cleaning ESP
- Lost revenue

7) Internal Design: Improper provision for the transient differential expansion, both horizontal and vertical, which occurs between the collecting and discharge electrodes and the spacers and supports connected to the casing, results in placing these relatively fragile elements in compression. These electrodes, when subjected to compression, will deform permanently; and efforts to prevent such by "brute Force" spacers have not always been effective.

Hot Side Precipitator Solutions

Introduction.

Eventually, utility management asks the question, "Is there a long-term reliable solution to our hot side problems?" This section addresses this question and describes the work performed on a number of deficient hot side ESP systems.

Cold Side Conversion Advantages for Hot ESPs.

It is useful to summarize some pertinent advantages and basic factors in cold side conversion.

1) Gas flow rate reduction and corresponding increase in available SCA in existing systems. Situations range from marginal to liberal ESP sizing considerations at lower temperatures.

2) Improved boiler efficiency and plant heat rate are possible by reducing heat losses associated with the hot ESP, and often by judiciously implementing additional heat exchange capacity - large savings in coal costs. Also, can carry a higher load for improved system utilization and

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increased revenues.

3) SO_3 gas/dust conditioning becomes applicable to achieve high performance according to available ESP SCA and ash resistivity situation. Low gas temperatures favor the adsorption process efficiency: above 350° F (177° C), SO_3 conditioning becomes less effective and disappears in region 350° to 400° F (177°-204° C) depending upon fly ash characteristics.

4) Better mechanical integrity - elimination of serious thermal distortion problems characteristic of many hot ESPs.

5) Less maintenance, less unscheduled downtime due to ESP failures, no need for frequent washing, more long-term service reliability and sustained high performance can be built in. Thus, large operating cost savings.

6) One can take advantage of increased critical resistivity levels, typically 1-4x1010ohm.cm at about 300°+ F (149° C) gas, compared with order 204.0E+9 ohm.cm in low density gases at 700° to 800° F (370°-425° C). Note that at high site elevations, further reduction in working gas density in hot ESPs occurs to cause undesirable corona discharge characteristics - marginally suitable for good precipitation, particularly in the narrower duct width designs.

7) Improved basic corona voltage-current characteristics prevail at cold side conditions. Low density gases reduce sparking voltages and operating electric field strength and cause rather steep and unstable voltage-current characteristics, often compounded by increased and localized, free electron flow - especially deleterious effects in traditional U.S.A. 9" duct, wire-weight type hot ESP designs. Some wider duct, rigid frame type hot ESPs, plagued with serious thermal distortion, electrode alignment and ash resistivity problems, have also been successfully improved by cold side conversion with sustained high performance reliability and, with suitable coal selection, without need for SO_3 conditioning.

8) Reducing boiler load with cold side ESP typically improves performance, whereas ash resistivity increases and performance deteriorates in hot ESPs at reduced loads with reduced gas temperatures - especially critical towards ESP outlet with relatively large temperature changes across a hot ESP.

9) Under cold side conditions, less disturbances, stack puffing and opacity excursions with system soot blow than in the hot case. In the latter, blowing AH soot on the air side is helpful.

10) Applicable to a wide variety of coal-ash characteristics, including some of the difficult Powder River Basin coals. It is often possible to choose favorable coal sources or to use SO_3 conditioning.

11) With SO_3 conditioning, can often get fine particle agglomeration effects for improved ESP capacity. Also, SO_3 conditioning in reducing ash resistivity improves ease of electrode rapping when operating with native high resistivity ash - very desirable in original designs using deficient rapping systems.

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12) Reduces gas velocity for reducing v/AR (AR=ESP aspect ratio) and gas flow shear stress at collecting plate surfaces - hence reduced exposure to dust re-entrainment losses. For example, a hot ESP running at 5-6 ft/s might have average velocities about 3.5 to 4.4 ft/s (1.0-1.3 m/s) at 300° F (149° C), and peak velocities order 1.2 times average with proper upgrading. Rap-re-entrainment losses of 50% or more may be reduced to 30% and often less.

13) Meet air pollution control regulations consistently at high loads.

Critical Subjects and Factors for Investigation and Evaluation.

In the case of candidates for cold side conversion, each one is site specific and requires a careful, detailed, comprehensive study and evaluation for upgrading and systems analyses, not only to determine feasibility, but also to specify necessary modifications required to achieve acceptable long-term, compliance strategy well within applicable regulations. The following major critical areas and factors are involved. Some of the associated important methodologies are also discussed in the following sections.

1) Document Review - Original contract and ESP technical design factors, specifications, guarantees, performance test results; operations, maintenance, and problem history; modifications to the system and ESP since installation, attempts to improve performance and results or lack thereof; present situation status. A list of important information required to carry out proper ESP performance and system analyses would include the following items.

2) Plant Inspection - A careful internal and external inspection of the precipitator and system by experienced field engineers is essential. Emphasis is placed upon such areas as: structural factors; mechanical integrity, alignment and condition of both CE (collecting electrodes) and DE (discharge electrodes); electrode dust buildups; layouts and arrangements; electrical energization system; rapping systems; HT insulator purge air; HT frame stabilization; insulation and air inleakage; gas distribution system and possible maldistribution evidence, inlet and outlet transitions and flues, dust fallout, etc.; stack exit diameter, site elevation, terrain, ambient temperature range, type of ash removal system. At this time useful discussions with management, operator and maintenance personnel can also take place.

3) Compliance Regulations - Particulate and gaseous emissions, stack opacity (transmissometer type, location, averaging time and peak values). We note that in large units, stack opacity often controls ESP performance requirements. Possible future regulations changes to be dealt with. Information provides the minimum target for an effective compliance strategy.

4) Particulate Control Technology Options' Evaluation.

5) Boiler - Type, load factors, operation - baseload, cyclic or swing; size, heat rate, heat input rate, combustion conditions, slagging and fouling factors; particulate carryover.

6) Fuels and Sources - Proximate and ultimate analyses with ranges. Design fuel, present, possible future variations and effects on performance.

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7) Coal Mills - Number, type, grind specification, capacity and reserve.

8) Air Preheaters - Number, type, air inleakage situation, relative gas handling capacities, temperatures, transfer surface, RPM.

9) Ash Properties - Physical, chemical, electrical - including ranges; LOI; slagging and fouling characteristics and fusion temperatures for boiler; particle size distribution inlet to ESP and critical descriptive factors; resistivity factors; resistivity situation for operating conditions; allowable ESP current densities; possible need for enhancement, e.g., SO_3 conditioning, pulse energization. These data and evaluations may be assembled for up to 16 different coals in typical cases.

10) Precipitator Parameters - Number, size, arrangement, sectionalization (mechanical plus electrical); aspect ratio; CE and DE type, geometry, SCA; energization system, quality and controls; rapper types and working densities, capabilities, gas distribution quality requirements; electrode alignment expected; energy management options, etc.

11) Operating Conditions - Past and upgraded; gas flow and ranges; temperatures, range and ?T; static pressures; facilities or applicable methods for ESP gas temperature control; excess air combustion; inleakage; gas composition; rate of load change and effects; ash resistivity considerations; inlet particulate concentrations, soot blow effects.

12) Performance Analyses - Past results, conditions, stack opacity. For upgraded ESP, evaluations and predictions including effects of all critical factors, several possible coal-ash sources and properties, leading to specified requirements for upgrading (e.g., cold conversion) and operating conditions to satisfy the target compliance strategy.

13) Long Term performance - reliability factors evaluation.

14) Comparison with other Cold side Units.

15) Specifications - For selected modifications and A-E technical services.

Major ESP Performance Determinants.

Among the most important factors affecting precipitator performance capability and compliance strategy are these:

1) Ash resistivity - as controlled by ash chemistry, gas temperature and density, gas composition (H_2O, SO_3/H_2SO_4), auxiliary conditioning agents. Resistivity basically controls the allowable operating ESP current densities, hence useful power input density and size of equipment required.

2) Inlet particle size distribution and concentration - as influenced by fuel properties and boiler

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system factors. Associated inlet ash specific surface, particulate surface density and space charge effects.

3) Electrical energization - available electric field strengths, their quality and distribution, as controlled by operating voltages and current densities, electrode geometry and alignment, rapping efficiency, sectionalization, optimum waveforms, automatic control system quality and stability, possible use of pulse energization in lieu of chemical conditioning for high ash resistivity control. The electrical energization system and conditions most strongly influence effective particle migration velocities achievable.

4) SCA (Specific Collecting Area) - ESP total collecting area per unit gas flow rate.

5) Dust loss factors - as influenced by gas distribution quality, sneakage, local air inleakage, hopper sweepage, gas velocity erosion and rap-re-entrainment (v/AR and gas flow shear stress), excessive sparking, saltation, and long-term reliability factors.

These factors, with others, are strongly and synergistically interrelated, yielding performance capability as described by the well known Deutsch and Matts-Ohmfeldt precipitation equations. Appropriate adjustments for non-ideal conditions and loss factors are made.

Cold Side Conversion - General.

One of the largest successful cold side conversion ESP jobs was that at Arkansas Power and Light Company's White Bluff and Independence plants as proposed by the original hot side vendor, Combustion Engineering Company, circa early 1982. White Bluff 1, 2 had been built as hot ESPs and had serious problems in meeting performance guarantees at full load -860 MW gross. Comprehensive analyses by H.J. Hall for the utility company confirmed cold side conversion, with some basic system upgrading, to be a viable solution for long-term reliable high performance meeting contractual guarantees and A.P.C. regulations. All units, including the similar two at Independence, which were in construction, were converted. Results were reported consistent with the predictions for Powder River Basin coal sources.

The table to the right summarizes some

PARTICULATE CONTROL TRAINING MANUAL

Item	A	B	C	D	E
1. Gross MW/unit, rated	418	650	530	620	617
2. Design efficiency, %	99.4 min.	99.7	99.5	99.5	99.72
3. Gas rate, k ACFM	1600	2900 max	2420	2370	2600
4. Avg. gas temp., F	315	350 max	330	300	290
5. No. ESP/unit	2	4	2	2	4
6. Total SCA, ft^2/k ACFM	531	629	307	Double deck 433	470
7. Design w, cm/s	4.9	4.7	8.78	6.22	6.36
8. Total ducts	328	512	344	336	472
9. Duct width, inches	9	9	9	10	9
10. Plate height, ft.	36	36	30	40.8	36
11. No. of electric fields	6x6'	11x4.5'	8x4.5'	4x9.36'	8x4.5'
12. DE, type, dia.	WW, .105"	WW, .109"	WW, .109"	RF	WW, .109"
13. No. TR sets	48	88	64	48	64
14. Gross avg. gas v, ft/s	3	3.5	5.2	3.46	3.4
15. v/AR	3	2.54	4.34	3.76	3.4
16. T_O, dynes/cm^2	0.026	0.031	0.06	0.04	0.030
17. CE, avg. ft^2/rapper	2214	1296	1620	740	
18. DE, avg. ft/rapper	1970	1729	2383	360	
19. Stack dia. exit, m	7.93	7.85	6.4	7.22	
20. Nom. inlet ash, m^2/g	.606	.606	1.7 max	0.6-1.2	
Surf. dens. m^2/m^3	2.4	2.7	6.4	2.75-5.5 max	

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Summary of Some Typical Technical Data on Several Cold Conversion Projects
(Courtesy of EPSCO)

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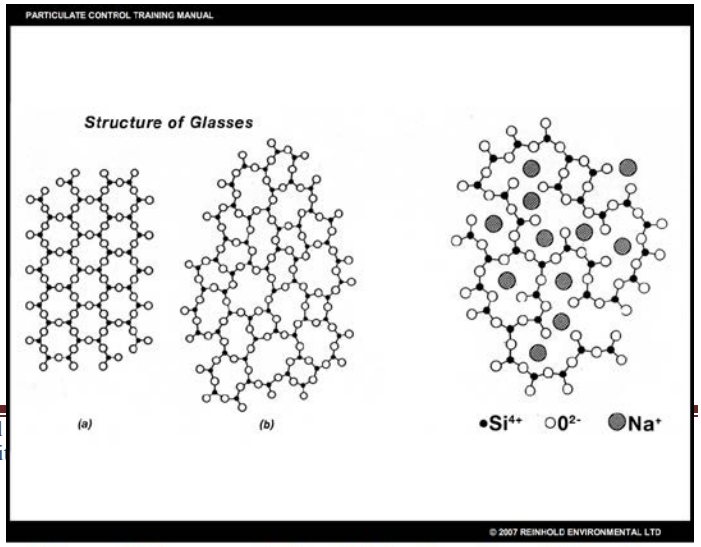
typical technical data on several cold conversion projects from which case E is excepted. Comprehensive analyses were carried out which lead to specific recommendations for necessary modifications and upgrading. All recommended using SO_3 conditioning as required to control ash resistivity for worst case Powder River Basin coals and conditions. It was noted that available SCAs range from near marginal to liberal (307629) for cold side operation. In most cases gas velocities come down to 3-3.5 ft/s (0.9-1.1 m/s), resulting in very favorable v/AR and shear stress values for minimizing re-entrainment losses and allowing very high performance capabilities. Smaller size ESPs, e.g. case C, naturally require special attention to achieving favorable gas temperatures, good gas distribution quality, adequate rapping, good energization, etc. To obtain high performance in smaller size ESPs also requires operations at higher current densities than in larger size units. This can be done with proper upgrading and effective SO_3 conditioning.

Case E has been in operation for several years with very good results reported in 1981 tests at 585 MW with 99.95% efficiency, 270° F (132° C) gas, 6-8 ppm SO_3 injection. This was a situation where an original hot ESP design was alter deemed unsuitable and changed to cold side for final installation with SO_3 conditioning.

Conclusions.

Cold side conversion, in which a number of fundamental synergistically interrelated advantages in the electrostatic precipitation process can be brought to bear, can indeed be a viable approach to the long-term solution of persistent problems extant in many hot side precipitators. More particularly, the method is well suited to those ESPs burning difficult, highly lignitic-type fly ashes characteristic of Powder River basin low sulfur coals. A wide variety of coal-ash properties can be successfully handled - some without SO_3 conditioning, others with SO_3 conditioning. Field experience has demonstrated the effectiveness of cold side conversion when carried out with proper attention to all critical details - not only for the more sensitive designs using traditional 9" (23 cm) duct, wire weight systems, but also for wider duct, rigid frame type ESPs.

When undertaking a conversion emphasis must be placed upon ESP fundamentals and a total systems approach with a site-specific detailed and comprehensive study by experienced scientists and engineers skilled in many disciplines. Not only is feasibility addressed, but also the investigation must produce specific and effective upgrading and operating criteria to ensure long-term, reliable, high performance meeting present and likely future APC regulations.



Schematic Representation of (a) ordered crystalline form and (b) randon-network glassy form of the same composition

1.8 Sodium Depletion and Back Corona

Sodium Depletion and Back Corona

Introduction.

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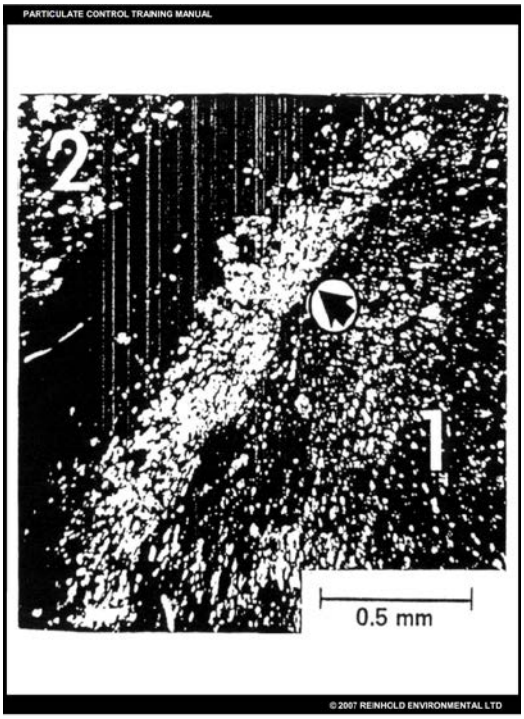
To fully appreciate the sodium depletion phenomenon, it is helpful to consider the chemical, physical and structural character of fly ash. It is produced from the accessory minerals occurring in coal. Dozens of minerals, such as quartz and kaolinite, produce fly ash containing a very large number of the elements appearing in the chemical periodic chart. Usually, ten to fifteen of these elements are reported in chemical analyses. Excluding combustibles, this group makes up about 96% to 98% of the total fly ash. The major elements are oxygen, silicon, aluminum, calcium or iron and minor percentages of other elements, including sodium.

During the combustion process, the accessory minerals are melted or vaporized. Some particles coalesce with others and the vaporized material condenses into individual particles or coats other particles. The resultant material is almost all spherical in shape and between 0.1 and 100 μ in diameter.

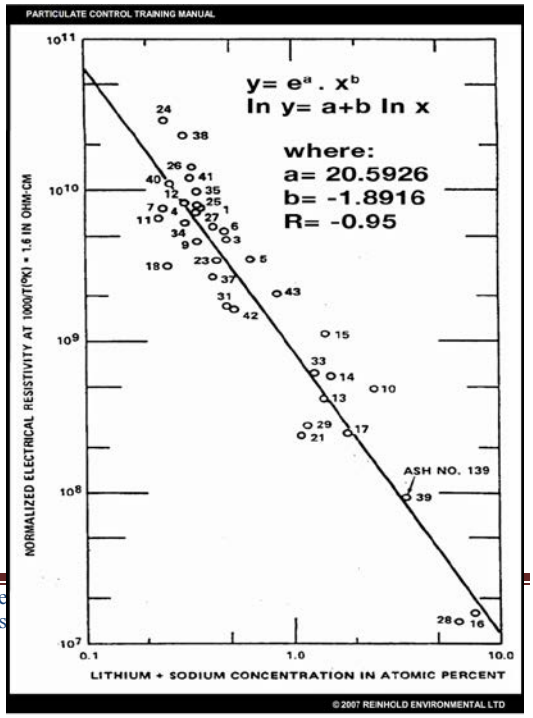


Effused Na at Negative Electrode

The atomic structure of fly ash is most important. One is deceived regarding the structure, because the chemical analysis is reported as oxides. Fly ash does not consist of a mixture of crystalline oxides. It is amorphous or glassy. At the peak combustion temperature of typically 2,400°F (1,300°C), the accessory minerals melt, and because of the rapid cooling rate, the material passes from liquid to supercooled-liquid to glass. X-ray diffraction analysis reveals the general pattern for a glassy substance with superimposed peaks related to crystalline materials. Quantitative X-ray diffraction reveals that the crystalline faction of fly ash is less than 10%. Therefore, the properties of the fly ash are related to the glassy portion. **Figure:**

Schematic Representation of Crystalline/Glassy Form

illustrates the difference between crystalline and glassy structure. The more rapid the cooling rate, the more open the glassy structure. Slower cooling large particles often contain precipitated crystalline material.



Resistivity vs. Lithium plus Sodium; Baseline Conditions at 352 Degrees Centigrade

Thirty years ago, the literature suggested that electrical conduction, in the absence of adsorbed acid vapor, was electronic due to the semi-conductor character of the crystalline ash. Chemical analyses from that time did not record data for the alkali metals. With the knowledge that the fly ash was really glass, it was suggested that conduction was due to an ionic

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mechanism rather than electronic. Because the semi-conductor idea was embedded in the literature, several experiments were conducted to demonstrate ionic conduction related to sodium.

In the scientific literature pertaining to glass, it is stated that the alkali metals lithium, sodium, and potassium, as well as ammonium ions, are capable of serving as charge carriers in a glassy medium. Under the influence of an applied DC voltage, the positively charged cations should migrate to the negative electrode.

A disc was fabricated from fly ash and platinum elec-trodes were painted on opposing faces. A constant electrical potential was applied for a long time during which the current decreased. When the experiment was terminated, the negative electrode shown in **Figure:**

Effused Na at Negative Electrode

was covered with a substance that was determined to be products of the reaction of sodium with the various components of ambient air.

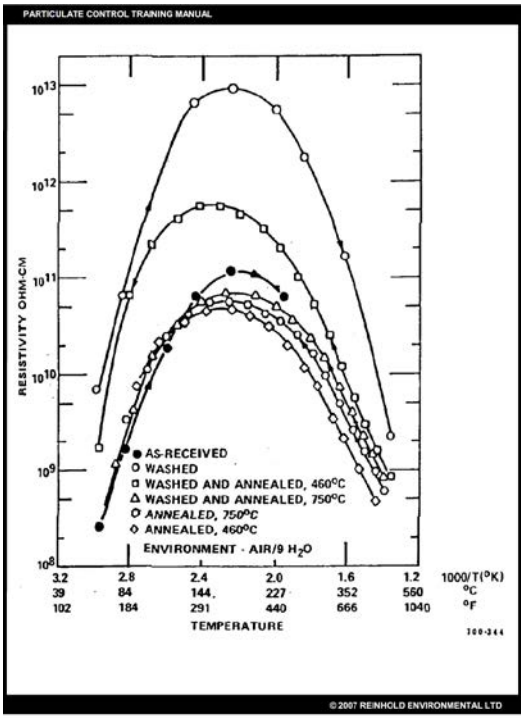
Chemical transference experiments were also conducted to determine which alkali metal was the principal charge carrier. Conclusive data indicated this was sodium. Lithium migrates readily, however, in the case of most ashes, the low lithium concentration makes it ineffective. Potassium is capable of charge carrying, but its large size makes it much less mobile than sodium.

The charge carrying ability of sodium is also demonstrated by the linear relationship between resistivity and the sodium concentration of similar ashes at precipitator hot side temperatures. This is shown in **Figure:**

Resistivity vs Lithium Plus Sodium; Baseline Conditions at 352° Centigrade.

This linear relationship also was demonstrated for cold side temperatures. In both temperature ranges, sodium is the principal charge carrier. The absolute resistivity value is modified by the iron and calcium concentrations.

In the absence of sulfuric acid vapor, sodium also serves as the principal charge carrier in the cold side temperature range. Adsorbed water vapor interacts with the ash surface to free sodium ions and increase their mobility. At 300°F (150°C) in an air-water environment, current density decreases with time of applied constant electrical stress with the accompanying migration of sodium. The results of an interesting experiment are shown in **Figure:**



The Effect of Water Washing and or Thermal Annealing on the Resistivity of an Ash

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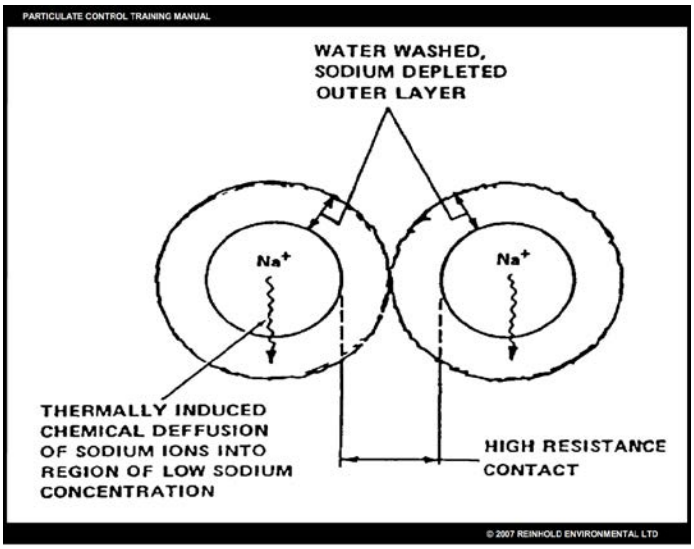
The Effect of Water Washing and/or Thermal Annealing on the Resistivity of an Ash.

It demonstrates that residual adsorbed acid vapor and water alone do not control the resistivity of an ash. Washing and drying the ash removes any adsorbed acid or water and the sodium in the near surface of the ash particles. Thermally annealing the ash causes interior sodium ions to diffuse to the surface and restore the original resistivity. This is illustrated in **Figure:**

Schematic Sections of Water Washed and Thermally Annealed Fly Ash Particles.



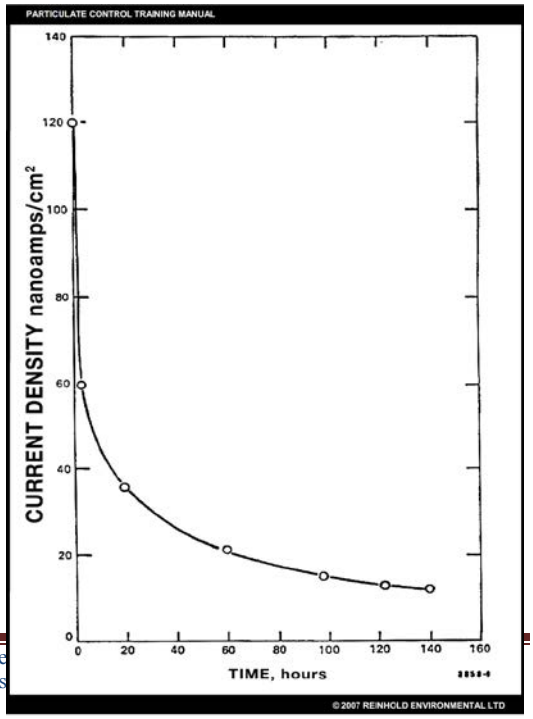
Schematic Sections of Water Washed and Thermally Annealed Fly Ash Particles

In the foregoing text, experiments have been recalled simply to emphasize that fly ash is a glassy substance and that sodium by virtue of its ability to migrate or diffuse through and over the surface of the particles is the principal charge carrier in the absence of adsorbed acid vapor. With this in mind, sodium depletion can be considered.

The Sodium Depletion Problem

The adaptation of the hot side precipitator was thought to be the final answer to high resistivity problems, and one did not need to consider the composition of the ash to be collected. However, many problems occurred. Structural difficulties related to inadequate design, elevated temperature, and temperature variations became common. Failure to consider the possibility of lower dielectric strength of ash layers at elevated temperatures produced problems. High inherent ash resistivity occurring at typical hot side precipitator temperature was ignored. Temperature variation with electrical load caused additional resistivity problems.

However, even when everything pertaining to the collection of fly ash in a hot side precipitator was satisfactory, another problem ultimately named "sodium depletion" was identified. This phenomenon was manifested by the degradation of precipitator performance as a function of time. Days, weeks or months might elapse before performance decreased to point requiring cleaning.



Attenuation of Current Density with Time of Continuously Applied Direct Current Voltage: parallel plate resistivity test cell

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Above it was emphasized that the positively charged sodium ion is the principal charge carrier in a fly ash layer. Also it was stated that the current passing through a fly ash layer decreases and approaches a lower level, when subjected to a constant applied voltage. This illustrated in **Figure:**

Attenuation of Current Density with Time of Continuously Applied Direct Current Voltage; parallel plate resistivity test cell.

When the precipitator collection plates are rapped, normally some ash remains. That is rapping, even power-off rapping, does not usually produce bare metal surfaces. A thin layer remains. This layer is created by the electric field and enhanced by plate surface roughness, particle cohesiveness, corrosion, and chemical reactions. It was hypothesized that this layer eventually becomes depleted of charge carrying sodium ions and therefore current decreases with time of applied voltage.

To illustrate this effect, laboratory experiments using a wire-plate corona discharge device were conducted. In one case, a 100µ deep recess was milled into the face of the "collection" electrode on which a 5-mm layer of fly ash containing 0.3% sodium rested. A negative corona was established for a long time at 665°F (330°C). After this, ash was removed for chemical analysis from the ash layer surface and the ash located in the 100µ depression. The chemical results are shown in **Figure:**

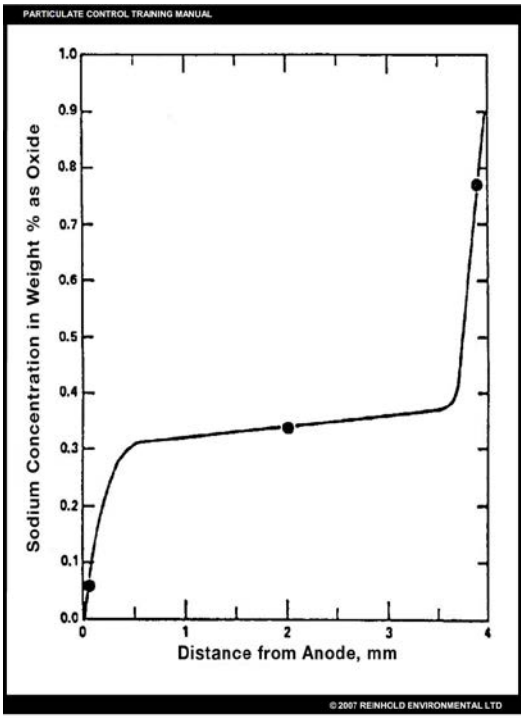
Suggested Sodium Concentration Profile.

Although one cannot attest to the shape of this chemical profile, it is obvious that the ash contiguous with the positive electrode is almost completely depleted of sodium and the ash layer surface has been significantly enriched.

Since the current versus time of applied voltage curves degrade to some lower value without developing an open circuit, some other conduction mechanism must be involved. **Figure:**

Distribution of Charge Carrying Ions in an Ash Layer after Long-time Exposure to an Applied Direct Current Voltage

illustrates a suggested mechanism. Positive sodium ions migrate toward the ash surface and are neutralized by the incoming negative charge. At the collection plate, unattached and unassociated negative oxygen ions combine to form molecular oxygen giving up electrons to the plate. This has not been demonstrated in the laboratory using fly ash. However, the scientific



Suggested Sodium Concentration Profile

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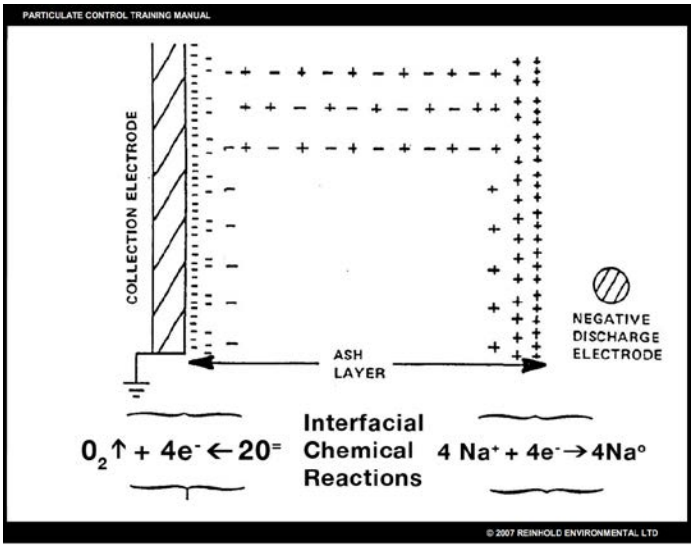
glass literature records experiments illustrating this process using a soda-lime-silica glass and shows that the quantity of electricity conducted was directly proportional to the amount of oxygen evolved.

As the sodium depleted zone becomes stable, current as a function of time of applied voltage decreases to a new lower level. The oxygen migration becomes the rate controlling mechanism and is manifested by an increase in ash resistivity of about an order of magnitude. All ashes do not produce the same sodium depleted resistivity because the oxygen ions available for charge transport are directly related to the sodium concentration. Consequently, one can bring a hot side precipitator on line collecting an ash having a desirable inherent resistivity and ultimately have great difficulty when the sodium depletion effect occurs raising the resistivity an order of magnitude. **Figure:**

Computer Plot of Predicted Volume Resistivities Versus Temperature

illustrates inherent and sodium depleted resistivity as a function of temperature.



Distribution of Charge Carrying Ions in an Ash Layer after Long-time Exposure to an Applied Direct Current Voltage

Remedial Measures

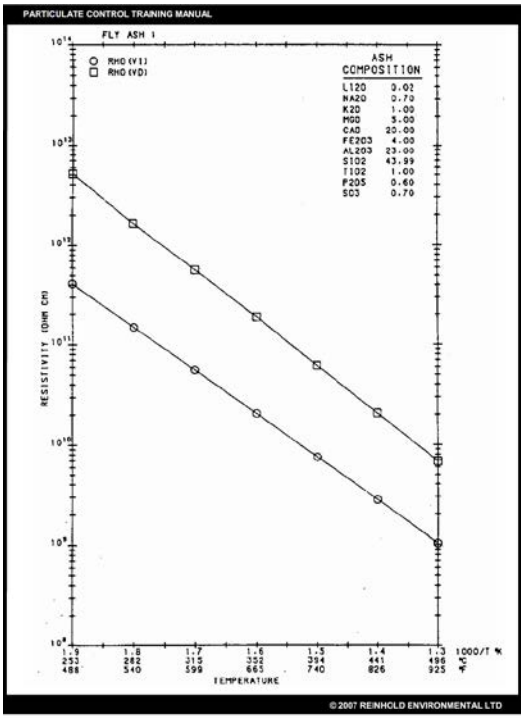
Coal switching:

Review the available coal and ash analyses to determine whether a different coal will be compatible with the boiler and produce an ash having a sodium depleted resistivity in the desirable range for the specific precipitator temperature range. Certain western coals and eastern metallurgical coals are possible candidates.

Sodium conditioning:

If the boiler is not marginal with respect to slagging or fouling problems, conditioning can be considered. **Figure:**

Chronological Display of Precipitator Power and Particulate Emssion Rate



Computer Plot of Predicted Volume Resistivities vs. Temperature

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shows the effect of sodium conditioning on precipitator performance. This effect also has been demonstrated in the laboratory.

The application of the sodium is very important. The sodium compound in solution or as very fine particles should be added to the coal prior to entering the bunkers. The purpose is to uniformly disperse the sodium. It is desirable to have the sodium compound vaporize and become an integral part of the ash particles. It is understood that some vendors supply coal with the sodium added.

Plate doping:

This also had been demonstrated in the laboratory. If the collection electrode has a source of sodium, the depletion problem should not occur. Doping might be carried out by spraying the clean collection surfaces with a sodium compound solution or with a substance such as sodium silicate. The sodium silicate should adhere very well. The objective of doping is to delay cleaning as long as possible. It is not known whether doping has been tried. It would seem to be worthwhile to try it on one electric field for comparison with no treatment.

Polarity reversal:

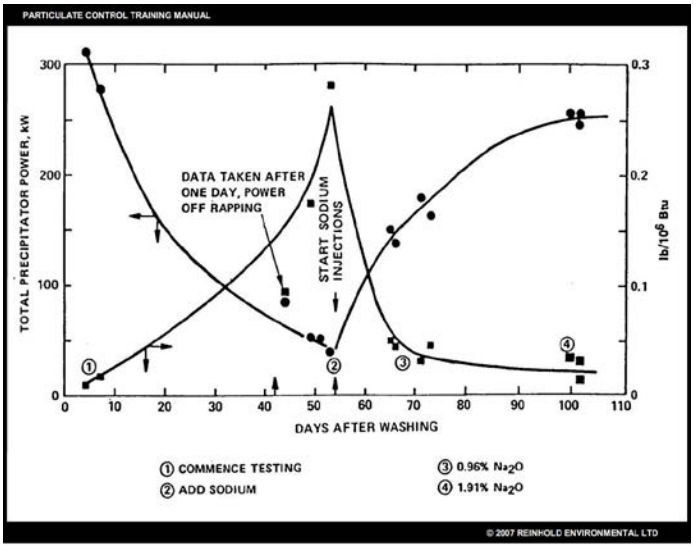
In the laboratory, it was demonstrated that periodic reversal of corona polarity avoided the sodium depletion problem. **Figure:**

Current Density as a Function of Applied Negative Voltage

shows this effect.

Proprietary conditioning agents:

It is understood that proprietary conditioning agents for hot side resistivity problems have become available.



Chronological Display of Precipitator Power and Particulate Emission Rate

Washing and grit blasting:

These methods were the initial methods of restoring precipitator efficiency. Ideally, one wants to restore the wires and plates to a bare metal condition. The extremely thin layer of sodium depleted ash contiguous with the steel surface should be removed. For a given ash composition and precipitator temperature, this will produce the longest time

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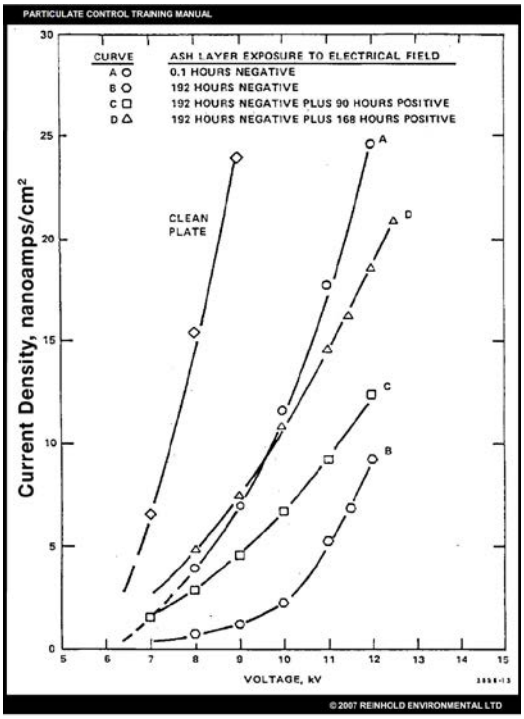
between cleaning cycles. Superficial cleaning will give short-lived improvement similar to power-off rapping. An inefficient washing produces some gain by assisting in the migration of sodium back toward the collection electrode.



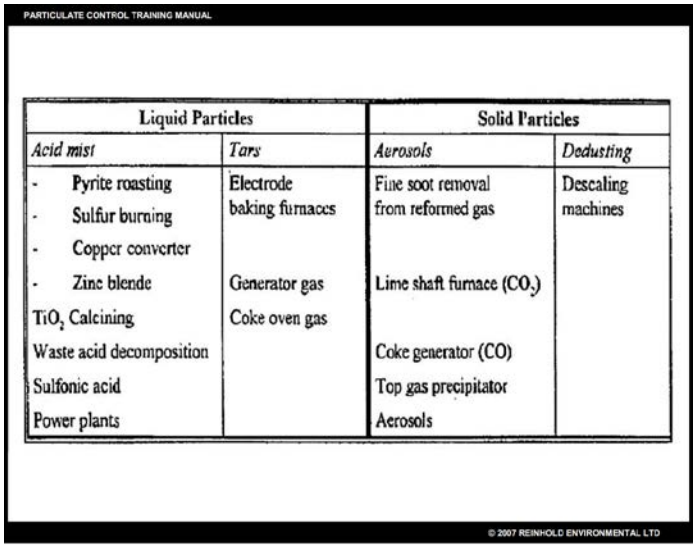
Current Density as a Function of Applied Negative Voltage

1.9 Wet ESP Designs

Wet ESP Technology

Introduction.

The first commercial electrostatic precipitator of the Cottrell design was a wet electrostatic device sold to the Anaconda Copper Company for sulfuric acid mist application at Selby, CA and at the Pinole Gunpowder Plant, also in California.



Liquid Particles		Solid Particles	
Acid mist	*Tars*	*Aerosols*	*Dedusting*
- Pyrite roasting - Sulfur burning - Copper converter - Zinc blende	Electrode baking furnaces Generator gas	Fine soot removal from reformed gas Lime shaft furnace (CO_2)	Descaling machines
TiO_2 Calcining	Coke oven gas		
Waste acid decomposition		Coke generator (CO)	
Sulfonic acid		Top gas precipitator	
Power plants		Aerosols	

Wet ESP Applications
(Courtesy of Lurgi)

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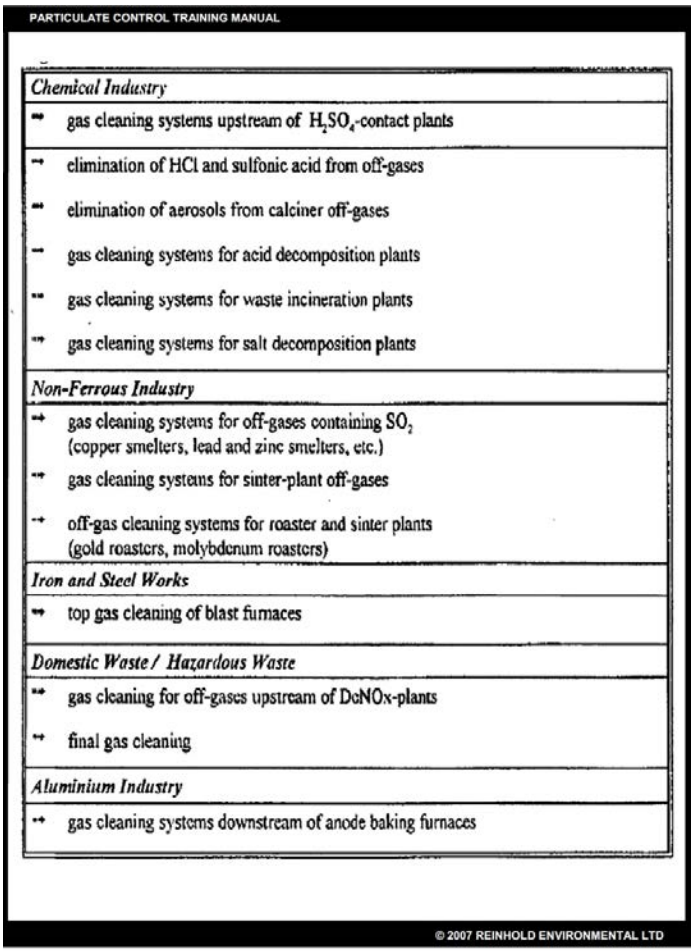
In wet ESPs, particles or droplets which have been electrically charged are transported in the direction of a collecting electrode which is covered by a descending liquid film, in contrast to the dry-type ESP. The strengths and weaknesses can be described as follows:

Advantages of wet-type ESPs.

- No problems in connection with dust resistivity (too high - back corona; too low - re-entrainment). Resistivity is never a problem since the collecting electrode is in fact a film of water or other liquid.
- Re-entrainment is not a problem since the liquid film effectively traps the collected material in the liquid film, which forms the collecting electrode. Successful wet electrostatics operate at velocities of up to 18 feet/second (5.5 m/sec).
- No rapping losses. There are no rapping devices and no need to optimize rapping to avoid puffing.
- Higher flow velocities viable because already collected particles are not entrained.
- Ability to separate liquid, pasty and sticky particles, besides solid particulate matter.



Wet ESPs in Various Industries
(Courtesy of Lurgi)

Disadvantages of wet-type ESPs.

- Potential for corrosion.
- Specifically more expensive because in most cases higher grade construction materials have to be used.
- The separated product occurring in suspension or solution must frequently be subjected to further treatment.
- Offgases are mostly discharged to atmosphere water vapor saturated, and this may lead to water vapor plumes which are an optical nuisance unless reheating is provided.

Because of the aforementioned advantages and the high collection efficiency attainable, there are many applications for particulate collection as shown in **Figure:**

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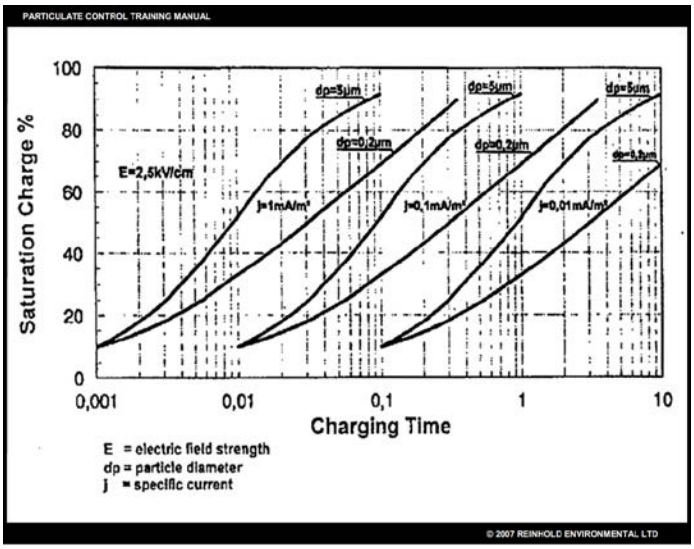
broken down by particulate type and in **Figure:**

by Industry.

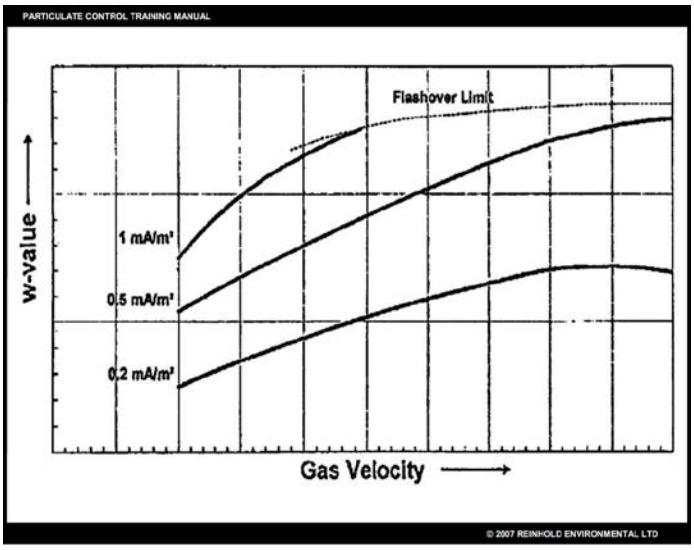
Essential Factors of Influence for Particulate Collection

Wet ESPs are high-performing collectors by which even submicron particles can be separated efficiently. **Figure:**



Particle Charge as a Function of Charging Time
(Courtesy of Lurgi)

shows the attainable saturation charge as a function of charging time for both particles less than 1 µm (diffusion charge) and particules greater than 1 µm (impact charge) in accordance with the evaluation of the equations by Dr. Harry White. It is evident that for submicron particulates in particular the charging current is of paramount importance with respect to short retention times, high migration velocities which lead to high collection efficiencies (**Figure:**



w-value as a Function of Spec. Current and Gas Velocity
(Courtesy of Lurgi)

).

Wet ESPs - Designs/Processes.

Wet ESPs have one characteristic in common, namely that the collecting electrodes act as carriers of a liquid film. Based on this characteristic different designs and different process modes have been developed.

Tubular/Honeycomb type (vertical gas flow):

This is the conventional design of wet ESPs. Typical applications are: sulfuric acid production, titanium dioxide production etc. In many cases a nozzle system is installed to achieve the necessary electric conductivity on the collecting plates. State-of-the-art wet ESPs are furnished with collecting electrodes made of

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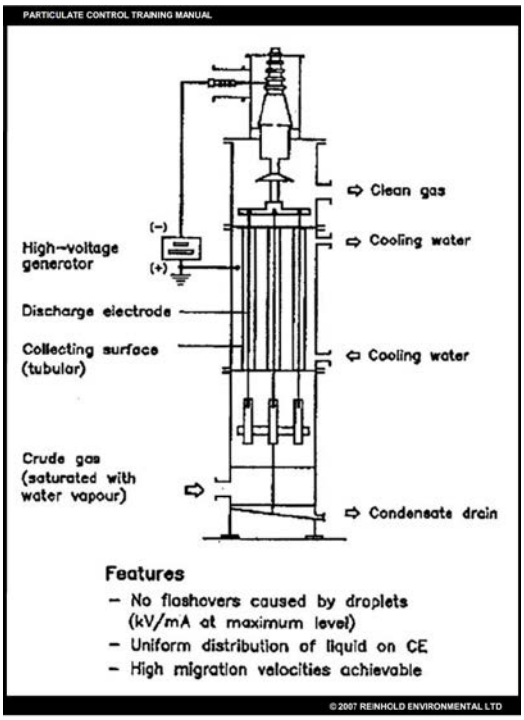
plastics. This has an advantage in that a light-weight design can be applied which can be largely prefabricated in the workshop. What is more, these materials exhibit effective resistance to corrosion and consequently low maintenance costs when offgases have to be treated which contain acid components like HCl, SO_2, HF.

Condensing type (vertical gas flow):

Cooling water is led around the collecting plates with condensation occurring on the inner side of the tubes. Since no water droplets are in the gas passage, no flashovers can be caused by droplets and the high tension and subsequently charging currents can be kept at the maximum level (**Figure:**

Condensing-type ESP Principal Sketch

). No nozzles have to be applied. The main applications of this precipitator type are the secondary dust collection from offgases originating from the thermal treatment of hazardous waste, contaminated effluents and production residues.

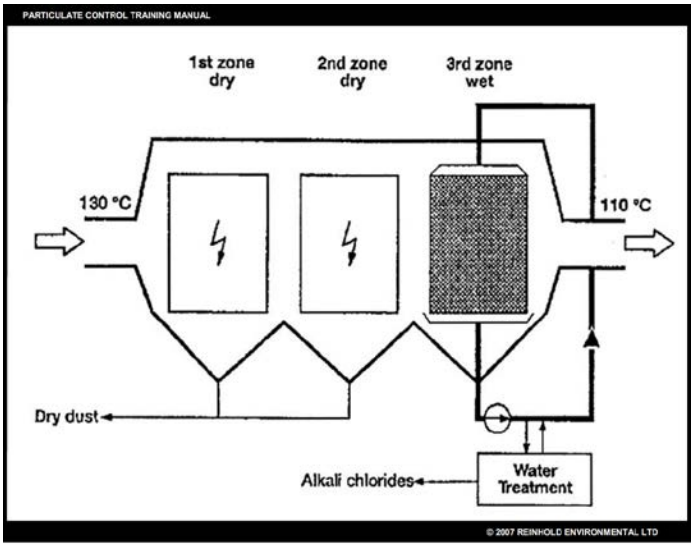


Condensing-type ESP Principal Sketch
(Courtesy of Lurgi)

Hybrid ESP (horizontal flow):

In this design, the last field of a dry ESP is replaced by a wet ESP. In a special application with large gas volumes, this design was modified with a water film running down the plates, eliminating the water spray. The flue gas is not saturated in the hybrid design, merely cooled by about 35° C. Therefore, reheating is not necessary and there will be no visible plume. The construction material of the box is standard steel. SO_3 can be efficiently separated, SO_2 and HCL slightly reduced, and particulate matter can be removed (**Figure:**

Principle Arrangement of Hybrid ESP



Principle Arrangement of Hybrid ESP
(Courtesy of Lurgi)

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).

Conventional Horizontal WESP:

This design is suited for large gas volumes. The migration velocities are not so high as in tubular ESPs. The flue gas is saturated and most of the material must be stainless steel because of the corrosion hazard. This precipitator type is suitable for the collection of particulate matter from power plant offgases and in the steel industry.

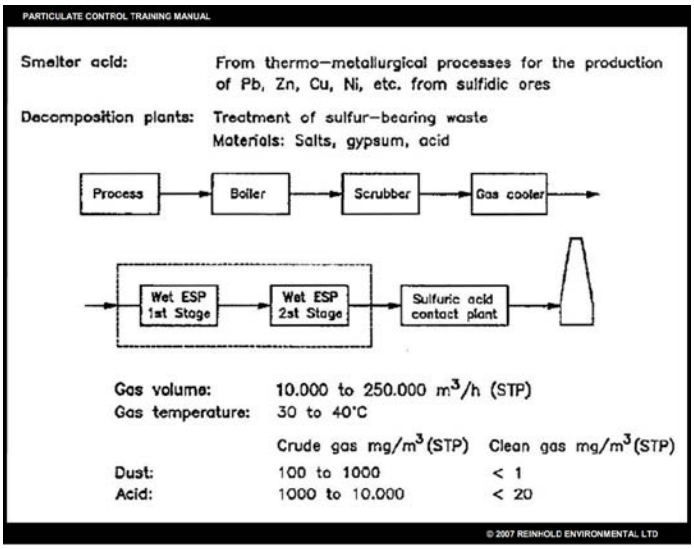
Applications of Wet ESPs.

Some applications of wet ESPs should be described as well as their position within gas cleaning chains.

It should be mentioned in principle, that for the cases described in part purpose-developed wet ESP designs are available. The construction materials used for wet ESPs range from simple steel grades right down to special materials (lead, Hastelloy, titanium) and from coated steels to the application plastic materials.

Metallurgical Processes including Sulfuric Acid Contact Plants/Sulfuric Acid Decomposition Plants:

The most frequent application of wet ESPs is for the removal of extremely fine dust and sulfuric acid from SO_2-containing process gases. These process gases are principally generated in metallurgical processes in connection with the production of copper, zinc and lead from sulfidic ores or in decomposition plants (**Figure:**



Sulfuric Acid Production
(Courtesy of Lurgi)

Sulfuric Acid Production

). Wet ESPs are able to dedust the process gas to residual dust contents of less than 1 mg/m3 (0.0004 gr/acf) (STP) and sulfuric acid mist contents of less than 20 mg/m3 (0.008 gr/acf) (STP). Wet ESPs (normally in two-stage design) serve to safeguard the quality of the sulfuric acid pro-duct (dust collection) and for protecting the heat exchangers in the sulfuric acid plant from corrosion (removal of sulfuric acid mist).

Waste and Hazardous Waste Incinerators:

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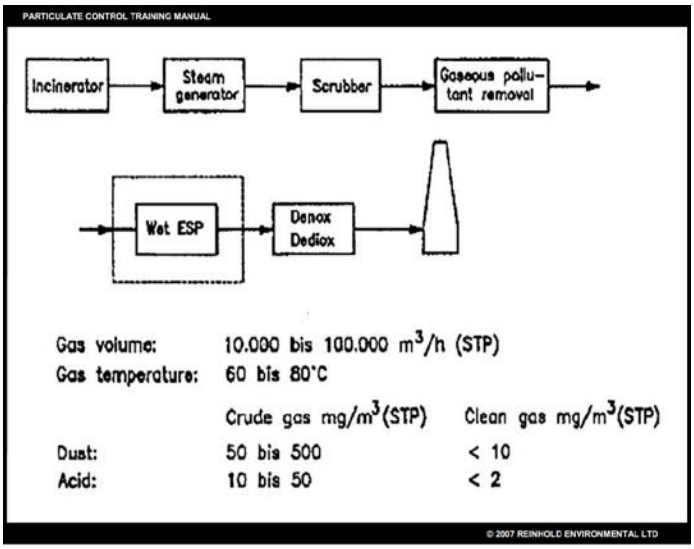
In this case, wet ESPs serve for the secondary dust collection downstream of scrubbers. The dust contents after the single-stage wet ESP are below 10 mg/m3 (0.004 gr/acf) (STP) (partly below 2 mg/m3 (0.0008 gr/acf) (STP)). If another offgas cleaning section reacting sensitively to sulfuric acid and or other aerosols is arranged downstream, the wet ESP is also designed to separate these aerosols (**Figure:**

Wastes/Hazardous Waste Incineration

).



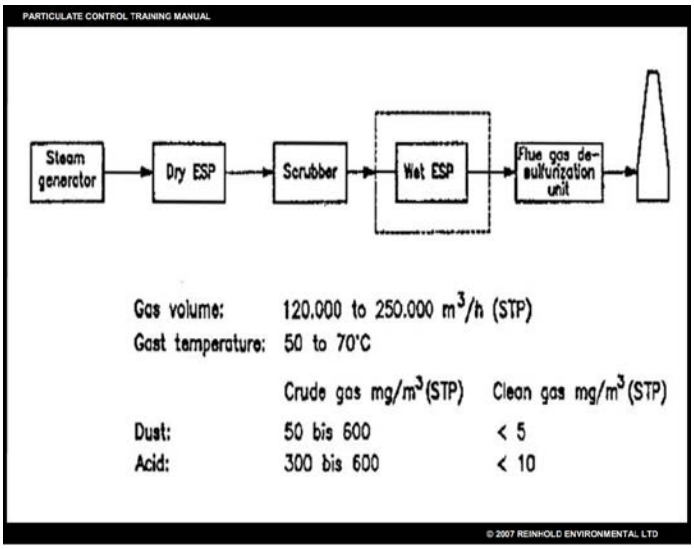
Wastes/Hazardous Waste Incineration
(Courtesy of Lurgi)

Power Stations (especially power stations in refineries):

These power stations are designed to burn distillation residues. These residues have high contents of catalytically active substances. These substances (mainly vanadium) convert most of the SO_2 to SO_3. Consequently, sulfuric acid aerosols are forming in the wet scrubber. These aerosols are collected in wet ESPs arranged either upstream or downstream of the flue gas desulfurization unit. If the wet ESP is arranged upstream of the flue gas desulfurization unit, this has an additional advantage in that together with the sulfuric acid mist also dust is separated so that the gypsum from the flue gas desulfurization unit occurs in are largely pure form (**Figure:**

Power Stations in Refineries

).



Power Stations in Refineries
(Courtesy of Lurgi)

Further Applications

Tar Removal:

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In this application, wet ESPs remove tar mists and dusts from the offgas of coke oven batteries and/or burning furnaces (annular chamber furnaces for anodes used in electrolytic aluminum plants). The wet ESPs applied for this purpose are made from metallic materials. It should be mentioned that the gas in the wet ESP consists of H2 and CH4 for the most part. The presence of oxygen should be monitored in order to safely avoid that the explosion limit can be reached under any circumstances with the high-tension system in operation. These applications which are very rare, also include the separation of low-boiling hydrocarbons and soot from the offgas of petrochemical decomposition plants. Up until today wet ESPs have occasionally been applied for the separation of chlorine vapors from chlor-alkali electrolysis plants and for the separation of sulfonic acid in connection with sulfonic-acid production.

Calciners:

In this application, dust and sulfuric acid mists are removed from the calcining furnace offgas by a wet ESP arranged downstream of a scrubber/quencher. The dust contents are below 20 mg/m3 (0.008 gr/acf) (STP) and the sulfuric acid contents, below 30 mg/m3 (0.012 gr/acf) (STP). In this case, the plastic wet ESPs are operated at temperatures of up to 80°C (176°F).

1.10 ESP Doors

The importance of good access doors in air pollution control equipment should not be overlooked. Loss of efficiency, interior corrosion and equipment deterioration due to inadequate insulation and leakage are obvious problems and should be of prime concern. However, the ease of access may be equally important because it will enhances the speed and thoroughness with which inspections and maintenance tasks are performed. The minimum requirements for good access doors are few and obvious:

- They must be gas/liquid tight.
- The seals must be reliable through many operations.
- They must be safe and easy to open and close.
- The insulation, where required, must be durable and efficient.
- They must be easy to get through.

As plant personnel will testify, there are many existing doors in the power plants, which do not meet these basic requirements. To better understand what makes a difference in door quality it is helpful to carefully look at each basic requirement in greater detail.

Doors must be gas/liquid tight.

- Any leakage will theoretically result in some loss of equipment efficiency. This should be a fundamental reason to require tightness.
- In-leakage into ducts and equipment can cause serious acid condensation and corrosion damage on door frames, casing walls and expensive internals, especially in a cold climate and with high sulfur content in the flue gases.

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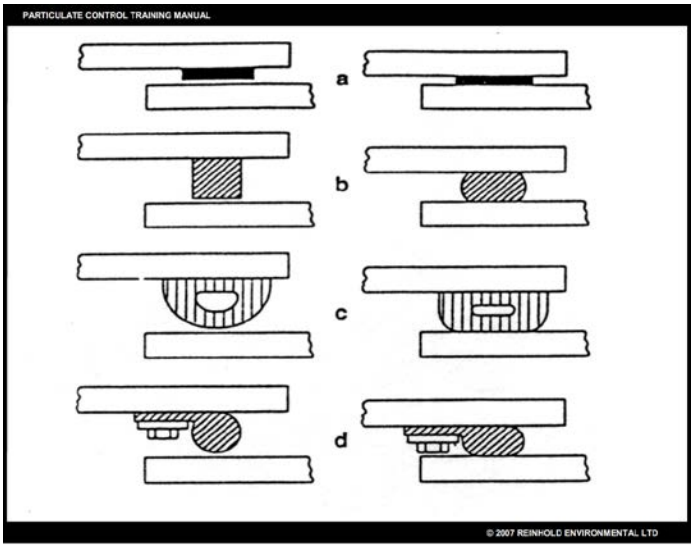
The seal must be reliable.

Seals must be reliable, so that plant personnel do not have to adjust, repair or replace seals each and every time the door is used. The main sealing methods for access doors are generally one of the following:

- Rigid door construction, i.e. usually a cast door with machined contact surfaces and often with a rather thin gasket.
- A less rigid door using a rather small gasket and several "dogs" around the perimeter.
- A flexible door with a heavy, flexible gasket.

Operational data suggest that the flexible door with heavy gasket is the best method.

The sealing gasket can be placed on either the door frame or the door plate. Placement on the frame should be avoided unless the gasket is hidden in a groove or otherwise shielded from abuse since traffic through the open door will invariably cause damage to an exposed gasket especially in the area below the opening.



Gasket Shapes

Gasket material will contribute to seal reliability. Sealing gaskets are available in many materials and shapes and can be divided into two main categories; fibers and elastomers. There are several brand names and choices of specialties for different applications. Some brands are made as a combinations of both categories.

The fibers can be anything from heat resistant metal alloy wool to glass fiber. The fibers are usually braided or woven and shaped into the desired profiles. Woven or braided ceramic fiber gaskets are mostly used for gas temperatures above 400°F (205°C). Some are slightly porous and may breathe a little, especially when new. This slight leakage is usually too faint to cause any concerns with negative pressure, but it will cause exterior corrosion with positive pressure and corrosive gases.

Most elastomer gaskets will only serve at gas temperatures below 400°F (205°C). An example is the expensive fluoroelastomer gaskets which can take excursions above 600°F (315°C). These molded, or extruded gaskets, can be made either as a closed cell sponge or as a solid profile with or without a hollow core. Fluoroelastomer sealing gaskets can give a completely tight seal even for liquids under positive pressure if they are correctly designed, manufactured and installed and receive reasonable maintenance. Examples of gasket shapes can be seen in **Figure:**

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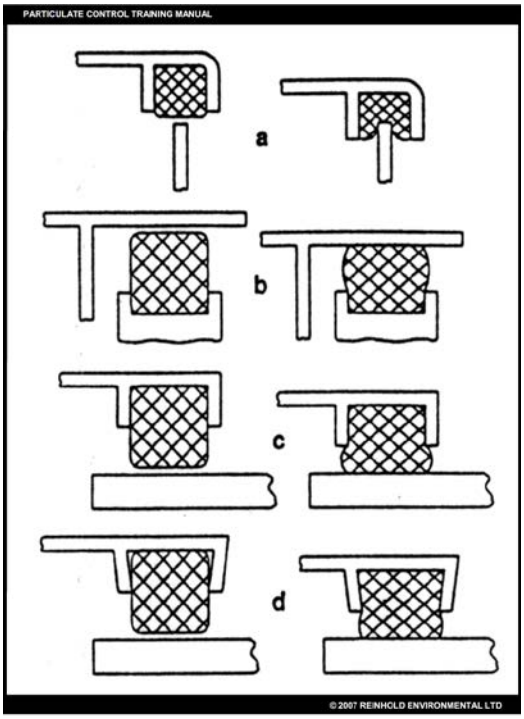
Gasket Shapes.

There are different ways to seat gaskets and to use them for sealing. For braided ceramic fiber gaskets, the most common method is the "knife edge design" shown in **Figure:**



Different Ways to Seat Gaskets
(Courtesy of IMTEC)

Different Ways to Seat Gaskets - View a

. This is fine for the first closing, but usually leaks after just a few closings. **Figure:**

Different Ways to Seat Gaskets - View b

shows a poor design sometimes seen for elastomer or braided ceramic fiber gaskets. Even if adhesive is used, the groove in this common example is made far too shallow to retain the gasket after even the first cycle of operation. The method in **Figure:**

Different Ways to Seat Gaskets - View c

may be acceptable for braided ceramic fiber gaskets, but **Figure:**

Different Ways to Seat Gaskets - View d

shows an even better method where a square gasket in compression will adopt the dovetail shape of the grove. The tadpole gasket shown in View d will make a good seal if the placement and strength is adequate to prevent damage and the size is ample enough to prevent the fastening screws from touching the seal surface. Retainer strips and screws must be rather heavy and in good quality stainless steel to prevent deterioration.

For elastomer gaskets, the methods of seating also include bonding. This gives the freedom to use gasket profiles with an ideal shape for sealing and resistance to abuse. The gaskets themselves must also be reusable many times. This requires a low compression set for the gaskets, not only in the laboratory, but also when inhibited by the way they are retained on the door and deformed when the door is closed. This deformation is what makes the very common "knife edge design" less appealing after the first few cycles.

Doors must be safe and easy to open and close

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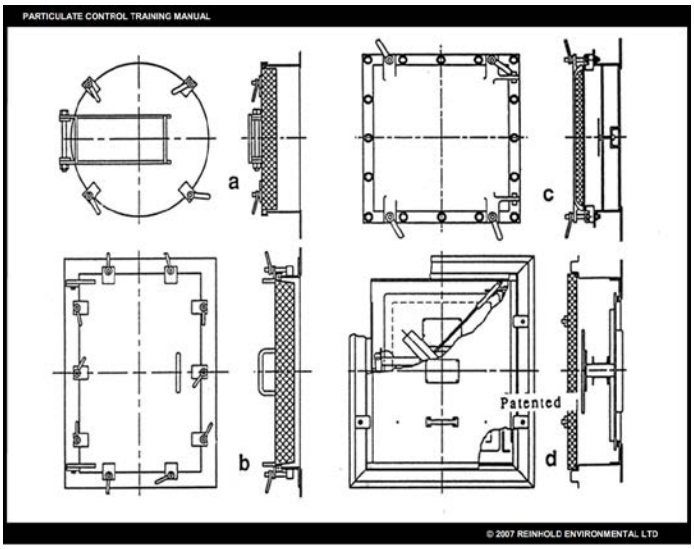
Doors, which are easy to open and close, will enhance interior equipment inspections and maintenance. Typical door types are shown in **Figure:**

Typical Door Types.



Typical Door Types
(Courtesy of IMTEC)

Even after years of service a door should be able to be opened and closed by hand in just seconds without the use of any tools and without any service of a maintenance crew. This requires a small number of closing devices on each door, non-corrosive hardware and a design heavy enough to stand up to abuse. An example in **Figure:**

Typical Door Types - View d

is the IMTEC door with only one or two stainless steel closing mechanisms.

When opening this door type a feature in the mechanism retracts the door plate from the frame, thereby pulling any sticking sealing gasket away from its contact surface. This door type also has a safety mechanism, which prevents the door from being opened if there is a dangerous gas pressure inside.

Appropriate warning signs of durable quality must be placed on access doors. On electrostatic precipitators, all doors must have key interlock systems, which can be field installed with little difficulty. In hoppers and other places where material can build up behind closed doors, it is mandatory that the doors be equipped with a safety chain with easy hook-on features. The chain should be just long enough to allow probing behind the door for a deadly avalanche of material.

Occasionally there are requirements for doors to be lockable in open position. This is relevant for doors with "dogs" which could conceivably fall into their closed position if the door gets slammed closed thus trapping personnel inside. Suction from induced draft on large doors can also prevent opening.

Door insulation must be durable and efficient

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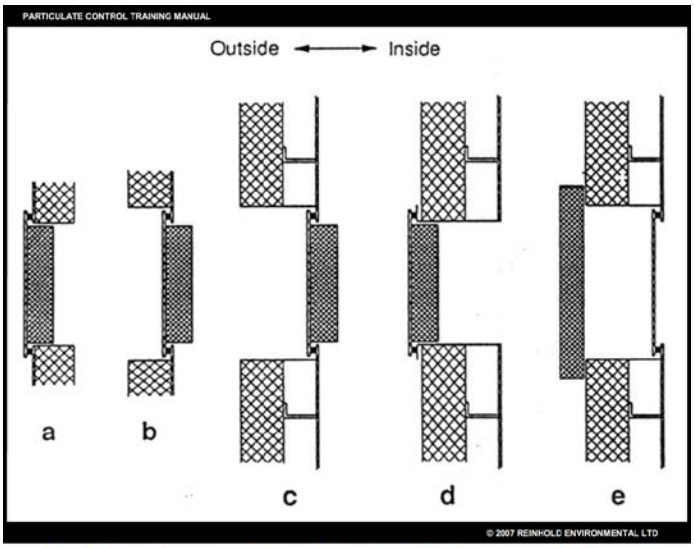
If an insulated door is required it is important to define why it is or should be insulated. Doors are insulated for one or more of these four different reasons:

- To protect personnel from being burned by high temperatures.
- To protect doors from being damaged by temperatures.
- To prevent cooling of process gases and loss of system efficiency.
- To protect against interior acid condensation and corrosion.



Combinations of Typical Insulated Doors on Different Insulated Walls
(Courtesy of IMTEC)

The last reason is the one least understood. This can be seen in many plants where ducts and air pollution control equipment for high sulfur flue gases below 370°F (188°C) are incorrectly equipped with just insulated, single doors. Only insulated, double doors like **Figure:**

Combinations of Typical Insulated Doors on Different Insulated Walls - View e

can prevent acid condensation and corrosion on the door frames and the surrounding casing walls.

Figure:

Combinations of Typical Insulated Doors on Different Insulated Walls

shows schematically a few combinations of typical insulated doors on different, insulated walls. SCR units and other air pollution control equipment with about 700°F (370°C) should normally be able to use single doors as shown in **Figure:**

Combinations of Typical Insulated Doors on Different Insulated Walls - Views b or c

. However, in low load modes or if the equipment is partly by-passed there may be situations with low temperatures, which could lead to acid condensation and corrosion around the doors.

Doors must be easy to get through

It is still common to see 24" (61cm) round or square doors in new ducts and air pollution control equipment. This may be adequate for hoppers and roof access, but for side access it is hardly conducive to enthusiastic internal maintenance. Side access doors should not be less than 30" (76cm) tall and 18" (46cm) wide. This size allows an average size person to "step through" the

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door rather than "crawl through", provided it is installed in the correct elevation, i.e. with the centerline 39" (100cm) over the walkway. A sturdy grab handle should be installed approximately 12" (30cm) above the door opening.

Adequately sized doors are also advantageous for craft personnel during the construction phase. Larger doors can play a role in safety in confined space work rule requirements. OSHA requires 24" (61cm) width for stretchers.

Other miscellaneous items

- Inner face of door should be about flush with the inner casing wall to prevent build up of material in a pocket inside the door as shown in **Figure:**

Combinations of Typical Insulated Doors on Different Insulated Walls - View d

- The exterior parts of the door should extend beyond the side wall as little as possible to assure good clearance on passing walkways.
- Door sag may inhibit easy closing. Even if "alignment bosses" are provided at the bottom of the door, this may cause misalignment of closing surfaces and leaks, especially in combination with the "knife edge" seal shown in **Figure:**

Different Ways to Seat Gaskets - View a.

- Corroded or not, carbon steel lugs require tools for opening and closing and cause breakage and bothersome repair.
- Overall rugged design is necessary to take the many years of abuse and heavy handling during outages when heavy tools and parts are passed through the opening.

1.11 Photographs of Typical RDE Designed ESPs

ESP Casings

ESP Casing: On-site Erection of Two Chamber ESP

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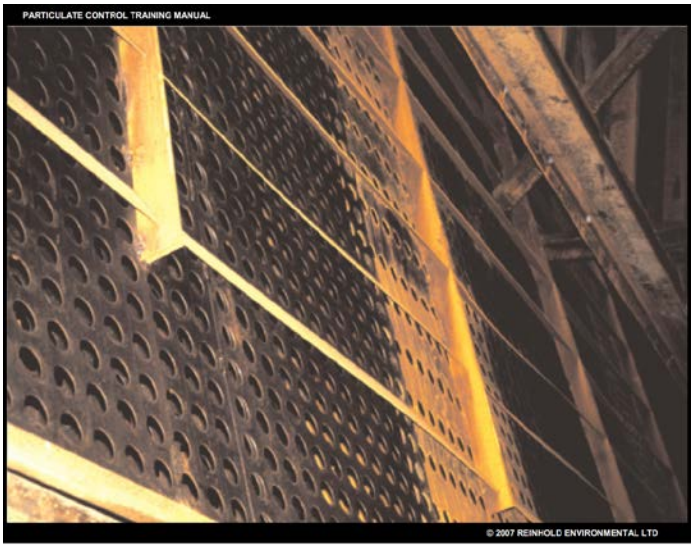
ESP Casing: Shop Fabrication and Assembly

The start of the erection of a new two chamber precipitator. The two side frames and the partition frame separating the two chambers have been erected and tied together with the top and bottom inlet and outlet end frames. The casing is ready for the installation of the collecting and discharge electrodes through the roof opening.

The fabrication and assembly, in a horizontal position, of a precipitator casing vertical side frame.



Perforated Plates

Perforated Plates

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Perforated Plate Installation

Collecting Plates

Assembly of Roll Formed Collecting Electrode Strips into an Interlocked Collecting Electrode Module

Method of assembly of the two roll formed
collecting electrode strips into an interlocked collecting electrode module. Note the tadpole support on top

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Fastening of the collecting electrode rapper bar to two collecting electrodes. Looking down you can see the RDEs between the collecting electrodes.

Fastening of the Collecting Electrode Rapper Bar to Two Collecting Electrodes

Assembled collecting electrodes are store in bundles to prevent distortion of individual assemblies.

Assembled Collecting Electrodes are Stored in Bundles to Prevent Distortion.

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Collecting electrode assemblies are lifted in vertical bundles to prevent handling problems with individual plates in the wind.

Collecting Electrode Assemblies are Lifted in Verticle Bundles to Prevent Handling Problems

The vertical collecting electrode bundles shown here are stored in the precipitator waiting to be installed in proper position and fastened in support.

Vertical Collecting Electrode Bundles Stored in the Precipitator Waiting to be Installed

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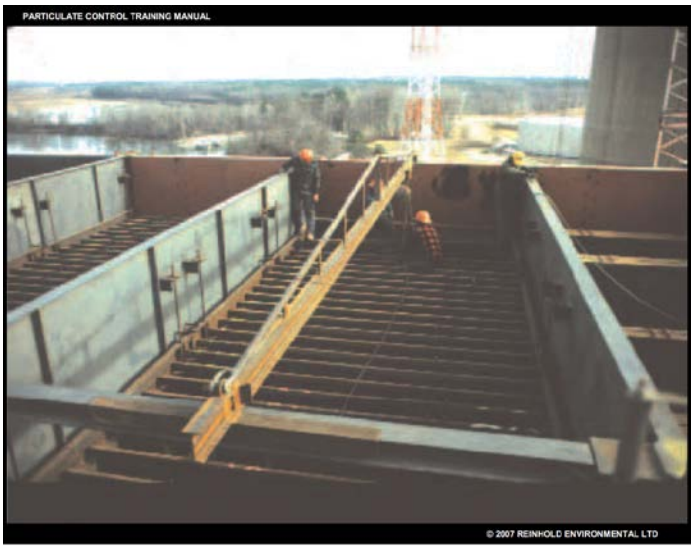
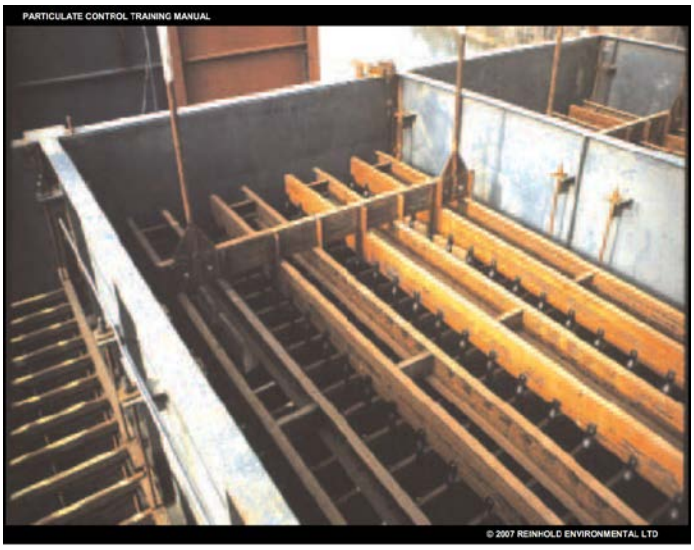
This photograph shows the collecting electrode support tension bolts to the left.



Collecting Electrode Support Tension Bolts

Rigid Discharge Electrodes

The RDE Discharge Electrode frame is resting on the tops of the collecting plates before the installation of the hot roof and the raising of the frame to its final position.



RDE Discharge Electrode Frame Rests on the Tops of the Collecting Plates before the Installation

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The RDE upper frame is raised into position. Note the collecting electrode rapper bars are in position and the hot roof is installed.

RDE Upper Frame is Raised into Position

The bottom, or lower frame, of the RDE Discharge Electrodes.

The Bottom, or Lower Frame, of the RDE Discharge Electrodes

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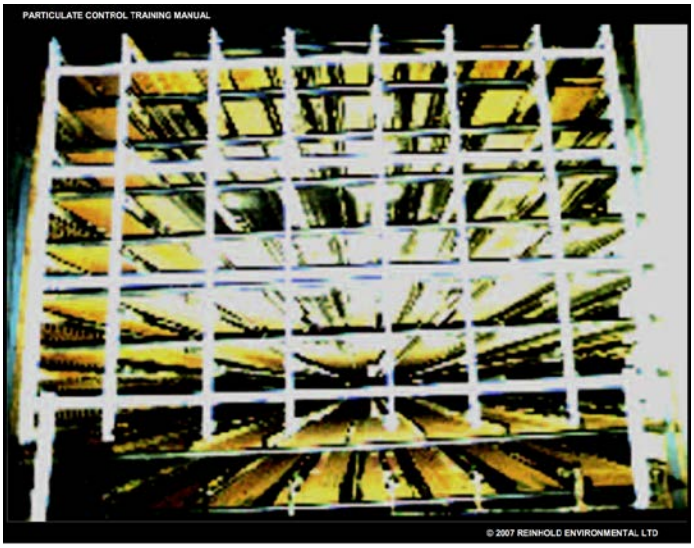
Bottom, or lower frame, of the RDE Discharge Electrodes looking up from hopper.



Bottom, or Lower Frame, of RDE Discharge Electrodes Looking Up from Hopper

The RDE is fastened to its support frame as shown in this picture.

RDE Fastened to its Support Frame

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Rappers

The individual collecting electrode rappers on top of the cold roof are shown here.

Individual Collecting Electrode Rappers on Top of the Cold Roof

Protector tube (volute) where the high voltage hanger pipe penetrates the hot roof.

Protector Tube (volute) where the High Voltage Hanger Pipe Penetrates the Hot Roof

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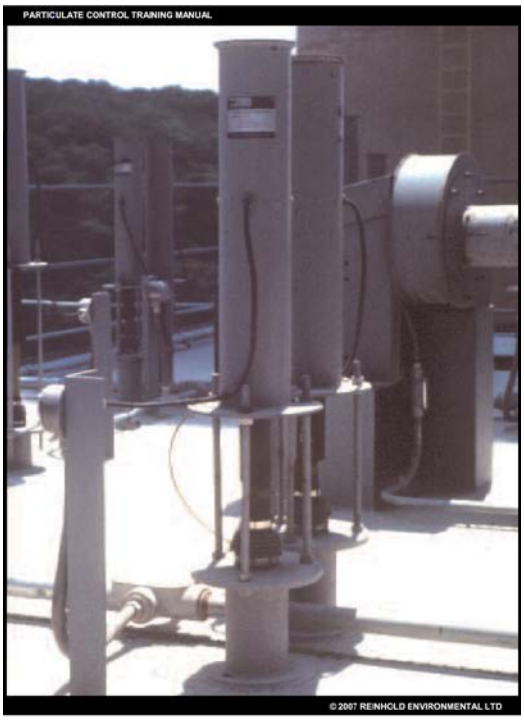
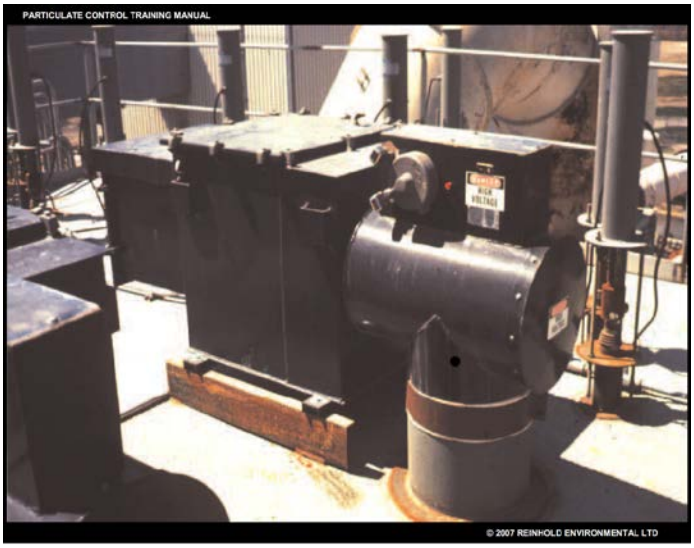
Collecting electrode impact rappers on the cold roof of the insulator housing.



Collecting Electrode Impact Rappers on the Cold Roof of the Insulator Housing

Electrical Equipment



High Voltage Transformer Rectifier Assembly with Bus Ducts Connected

High voltage transformer rectifier assembly with bus ducts connected. The high voltage bus ducts are not covering the side mounted high voltage outputs.

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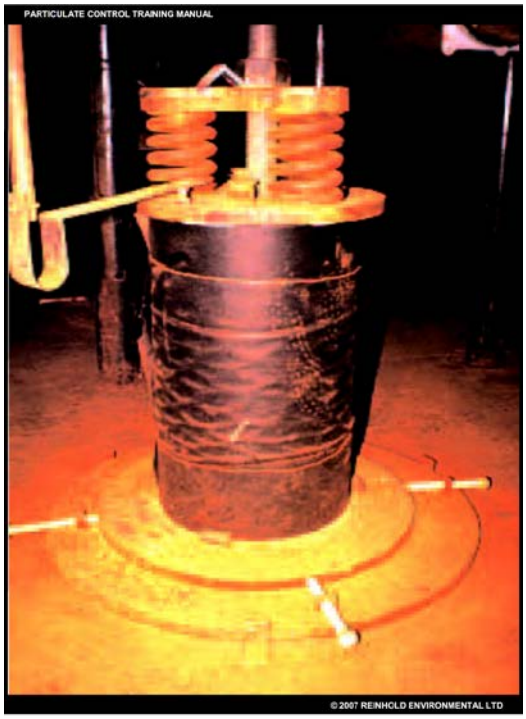
The access door on this transformer-rectifier control unit is open, showing the power components and wiring as well as the automatic control and instruments.

Transformer Rectifier Control Unit Showing the Power Components and Wiring

Insulators

Support insulator in top housing that is wrapped for integral heat insulation.



Support Insulator in Top Housing that is Wrapped for Integral Heat Insulation

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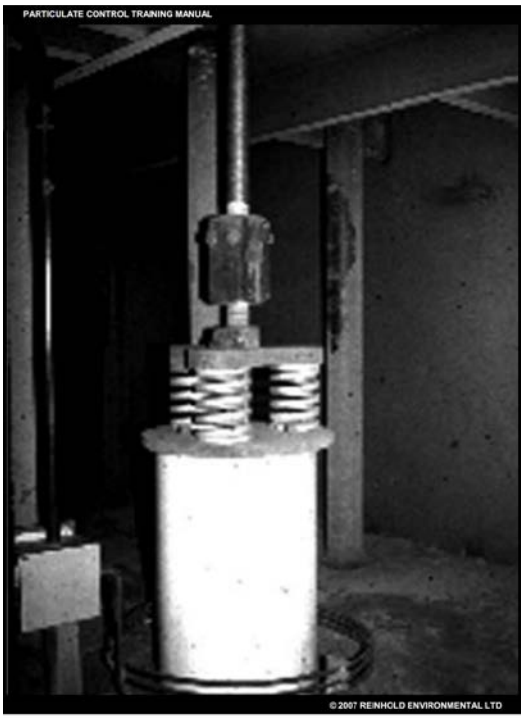
Note the electric strip heaters at the bottom of this support insulator in top housing.



Electric Strip Heaters at the Bottom of this Support Insulator in Top Housing

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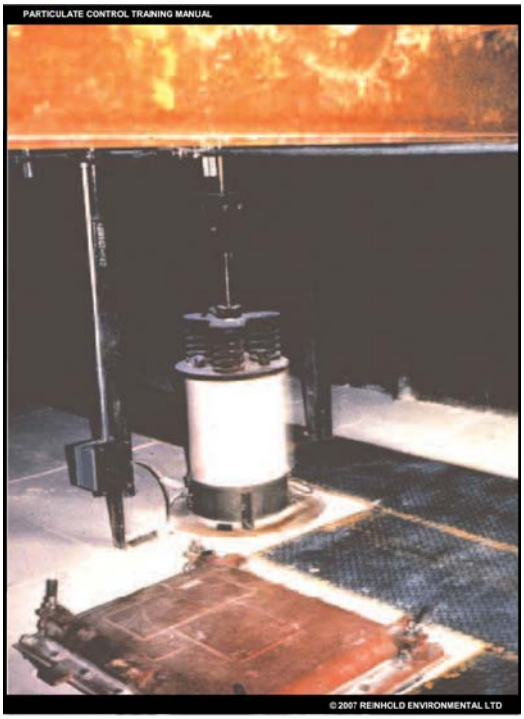
The inside of the top insulator housing. Note the hot roof collecting electrode rapper bars, HT rapper bars, support insulator and access ladder from cold roof.

The inside of the insulator housing, the hot roof, support insulators and access doors through the hot roof.



Insulator Housing, the Hot Roof, Support Insulators and Access Doors through the Hot Roof

Access Doors

Side Access Door on the Precipitator

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Side access door on the precipitator, not a removable heat insulation panel.

Note the key interlock and chain on this roof access door.

Key Interlock and Chain on Roof Access Door

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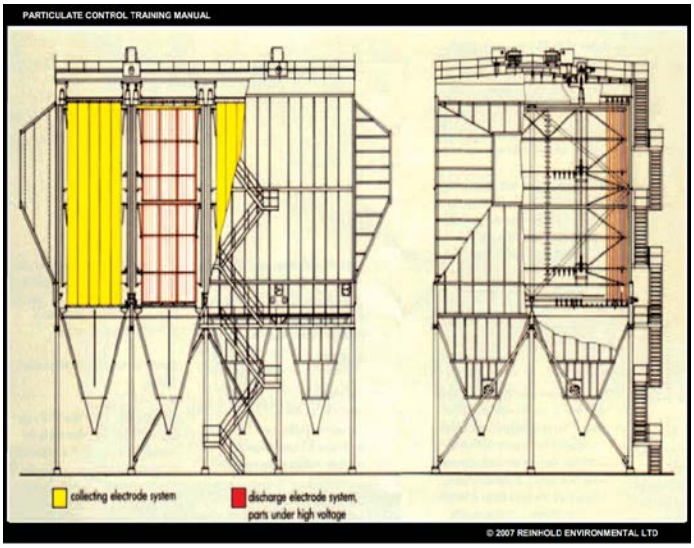
CHAPTER 2 - OEM DESIGNS FOR ELECTROSTATIC PRECIPITATORS & FABRIC FILTERS

This chapter discusses the history of ESPs and the Original Equipment Manufacturer (OEM) designs for Electrostatic Precipitators (ESPs), including:

- ***Joy Western (The Babcock & Wilcox Co.)***
- ***Research-Cottrell (Hamon Research-Cottrell)***
- ***Koppers/Environmental Elements Corp. (Clyde Bergemann EEC)***
- ***Lodge-Cottrell/Lodge Sturtevant (Korea Cottrell)***
- ***FLS Miljo AS (FLSchmidt Airtech)***
- ***Wheelabrator (Siemens)***
- ***Flakt/ABB (Alstom Power)***
- ***Buell, Envirotech, GEESI (Hamon Research-Cottrell)***
- ***Belco Technologies (LAB SA)***
- ***Walther (Balcke-Durr GmbH)***
- ***Lurgi (GEA Bischoff; Allied Environmental)***
- ***ELEX***



Walther Horizontal Type ESPs

2.1 ESP History

Vendors (OEMs), either directly or indirectly, provided much of the information in this chapter. Although some of the subjective claims have been edited out, in deference to the vendors, we tried not to edit their material significantly. As a result, information may contain vendor claims that are not necessarily supported by Reinhold Environmental, Ltd.

This chapter consists of material that was made available prior to the time of publication. In cases where no information was provide by a vendor, Reinhold Environmental used information from its consultant's files. Every effort was made to verify the accuracy of this information, however it cannot be guaranteed to be completely correct.

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U.S. Companies.

In 1906 Dr. Frederick Gardner Cottrell, at the University of California, discovered a practical and commercially successful way in which to apply the principles of Electrical Precipitation.

Dr. Cottrell's experiments extended to the sulfuric acid works of E. I. DuPont de Nemours, at Pinole, on San Francisco Bay. The experiments at Pinole led to a commercial installation, in 1907, at the nearby Selby Lead Smelter, for the collection of sulfuric acid fumes escaping from the gold and silver parting kettles. These fumes had become the source of serious litigation and, before the advent of Electrical Precipitation, no satisfactory method had been found for their abatement.

After the practical demonstration of the success of electrostatic precipitation, the International Precipitation Company was organized in 1907 as a holding company to administer the patents throughout the world. The founders of this company were Dr. Cottrell and three alumni of the University of California, which included Professor Edmund O'Neill, Dr. Harry East Miller and Mr. E. S. Heller.

These men at the same time also organized the Western Precipitation Company, as a wholly owned subsidiary, to undertake the commercial development of the process in the State of California. One of Dr. Cottrell's University associates, Allen C. Wright, and two of Cottrell's former students, Harry A. Burns and Walter A. Schmidt, joined the staff of the Western Precipitation Company, with Cottrell serving as technical consultant.

In 1910, Walter A. Schmidt took over the rights to the process of electrostatic precipitation for the Portland cement industry.

At that time the dust arising from the rotary burning kilns of the Riverside Cement Company, in Southern California had become the cause of serious damage suits filed by the nearby orange growers. After a year of study and experimentation, the problem of treating these hot kiln gases was successfully solved and a large commercial installation was built to treat approximately one million cubic feet of gas per minute. This installation was put into operation in 1912.

In 1911 Dr. Cottrell resigned his professorship at the University of California and joined the staff of the United States Bureau of Mines, of which he later became director. He and his business associates in the International Precipitation Company offered their patent rights for the United States, east of the six Western Precipitation states, except for the Portland cement industry, to the Smithsonian Institute, as an endowment for scientific research.

The Smithsonian Institute was not equipped to administer these patent rights and suggested that a special organization be founded for this purpose. This led to the formation of the Research Corporation of New York, to operate in all states not allocated to Western Precipitation Company excepting the cement industry to which Western Precipitation owned exclusive rights. Research Corporation was a non-profit organization devoting its entire income from the

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Electrical Precipitation process to the promotion of independent scientific research in various universities, the Smithsonian Institute and other scientific bodies.

During the same year, the Western Precipitation Company was acquired by Walter A. Schmidt and his associate, H. M. Mosher, and its field of activity was enlarged to embrace the six Western states of the United States and the Portland cement industry throughout the United Slates. They also acquired an option to purchase the International Precipitation Company. Headquarters were moved from San Francisco to Los Angeles, and Walter A. Schmidt became President and General Manager.

Subsequently, a complete reversal of the relations of the two original precipitation companies took place. Western Precipitation Company acquired its former parent, the International Precipitation Company, and thereafter successfully introduced the Cottrell Electrical Precipitation Process in all industrial countries throughout the world.

Under the continuous direction of Walter A. Schmidt, the Western Precipitation Company enjoyed a steady growth. In 1935 the Precipitation Company of Canada, Ltd. (PRECIPCO) was organized as a wholly owned subsidiary. In 1936 the company was reorganized without change of ownership and became Western Precipitation Corporation.

Through World War II, the Electrical Precipitation industry operated in the manner of a cartel. Territories were divided among licensees and competition was minimized. As a result of the Sherman Anti-Trust Act, a Justice Department ruling in 1947 cancelled all territorial agreements for Electrical Precipitation and extended Western Precipitation Corporation's territory to the entire United States. The ruling also resulted in the separation of Research Corporation from Western Precipitation and the formation of a Research Corporation subsidiary originally named Research-Cottrell Corporation and known today as Hamon Research-Cottrell.

In 1960, Western Precipitation was purchased by Joy Manufacturing Company and operated as a division of that company until 1987, after which point various changes of ownership have taken place. In 1996, Joy was acquired by Babcock & Wilcox.

European OEM Companies (as told by Dr. Richard Heinrich).

Dipl Ing Richard F. Heinrich, born in 1896, joined the precipitator division of the Siemens-Schuckert-Werke in Berlin in 1922 and was asked to investigate the considerable under performance of the electrostatic precipitator of the lignite-fired boiler installation of the Leuna works in Eastern Germany. The plant was equipped with wire mesh collectors. By actually observing the dust collection in the precipitator, he realized the deficiencies and developed highly efficient forms of collecting electrodes, the "catch space" type.

Equipped with these collectors, the plant performed better than guaranteed. Dr. Heinrich gave a full account of his development work in his dissertation and obtained the degree of Dr. Ing in 1932. In these tests he utilized in 1923 the design formula, later to become known as the

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"Deutsch formula".

Siemens decided in 1931 to transfer the installation business for precipitators to Lurgi in Frankfurt am Main but continued to supply the high voltage sets.

Dr. Heinrich joined Lurgi in 1937 where he worked as a project engineer. He was involved in precipitator development and continued to be responsible for the experience exchange which operated in the Siemens-Lurgi-Cottrell Association, composed of Siemens, Lurgi, Lodge-Cottrell in England and Research-Cottrell and Western Precipitation Corp. in the USA.

After the end of World War II the industries of the Allies were permitted under the terms of the armistice agreement to obtain industrial designs from all German companies. Simon-Carves Ltd. of Stockport, England, who was interested in expanding into the flue dust precipitator business, visited Lurgi and took with them the Lurgi precipitator design drawings. They met Dr. Heinrich during this visit.

The owner of Western Precipitation Corp., Mr. Walter A. Schmidt, wanted Dr. Heinrich to work for him in order to introduce more efficient designs. Dr. Heinrich went to Los Angeles in 1949 where he worked until 1951. Western adopted his "chute" type collecting electrode design with great success.

Simon-Carves offered Dr. Heinrich employment and a license agreement in 1951. He joined them in the autumn of that year as Chief Engineer of the newly founded precipitator division and worked for Simon-Carves until his retirement in 1961.

He concluded a license agreement with Walter & CIE A.G. in Cologne, Germany, in 1953 and, together with Simon-Carves, an agreement with CECA in Paris. The three companies cooperated in a joint experience exchange agreement.

In January 1959 Simon-Carves purchased Lodge-Cottrell in Birmingham, England, and the precipitator business was transferred to Lodge-Cottrell at the beginning of 1961. Lodge-Cottrell had Dingler-Werke A.G. in Zweibrucken, Germany, and SPIG in Milan, Italy, as licensees. Dr. Heinrich became an independent consultant to Dingler after he moved back to Germany. Shortly before his death in 1969 he concluded a license agreement, arranged by Dr. Senichi Masuda, with Mitsui in Tokyo which was executed by Nipponkai Heavy Industries in Toyama.

Dr. Heinrich's eldest son, Dipl. Ing Dieter O. Heinrich, born in 1926, entered the services of Simon-Carves as development engineer for mechanical and electrical dust collectors in 1950 after completing his engineering studies in Karlsruhe. He became a partner in Dr. Heinrich's license agreement with Simon-Carves. The company gave him leave of absence between 1955 and 1957 and he worked one year as head of Walther's new precipitator division.

Returning to Simon-Carves, he became responsible for projects and development and introduced his patented design of flat U-channel collecting electrodes which were rapped, unconventionally but more efficiently by impacts at right angle to the collecting surface (cross-rapping).

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After the take-over of Lodge-Cottrell, Dieter transferred to Birmingham and became Technical Director for continental projects until 1968 when he resigned from the company.

Dr. Heinrich's second son, Dipl. Ing, Gunter Heinrich, born in 1928, joined Walther in 1954 and worked in the precipitator division until 1958. He discovered in 1956, through an analysis of a great number of test results given to him by Dr. Heinrich, that precipitators with larger spacings worked well and thus conceived the concept of large collector spacings.

Full scale tests by Simon-Carves, made after Dieter's return, confirmed the concept and patents were applied for in England, France and Germany with Gunter, Richard and Dieter as inventors. For the British and French applications patents were granted but the German application was rejected after 15 years of examination on the grounds of an "insufficient level of inventiveness". The development of the large spacing concept was described for the first time by Dieter in a publication in “Staub” (no. 38, 1978).

Simon-Carves' partial rights in the British patent were transferred to Lodge-Cottrell but the company made no use of the invention. However, their licensee Dingler used the concept successfully in Lepol kiln applications. Also the Heinrich licensee Nipponkai Heavy Industries applied the concept successfully and Dieter, who had taken over the execution of Dr. Heinrich's license agreement after Dr. Heinrich's death, tried to introduce the concept more fully in the precipitator industry. A consulting agreement was concluded in 1975 with Research-Cottrell but no plant was built under the agreement. He also concluded consulting agreements with F. L. Smidth in Copenhagen and Svenska Flaktfabriken in Vaxjo, Sweden.

After a change in management Dingler showed no further interest in the German patent application and Dieter and Gunter concluded an agreement with Lurgi which took over the application until it was finally rejected by the German patent office in 1973.

2.2 Joy-Western (The Babcock & Wilcox Co.)

Since its inception in 1907, Western Precipitation has designed and installed thousands of precipitators in a variety of industries including: coal and oil fired power plants, steel, pulp & paper, sulfuric acid, copper and many chemical plants. Over the course of time, many design features have changed. Some changes resulted in great leaps forward, other changes may have been found to have lesser benefits than when first conceived. Below is a list of some of the design features, changes and options that were developed and/or utilized through the years.

During early development of electrostatic precipitators, collecting plate design was not firmly established. Differing designs were used. Early vintage collecting plates were just those, plain

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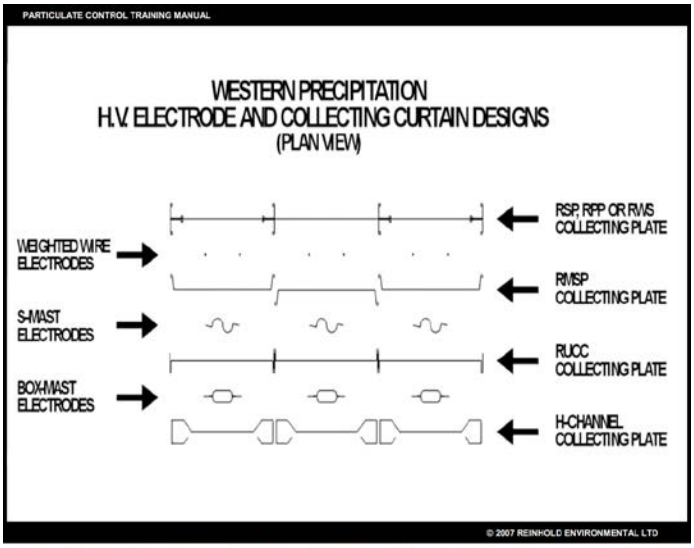
flat plates. It later became apparent that the plates could be stiffened to help alignment and that collection efficiency may be enhanced through the addition of ribs or baffles (**Figure:**

The Most Common Collecting Plate and Electrode used by Western Precipitation

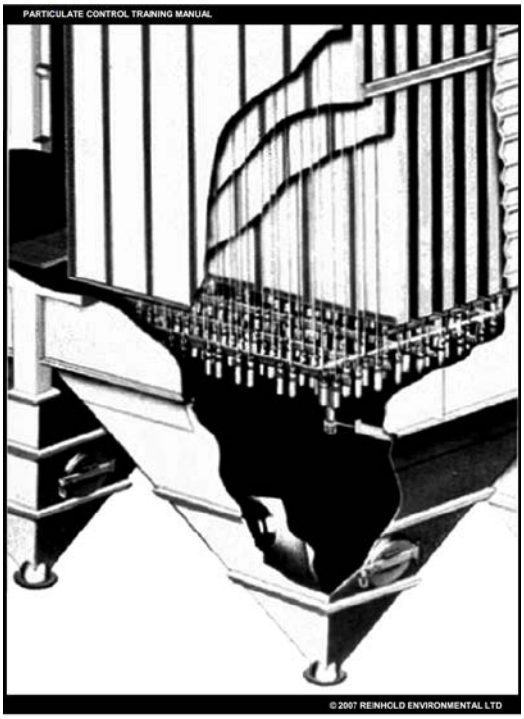
). It was claimed that the addition of these devices produced a quiescent zone downstream of the device, which enhanced collection by minimizing reentrainment of particulate from the collecting surface.



The Most Common Collecting Plate and Electrode Designs used by Western Precipitation

(Courtesy of Babcock & Wilcox)

In the early 1950s Western began developing standard collecting surface designs resembling those in use to the current day. The first design utilized flat plate to which were affixed roll-formed ribs that extended the full plate height and were equally spaced (nominally 1'-6" increments) along the collecting surface length. Three variations of this design were used. One design was a ribbed solid plate (RSP) for general-purpose applications. The second was a ribbed perforated plate (RPP) for specialty applications. The third was a ribbed wire screen (RWS) design which was used almost exclusively for outboard collecting surfaces near casing walls to allow hot gases to pass to the exterior walls, thus minimizing corrosion.



Single Wire Weight Precipitator

In the early 1960s, a ribbed module solid plate (RMSP;amp; sometimes referred to as an M-Channel) collecting plate was developed. The RMSP collecting plate was a variation of the earlier RSP design. Rather than fixing separate roll formed ribs to a solid plate, the RMSP design utilized single rolled-formed modules, which incorporated the rib, and the flat plate collecting surface in the roll forming. This design required field assembly and was utilized during the greater part of the 1960s.

In the late 1960s it was recognized that one way to minimize material and field labor costs was to completely review the precipitator designs used to that point. As a result of that review, a ribbed unitized collecting curtain (RUCC) was developed. The RUCC design eliminated the field labor

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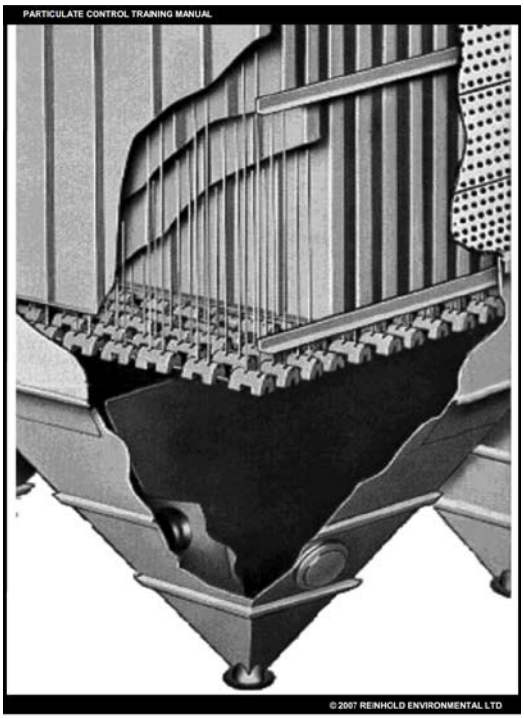
required to assemble collecting curtains. The RUCC design is a shop assembled collecting curtain. The design incorporates a plurality of interlocking modules joined at the top and bottom by a header or “tadpole” beam. In the RUCC design, the collecting curtains are supported at the leading and trailing edge of each field by notched channels. All RUCC designed collectors are edge rapped, the same cannot be said of other Western Precipitation collecting plate designs.



Double Wire Weight Design Developed in Conjunction with RUCC Collecting

In the late 1970s and early 1980s, the United States market was entered by companies offering the European style precipitator design. Most American manufacturers, to address this situation and to correct problems with weighted wire designs, either obtained licenses for European designs or began their own development of rigid electrode designs, which could compete handily with the European design. Western Precipitation utilized a H-Channel collecting module design similar to it's “sister” company in Canada, PRECIPCO, along with its mast design to compete with the European style designs. The H-Channel, so-called because of its H-shaped cross section, became the company standard in later precipitator designs. The H-Channel collecting curtain, as with many of its predecessors, required field assembly.

Early Western Precipitation designs utilized a number of discharge electrode designs. Discharge electrodes were fabricated from wires of many types as well as from steel rods. Discharge electrode suspension methods varied in the early designs, but, interestingly, many of the early designs resemble those still used in the industry today.

In the 1950s, Western Precipitation introduced the shrouded high voltage wire electrode. Shrouding both the top and bottom ends of the spring steel wires created more surface area, which lowered the current density and eliminated undesirable arcing and burn-through in this area. Each electrode was tensioned using individual cast iron weights to prevent vibration. The weights were accurately held in alignment using a lower guide frame suspended from the high voltage frame located above the collecting curtains. This framing arrangement prevented any swinging and allowed for free vertical movement with thermal expansion.

The barbed discharge electrode was also introduced in the 1950s. Barbed electrodes were used, and are still used, to improve electrical characteristics within a precipitator field. Essentially, the addition of barbs lowers the corona onset voltage. While somewhat more costly than a single wire electrode, the barbed electrode, in some applications, allowed for improvements in collection efficiency that could not be obtained from single wire electrodes alone. Barbed electrodes were used in applications where corona suppression was a problem.

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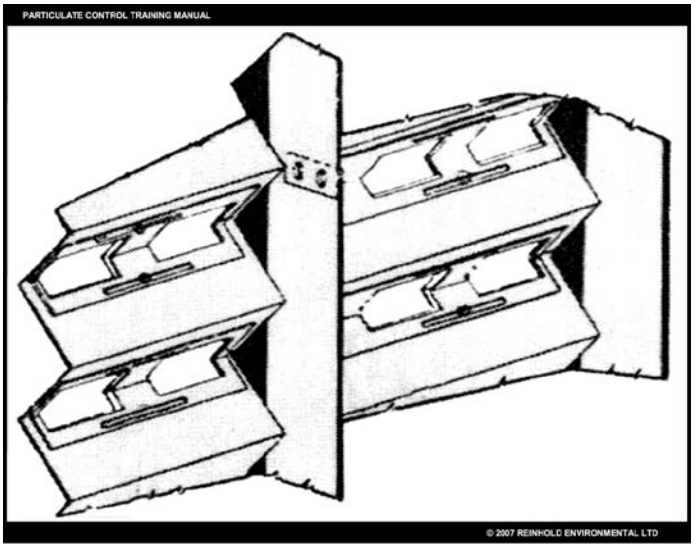
The RUCC collecting curtain was developed as part of an overall review of the Western Precipitation design at the time. Likewise, as a cost improvement feature, a double wire weight design was introduced as a result of the same review. In conjunction with the introduction of the double wire weight, electrode shrouds were changed, reducing the ferrule diameter from 3/8" diameter to 1/4" diameter. While it can be generally said that all RUCC designed precipitators also included the single wire weight design, the opposite is not true. In some industries, particularly the paper industry, the RUCC design was not considered acceptable. In such instances, the double wire weight designed electrode system was used with RMSP collecting curtains.

The late 1970s and early 1980's brought the European designed precipitator into the United States market. Coinciding with the introduction of the H-Module collecting curtain was the introduction of the rigid electrode. Western Precipitation introduced two rigid electrode designs during this period. The S-Electrode was generally used only in applications utilizing collecting curtains 30'0" in length or less. For collecting heights greater than 30'-0" in length, a box electrode was utilized. The S-Electrode is a roll-formed section with serrated leading and trailing edges. The box electrode is fabricated by joining two roll-formed halves by spotwelding. The box electrode provides a rugged structural electrode more suitable for the increased collecting heights. Either of the two electrodes can have square notched or saw-toothed scalloped edges. In some applications, the saw tooth design is modified to a “bent” saw tooth design, to provide electrical characteristics resembling those obtained with barbed wire.

Overall standards for Western Precipitation's electrostatic precipitators were developed over time. As with many American precipitator manufacturers, Western Precipitation settled on 6'-0" increments in collecting height and 3'-0" increments in collecting field length. High voltage system incremental changes were similar to those of the collecting field. The exception being when 9'-0" long collecting fields were utilized. In that instance, either one 9'-0" long high voltage system was utilized or two 4'-6" long systems could be used to improve precipitator sectionalization.



"Adjusta-Flow" or Zig-Zag Gas Distribution Device
(Courtesy of Babcock & Wllcox)

Generally speaking, Western Precipitation's casing design has not changed much over the years, save for the incorporation of changes set by overall industry practice. The one exception was the redesign that occurred when RUCC collecting curtains were introduced in the late 1960s. The casing design for the RUCC curtained precipitators is distinguished by the use of structural tubing columns in lieu of wide flanged shapes. Casing design reverted back to

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industry standard practice when H-Channel collecting plates and mast electrodes were introduced.

Gas flow uniformity through a precipitator is critical, especially when high collection efficiencies are required. The Western Precipitation "Adjusta-Flo" gas distribution plate, consisting of a zigzag plate (the Adjusta-Flo is sometimes referred to as a zigzag plate) was developed to provide uniform distribution of gas through a precipitator without the need for a large number of other devices. Essentially a plate comprised of multiple bent angles (bends are horizontal with multiple bends arranged vertically) and slotted holes with adjustable openings, the Adjusta-Flo distribution plate channels angular gas streams into horizontal gas streams rather than allowing the continuation of angular flow as might occur downstream of a flat perforated plate (see **Figure:**

"Adusta-Flow" or Zig-Zag Gas Distribution Device

). The Adjusta-Flo gas distribution device also allows for adjustment of gas distribution without expensive ductwork alterations. The combination of these two features is intended to insure optimal control of gas distribution to the precipitator.

Western Precipitation utilized spring assisted multiple impact electromagnetic impact rappers on most installations to clean collected particulate from the collecting and high voltage systems. On occasion, as with many precipitator manufacturers, electromagnetic vibrators such as Syntron or Eriez vibrators were used as high voltage system rappers. The early impact rappers were continuously improved over the years with the result being the ER-860 and the ER-1000 rappers, still in use today. The multiple impact rapper provides complete flexibility in impact energy, impact frequency, cycle timing and cleaning sequence. Having such flexibility results in only a minimal loss in rapping energy. Sufficient flexibility is available to effectively rap difficult dusts.

On early model precipitators supplied by Western Precipitation, rapper shafts utilized squared ends. Shaft adapters compliant with the rapper in use were provided at each rapper and shafts of differing lengths and/or materials were jointed with shaft clamps and filler plates. In later years, rapper shafts having tapered ends engaging in tapered seats and anvils for a sure, positive fit and best transmission of rapping energy have been used. In the case of the high voltage frame, a ceramic rapper shaft with tapered ends is used to isolate the rapper. Both pneumatic and magnetic impulse gravity impact (MIGI □) rappers were also offered

Western Precipitation historically has utilized support insulator compartments in lieu of penthouses with only minor exceptions. The use of insulator compartments provides full design versatility and access without the problems associated with penthouses and other means of insulator access. An insulator compartment heating and ventilation system (ICVS), developed and improved over many years, provided warm, clean air to the insulator compartments to eliminate thermal shock during startup and to prevent dust from collecting on the insulators and cause arcing. Today, Babcock and Wilcox offers either insulator compartment or penthouse type designs.

Precipitator hoppers were equipped with hopper baffles to minimize gas sneak-by and yet not

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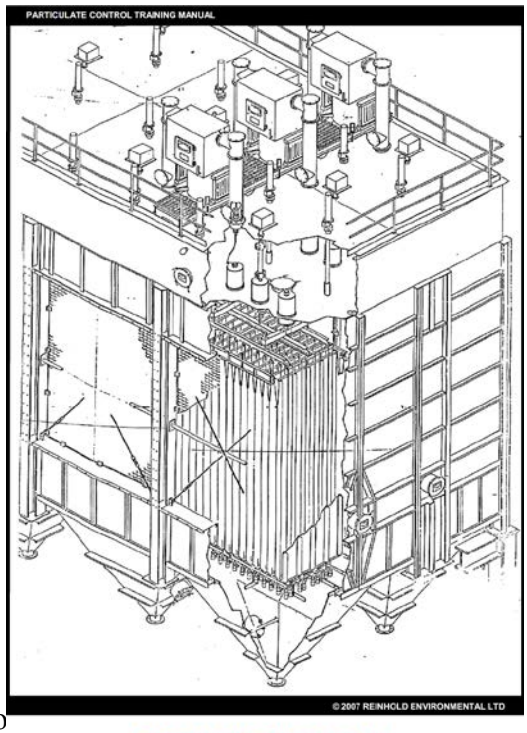
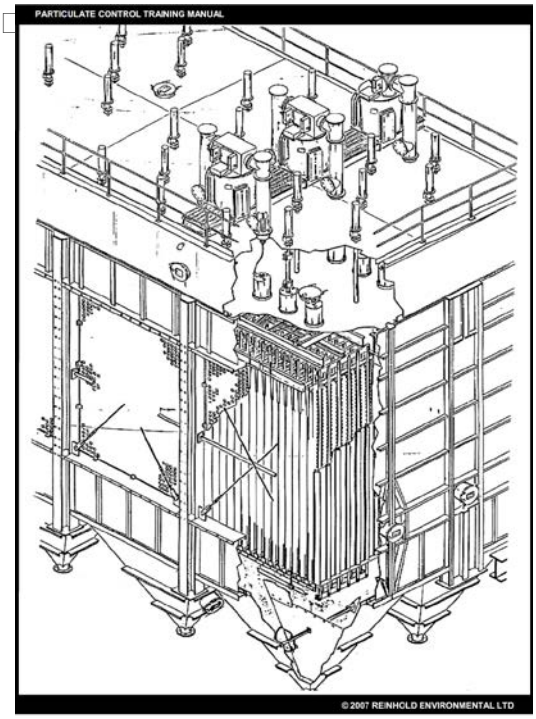
interfere with the free flow of collected dust.

2.3 Research-Cottrell (Hamon Research-Cottrell)

Research-Cottrell standardized its opzel dry plate precipitator design in 1960. This so called 48000 series design was used to construct at least 1000 precipitators of standard parts. This design had two collecting plate widths, 6 feet (1830mm) and 9 feet (2750mm) and plate heights of 17 foot six inches (5.3m), 20 feet (6.1m) and 24 feet (7.3m). Later 30 feet (9.1m) and 36 feet (11m) were added. Plate spacing was 9 inches (225mm). The design used weighted discharge electrodes. Cast iron tensioning weights were standardized at one pound per foot of length or 18, 20, 24, 30 and 36 lbs (8.2, 9.1, 10.9, 13.6, and 16.4 kg). Plate rappers were magnetic impulse gravity impact (MIGI es) were standardized electro with V-75 syntron vibrator rappers and loop ring termination's. They were 0.109 inch diameter at a later date shrouded termination's were provided and MIGI rappers were used for discharge electrode cleaning.



Duratrode Electrode-1



Duratrode Electrode

The following illustrations show typical opzel precipitators of the 48000 series design. They also show components.

The standard Research-Cottrell casing is of 3/16 (4.75mm) steel plate stiffened with channel sections the vertical columns are connected to struts in the gas stream to reduce column length and reduce weight. The Research-Cottrell nomenclature for parts of the casing is as follows:

- Hopper
- Side Frame
- Partition Frame
- Bottom end frame (inlet or outlet)
- Supporting Bottom Baffle
- Top End Frame (inlet or outlet)
- Intermediate roof beam
- Roof frame (hot roof)

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The support insulators on the roof are protected by either insulator compartments or a top housing. If a housing is used, its roof is called the cold roof. The collecting electrodes or plates are supported and rapped through anvil beams, which are supported by tension bolts fastened to the end frames and intermediate roof beams. See **Figures:**

Duratrode Electrode

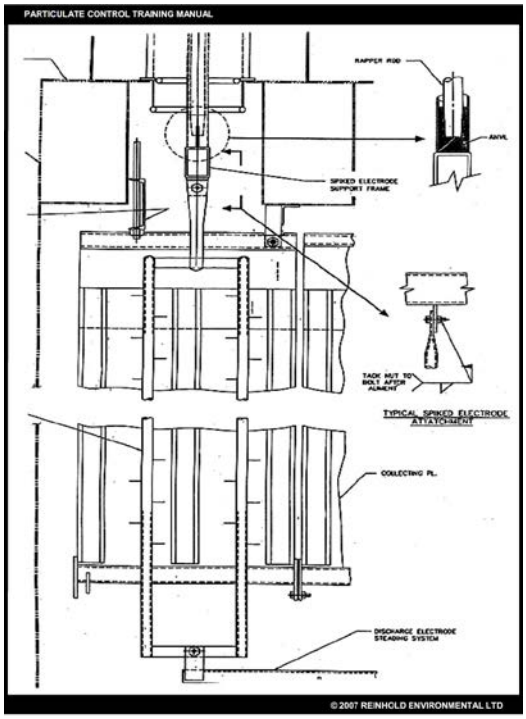
.

The discharge electrodes are supported by the high tension frame (HT) constructed of angles held up by channels supported in turn by tension bolts from a bridge connected to the high tension hanger (hot pole) resting on the support insulator. At the bottom the discharge electrode weights are positioned by the lower high-tension steadying frame, which is positioned by anti sway insulators. The hightension rapper energy is delivered by a rapper shaft passing inside the HT hanger to an anvil beam connected to the HT frame angles. An isolating ceramic shaft is used in the high-tension rapper assembly. See **Figures:**

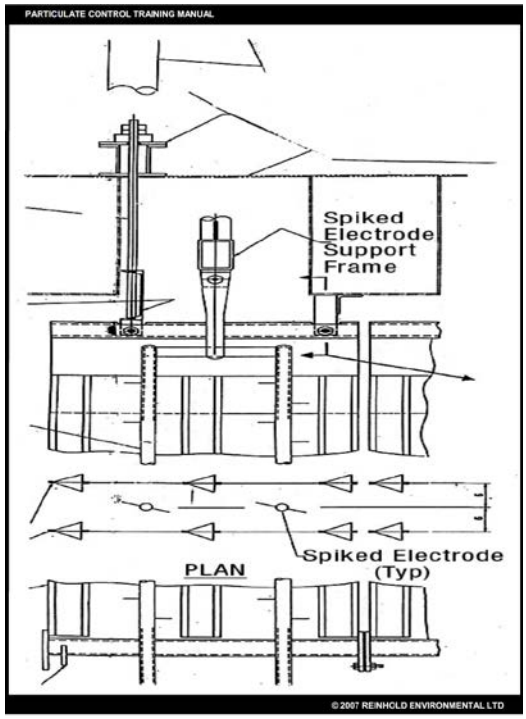
Duratrode Electrode

.

Following the 48000 series design, Research-Cottrell developed a rigid discharge electrode, which it named the Duratrode. At the same time it started using a less costly collecting electrode called the g-opzel. The plate width was standardized at 7 feet three inches (2210 mm). The collecting electrode was lighter and it was claimed to have better rapping characteristics. The Duratrode had some problems due to poor corona discharge characteristics especially with fine particulate and resulting space charge. A generic pipe and spike rigid electrode was substituted. With the use of RDE, the plate spacing has been increased to 12 inches (300mm) and 16 inches (400mm). This has of course raised voltages from the usual 45 KVp for 9 inch (225mm) spacing to 100 and 120 KVp. Research-Cottrell now uses Redkoh Industries controls.



Pipe and Spike



Pipe and Spike-1

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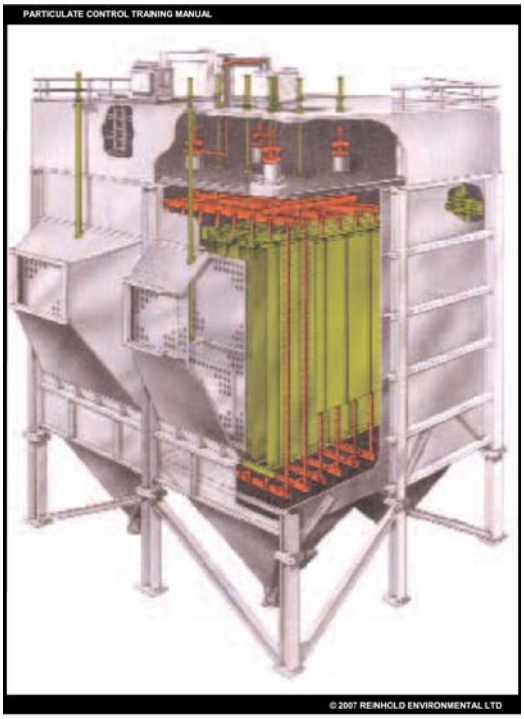
2.4 Koppers/Environmental Elements Corp. (Clyde Bergemann EEC)

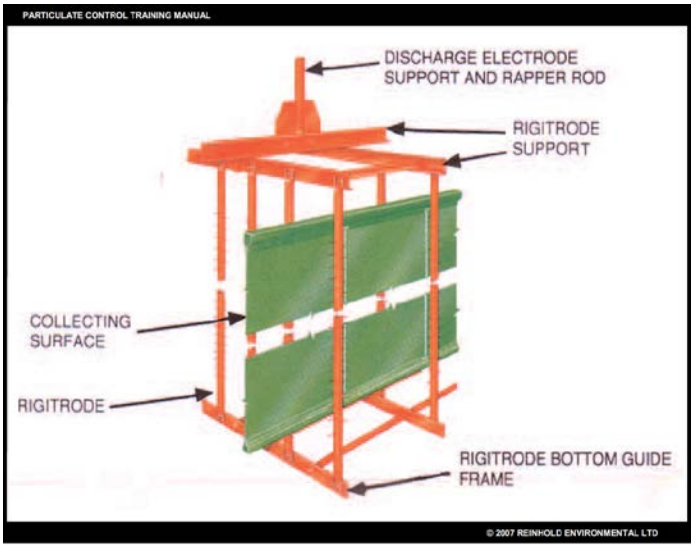


Typical Precipitator Cross Section Using Rigitrode Discharge Electrodes

Environmental Elements Corporation (EEC) started designing and marketing electrostatic precipitators over 50 years ago as the metal products division of the Koppers Company. The original precipitators were built under license from ELEX of Switzerland. After about 15 years, Koppers let the ELEX license lapse and began marketing their own design of precipitator, initially a weighted wire design.

About 15 years ago, Koppers withdrew from the precipitation business and the new company, ENELCO (now known as EEC) was formed to continue the precipitation and other pollution control business. They presently market both weighted wire and rigid discharge electrode precipitators.

Experience.



Rigitrode Discharge Electrode System

EEC has installed over 1,200 ESP's on five continents. Products collected include fly ash, cement dust, recover boiler fume and metalurgical fume.

The engineering group has been using Computer Assisted Design equipment since 1977. Now in its third generation, the EEC system integrates both design and engineering aspects into the final drawings. This degree of automation can produce a timely response on short turnaround projects.

Depending upon specific contractual arrangements, EEC erection capabilities range from the providing of jobsite construction advisory services for

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projects erected by EEC customers to complete field supervisory services for turnkey projects.

Environmental Elements offers complete turnkey systems including process analysis, design, erection and start-up including:

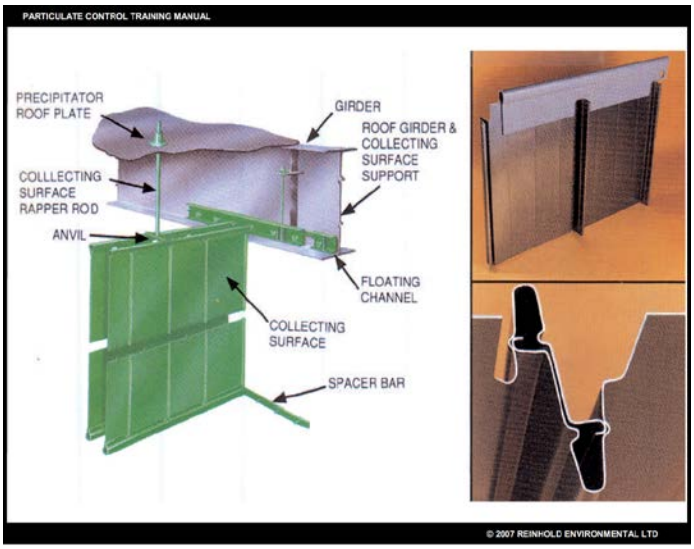
- Ductwork
- Support steel
- Pre-wired control rooms
- Low voltage wiring Thermal insulation
- Computerized data management
- Ash handling systems

RIGITRODE Discharge Electrode System.

The rigid discharge electrodes (PIPE & SPIKE) are arranged in a structural matrix for maximum resistance to deflection. Corona discharge is provided by parallel rows of studs welded to each electrode in the correct pattern required for each application.

MODULOK Collecting Electrode System.

Shop assembled panels are snapped together to produce a patented collecting plate available in incremental widths of up to 15 feet and heights of up to 50 feet. Rapping energies are distributed over the entire surface, which is free from stresses induced by welding.



MODULOK Collecting Surface Arrangement

2.5 Lodge-Cottrell/Lodge Sturtevant (Korea Cottrell)

Casing.

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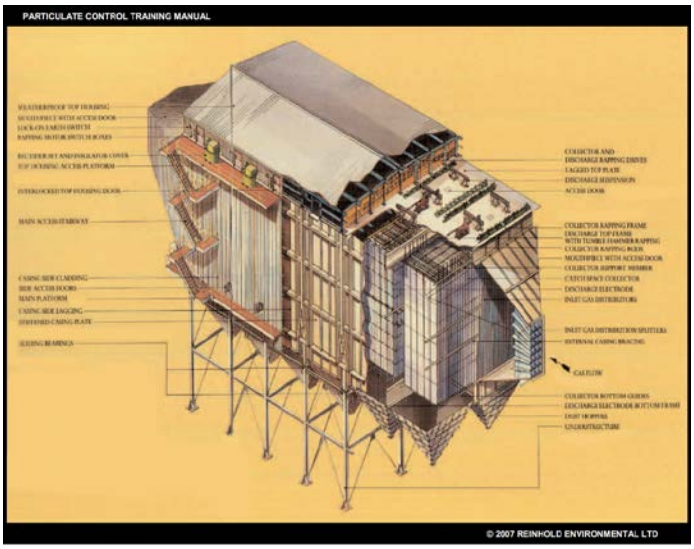
The Lodge Sturtevant casing is designed and built to avoid unwanted dust build up and air infiltration. The elimination of stagnant gas pockets prevents harmful corrosion and the build up of toxic and explosive gases. Casings can be built from concrete or steel.

Each unit has dust hoppers and is supported from ground level by a separate understructure. On the top of he unit is a weatherproof top housing which houses rapping gear and HT electrics.



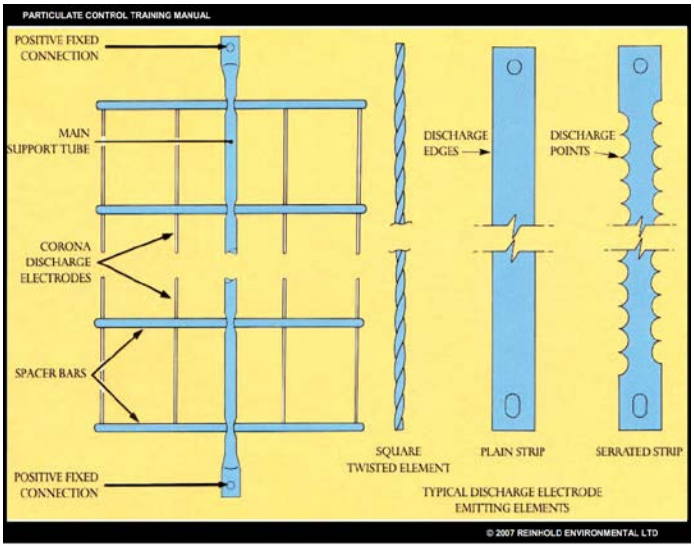
Dry Type Electrostatic Precipitator

Discharge Electrodes.

The Lodge Sturtevant Discharge Electrode is the mast type electrode, which has been in service for over 30 years. The design of the discharge electrode attached to the mast has the following features:

- For many applications it is a 4mm square twisted element running the full length of the mast.
- For difficult dust applications high emission strip electrodes are supplied.

The discharge electrode elements are subject to dust build up which needs to be removed by rapping. The discharge elements are linked together to form a frame, the support steelwork being rapped by one or more drop rods. Where higher intensity levels are required, the electrodes will be rapped by a tumbling hammer system. Process conditions will govern which system is employed.



Discharge Electrode Assembly

Collector Electrodes.

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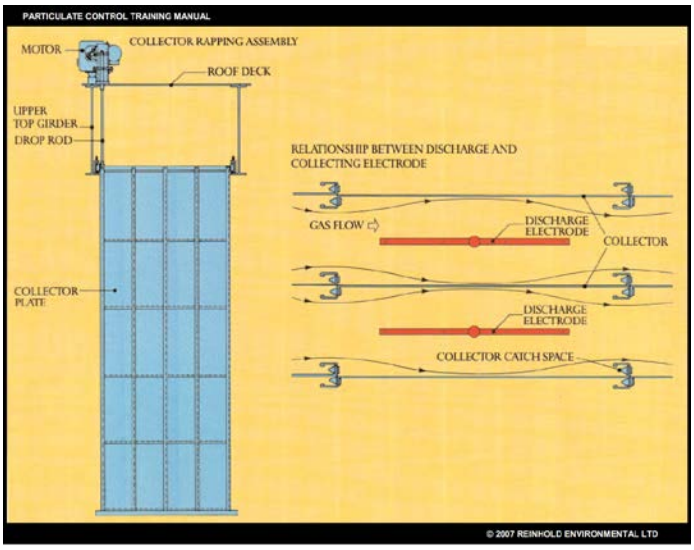
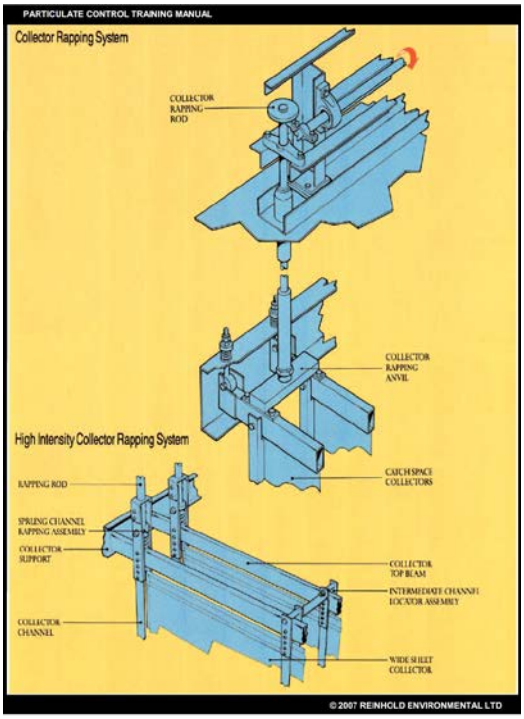
The collector electrodes are constructed of interlocking flat sheets riveted to vertical rolled channels. The vertical channels face into the gas stream creating a quiescent zone on the collector surface. This type of collector, called a Catch Space Collector, restricts dust scouring, and rapping re-entrainment.



Collector Assembly

The inherent rigidity of the collector assembly, ensures small alignment tolerances can be maintained, resulting in the maximum applied voltage.

During the precipitator process the dust layer on the collector electrodes sheets is allowed to reach an optimum thickness prior to its removal by rapping. The collectors are rapped in the vertical plane to shear the dust layer from the collector sheets. The impact is normally via a drop rod with a disc lifted by a cam at preset time intervals. Although many refinements of the rapping system have taken place, the basic approach has remained unchanged.



Collector Rapping System and High Intensity Collector Rapping System

Two of the established design concepts are shown in the previous figures.

The Lodge Sturtevant standard and high intensity collector rapping system meets the demands of wide ranging process conditions having facilities to adjust both frequency and intensity.

Successive zones or banks of the precipitator have a reduced rate of dust layer build up hence dust reentrainment is minimized by rapping less frequently.

Electrical Equipment and Control Systems.

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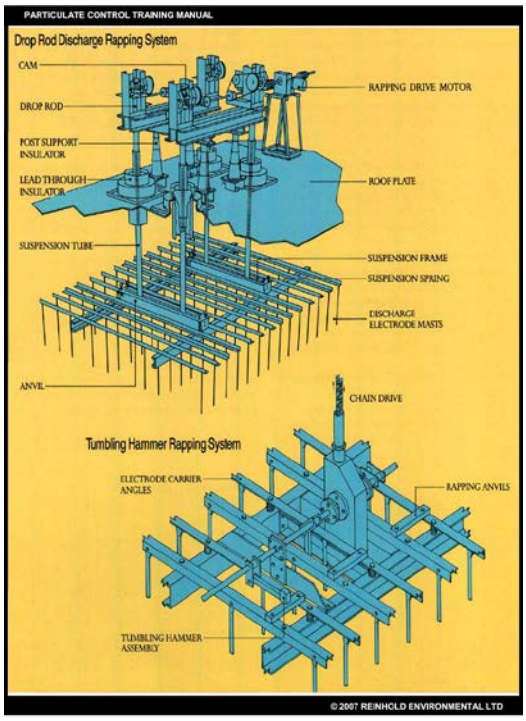
Lodge Sturtevant precipitators are energized by specially designed thyristor controlled transformer rectifiers. Each precipitator field is controlled by a microprocessor based Automatic Voltage Controller for control of the DC high voltage power supply.

Features that can be included are:

- Optimum ESP performance with minimum power consumption
- Energy control by intermittent energization
- Increased flexibility through advanced back corona detection and automatic optimization of control settings.
- Emission reduction via power down or power off rapping.
- Optional power saving via feed back from opacity monitor.
- Communications to IBM compatible computer or

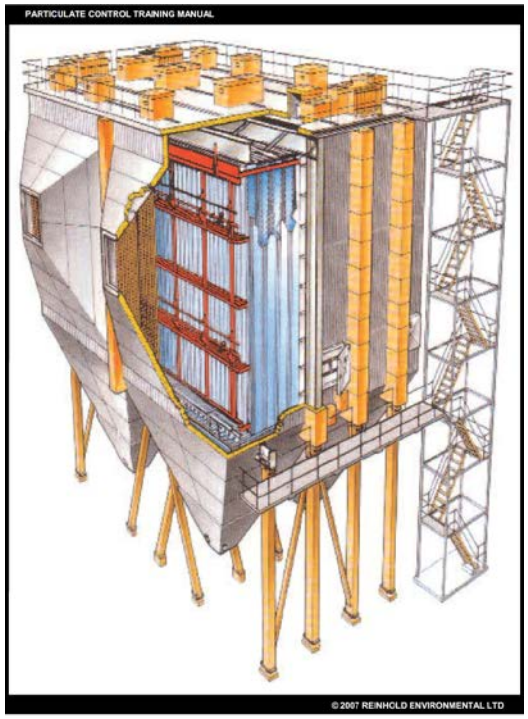
PLC linked to a total control system.



Drop Rod Discharge Rapping System and Tumbling Hammer Rapping System

Weatherproof Top Housing.

Lodge Sturtevant Electrostatic Precipitators features a weatherproof top housing.



Type F Precipitator with Pyramidal Hoppers & 2 Central Inlet Transition Pieces each Incorporating 3 Vertical Gas Distribution Screens

2.6 FLS Miljo A/S (FLSchmidt Airtech)

FLS miljo A/S electrostatic precipitators Type F and C are manufactured in standard sizes ranging from 3 to 30 m in width and from 4 to 15m collecting plate height. The duct spacing can be 250, 300 or 400mm.

The Type F ESP is primarily used for medium to very large gas flows, i.e. from approx. 50 to 500 m3/sec per precipitator chamber.

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The Type C ESP is primarily used for small to medium gas flows, i.e. from 10 to 50 m3/sec.

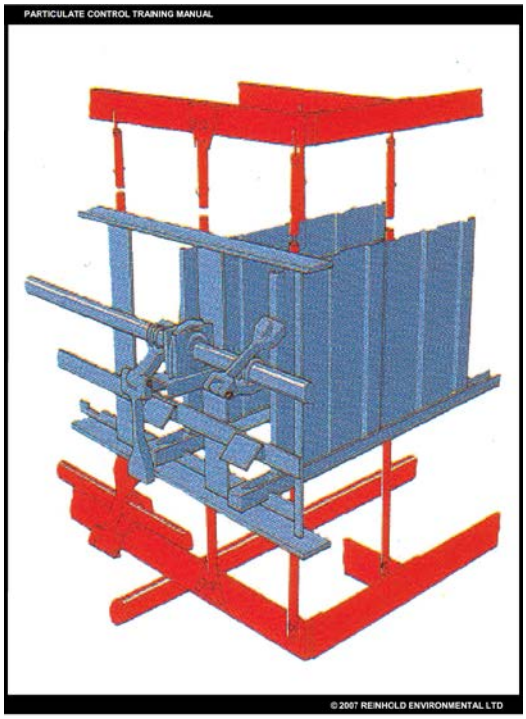
A precipitator may be built as one or more casings in parallel, the so called "chambers". Each chamber usually comprises several fields ranges from 2 to 5.4m in modules of 0.5 to 0.45m depending on precipitator type. Fields installed in series can furthermore be divided into two or more electrically separated bus sections in parallel.

The casing is made of reinforced steel plate, designed to withstand specified pressures and temperatures as well as wind forces and snow load.

Depending on the design chosen, the precipitator is equipped with either a roller bearing supporting system, a slide bearing system or a pendular supporting system, to ensure that minimum stress is exerted on casing and foundation as a result of thermal expansion and contraction of the precipitator.

Gas distribution screens are installed in inlets as well as the outlets of most FLS ESPs to ensure even distribution and aerodynamically balanced gas flow through the precipitator internals. The screen design is pre-determined in the laboratory, a final check being made at site to ensure optimum gas distribution. When handling sticky dust, the screens are equipped with vibrating devices to loosen any material deposits. The inlet transition piece has up to three gas distribution screens depending on the type of inlet arrangement.

The discharge system consists of a rigid frame of beams and tubes, the discharge electrodes being suspended within this framework. Each electrically independent discharge system is carried by stainless steel rods suspended from supporting insulators installed on the precipitator roof inside heated and thermally-insulated boxes. The insulators are provided with airtight gaskets, which allow for thermal expansion between insulator and roof.Two kinds of discharge electrodes are available, helical or rigid, either of which may be fitted in the Type F precipitator, whereas, the Type C precipitator can only have rigid electrodes.



Electrode Arrangement and Rapping System, Type F

The helical discharge electrodes are of smooth, colddrawn stainless steel wire supplied in coils. During erection the coils are stretched and fitted by means of special tools to ensure uniform tension of each single electrode. The ends of the electrodes are provided with reinforced hooks, which, together with special clamps welded to the framework, form a flexible link to prevent fractures due to fatigue.

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Rigid discharge electrodes are manufactured from ovalshaped mild steel tubes, which are provided with welded-on-emitters positioned parallel to the flow of gases. The larger axis of the oval tube is oriented perpendicular to the gas flow. Based on the principle of least resistance, possible oscillation of the discharge electrode occur in the direction of the smaller axis of the oval tube, i.e. parallel to the flow of gas. Oscillations ill therefore not reduce the voltage distances to the collecting plates.

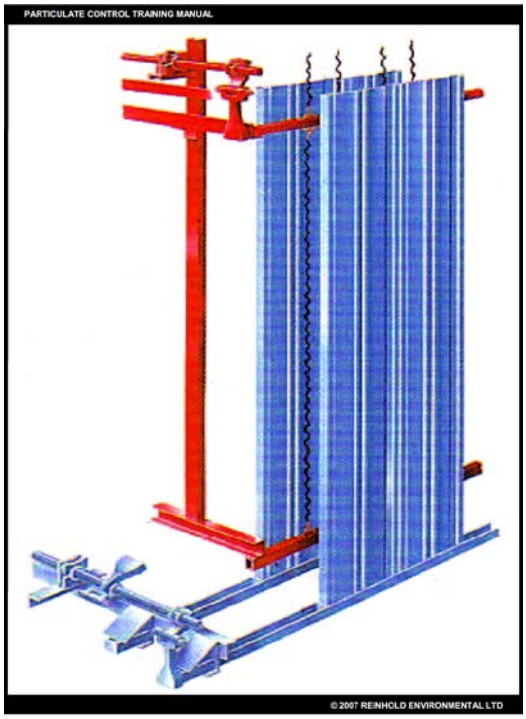
The collecting plates are manufactured from rolled steel plate, and are eccentrically suspended from the precipitator roof.

As shown in the **Figures:**

Electrode Arrangement and Rapping System, Type F

and

Electrode Arrangement and Rapping System, Type C



Electrode Arrangement and Rapping System, Type C

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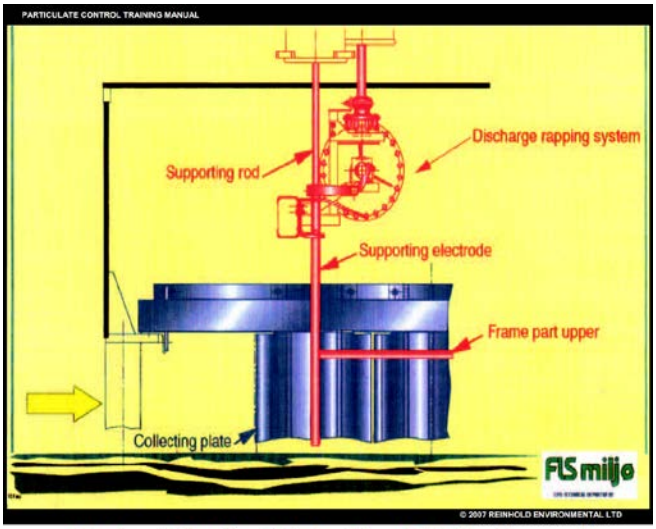
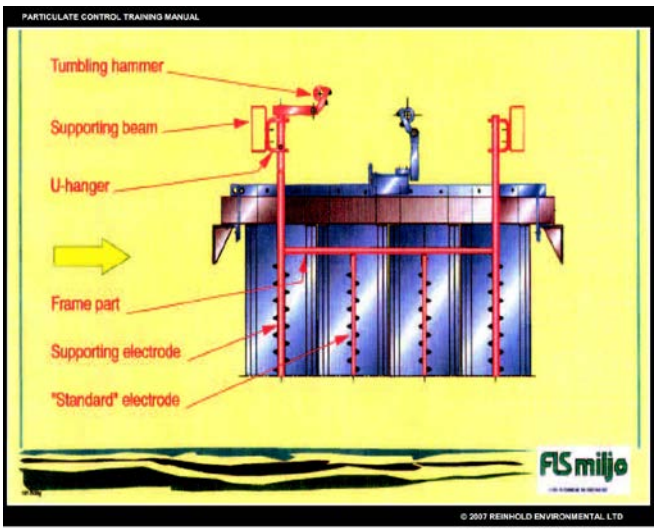


Electrostatic Precipitator Type E Collecting and Discharge System
(Courtesy of FLS miljo)

, the rapping bars consist of two parallel flat bars linked by specially shaped intermediate pieces, one for each collecting plate. An impact anvil is mounted at the end of each rapping bar. This arrangement avoids a fixed connection between collecting plates and rapping bars. Being eccentrically suspended, each plate presses against its intermediate piece, providing close contact for impact transmission. This mode of suspension also allows individual thermal expansion of the collecting plates. The rapping bars do not move vertically in spite of the thermal expansion of the plates, and their position relative to the tumbling hammers will remain unchanged. Consequently the hammers will always strike the correct point on the bars.



Electrostatic Precipitator Type E Discharge Systems
(Courtesy of FLS miljo)

Like the collecting plates, the discharge electrodes are rapped sequentially by tumbling hammers

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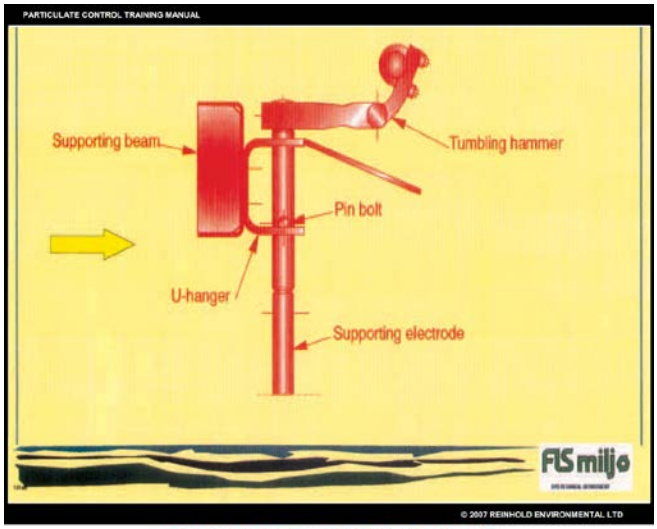
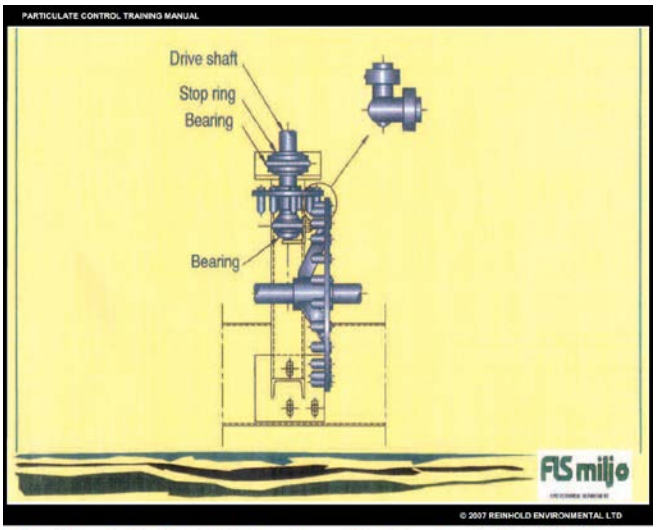
mounted on horizontal shafts. The hammers strike the impact beams, which transfer the impact force to the electrodes. This rapping is designed to remove the small amount of dust precipitated on the negative discharge electrodes.

The driving mechanisms and gears for the rapping hammers - for collecting plates and for discharge electrodes - are mounted on the outside of the precipitator casing. A maintenance-free slide ring seal is fitted around the passage through the precipitator casing.



Electrostatic Precipitator Type E - Discharge Rapping System
(Courtesy of FLS miljo)



Electrostatic Precipitator Type E - Pinwheels for Discharge and Collecting Rapping System
(Courtesy of FLS miljo)

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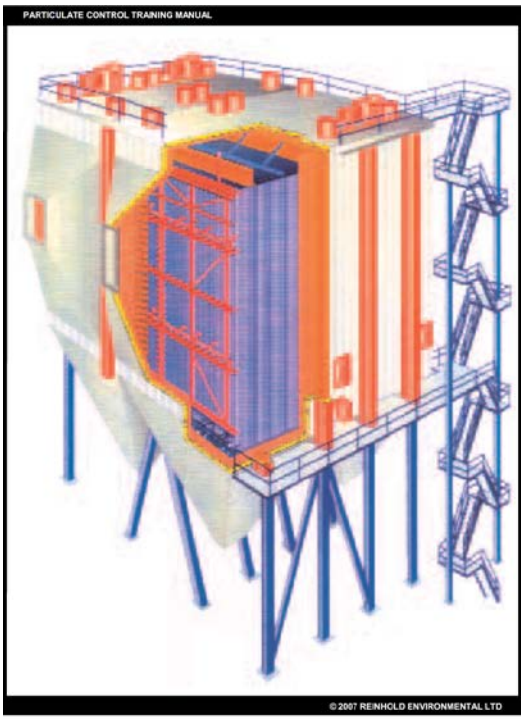
FLS has also supplied a top tapped Type E design which permits minimum spacing between fields in direction of gas flow. The previous four illustrations describe the rapping features of the "E" Design.



Electrostatic Precipitator Type FM

2.7 Wheelabrator (Siemens)

In 1965 Wheelabrator Air Pollution Control (WAPC) signed an ESP license agreement with Lurgi and offered an Americanized version of the Lurgi rigid frame ESP through 1985, when the license agreement was terminated. Wheelabrator still has the right to sell a version of that design today. During this period, tumbling hammer rapping was used on the collecting plates and lift-and-drop hammer rapping was used for the pipe frames.

In 1983 Wheelabrator acquired the Air Correction Division of UOP and then could also offer a weighted wire ESP design with gravity impact rapping. The collecting plate consisted of ribbed 18" wide sections that were crimped together and supported with a wide tadpole at the top and guided with a narrow tadpole at the bottom.

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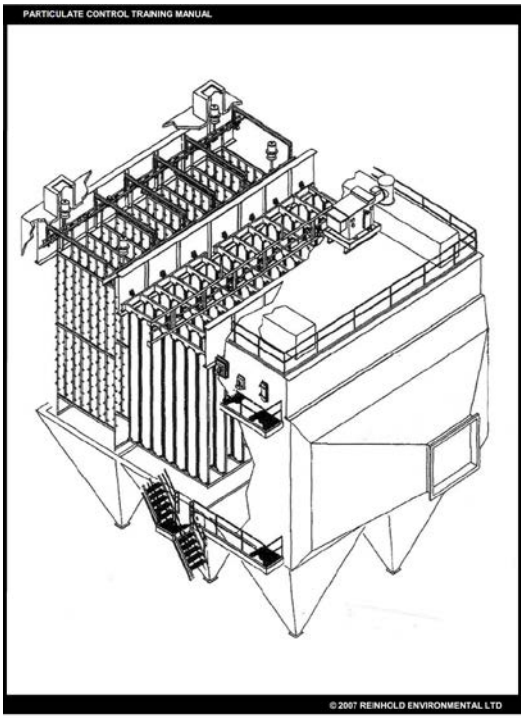
Upon separation from Lurgi, WAPC began to offer a rigid discharge electrode (RDE) precipitator. Their proprietary RDE was unique in the industry, deviating from the common pipe and spike designs. The RDE was a rolled, Cshaped electrode with spikes. There were two versions of this electrode, the 3-1/2" by 1-3/8" body termed the Readi-C electrode and the wider 4-1/2" by 1-3/4" body, termed theWreadi-C (wide Readi-C) electrode. The larger electrode was typically used with field heights over 36 feet. WAPC also offers the generic pipe and spike electrode, which is common in the industry.

There are two versions of the WAPC RDE ESP, distinguished by the rapping. The first uses gravity impact rapping on the plates and RDEs, and is termed the VIGR RDE ESP. The plates and their suspension are similar to the UOP design. Rapping is through the support beams, as is typical with many designs. The RDEs are rapped through the high voltage support insulators, either on a spring-isolated anvil plate or directly on the upper, high voltage support frame.

The second RDE ESP uses tumbling hammer rapping for the RDEs and plates and is termed the "HaRDE" ESP. The RDE rapping is at the top, where one hammer impacts an anvil that spans two RDE support channels. The collecting plates are segmented 20" wide strips hung individually and connected at the bottom with a rapper bar and anvil. The collecting plate rapping is similar to the tumbling hammer rapping of the Lurgi rigid frame ESP.



Typical Alstom ESP

2.8 Flakt/ABB (Alstom Power)

Casing Design.

The ash hoppers and hopper support beams are shop fabricated to the greatest extent possible and the ABB slide bearing arrangement accommodates thermal expansion.

The "FTA" casing design utilizes a system of internal columns to transfer the load of the internals to the support structure. Large shop fabricated side wall panels which are attached to the columns utilize a system of continuous horizontal external stiffeners that simplify the wall construction and installation of thermal insulation. Additionally, the internal columns also serve as side wall gas baffles.

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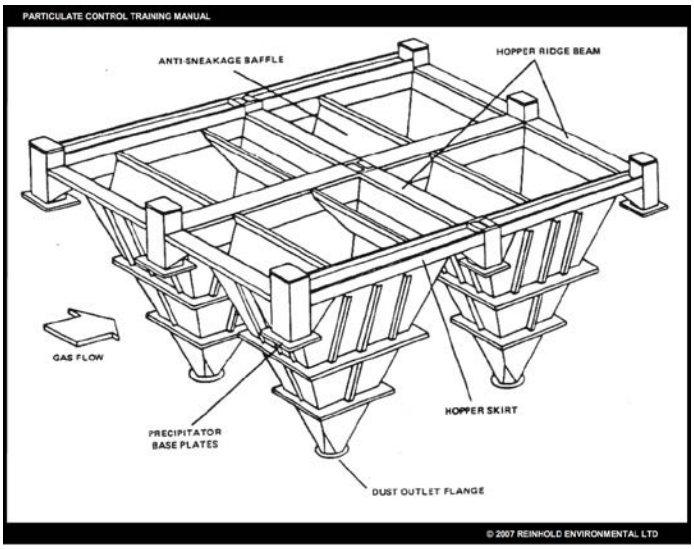
Constructability.

In addition to the foregoing features described, the "FTA" design is suited to meet condition requests such as:

- Large sections assembled at ground level and set into position to minimize welding requirement in the air.
- Prefabricated support systems and modules can be shipped containing casing and internals, significantly reducing site construction constraints for lay down area, cs, schedule, etc.
- To minimize outage time, the FTA can be completely preassembled then rolled into position along side the unit to be replaced.

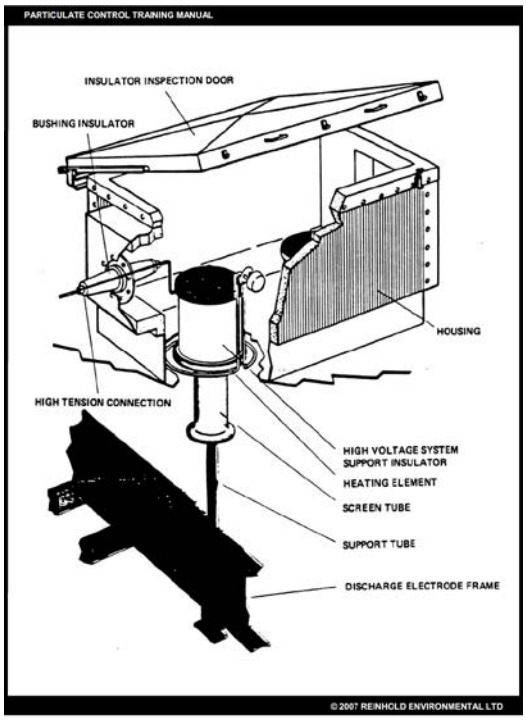


Typical Hopper Construction

Collecting Electrodes.

The collecting electrode system for the "FTA" ESP consists of a roll formed panel design. The individual non-interlocked panels are specifically designed to accommodate thermal expansion during load swings and maintain electrode alignment throughout the life of the installation without the need for plate straightening devices.

The ABB standard collecting electrode upper suspension system is shop fabricated as modules. Bundles of collecting panels are placed within the casing for internal distribution. And, once in the casing, final positioning of the collecting panels is a simple manual technique, not requiring use of the main crane, leaving it available for other work. Because the suspension system modules are shop assembled to close tolerances, final alignment and adjustments are minimized.



High Voltage Insulators and Enclosures

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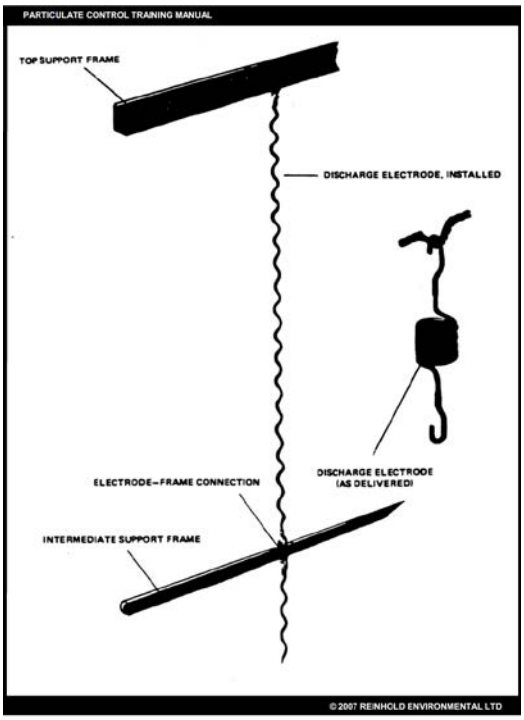
Discharge Electrodes.

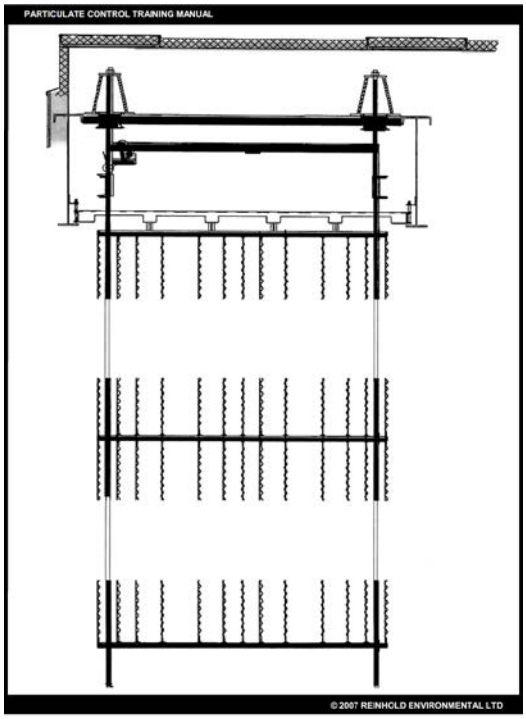
ABB recognizes that no single discharge electrode is ideal for all applications, processes or even all types of flyash. The ABB "FTA" design is offered with the Multipeak™ rigid discharge electrode or the spiral electrode configuration to match the requirement of the full range of utility applications.

Rigid Discharge Electrodes (RDE) were initially developed to overcome the reliability problems associated with weighted wires. The ABB Multipeak™ RDE was specifically developed for use in high space charge or low resistivity applications where high current densities are needed for particle charging or ash retention on the collecting plates. The ABB Multipeak™ RDE is suited for the collection of low resistivity ash produced by high sulfur fuels or for particular applications where large quantities of fine particles are present.



Spiral Wire Discharge Electrode System

Both electrode designs can be provided to the field in shop assembled frames to simplify field installation and minimize final alignment. A four point suspension system is provided for each bus section. And, since the electrodes are contained within the collecting electrode system, damage to the electrodes resulting from accidental overfilling of the hoppers is diminished.



Discharge Electrodes in Top-rapped Rigid Frame Designed for ESPs without Space between the Fields

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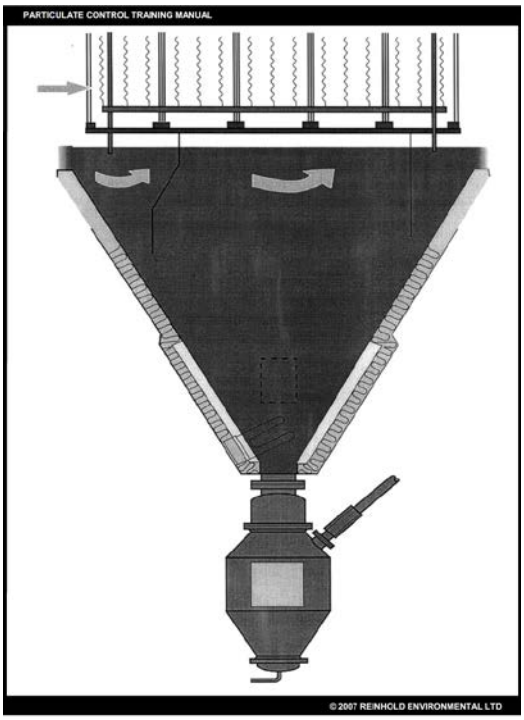
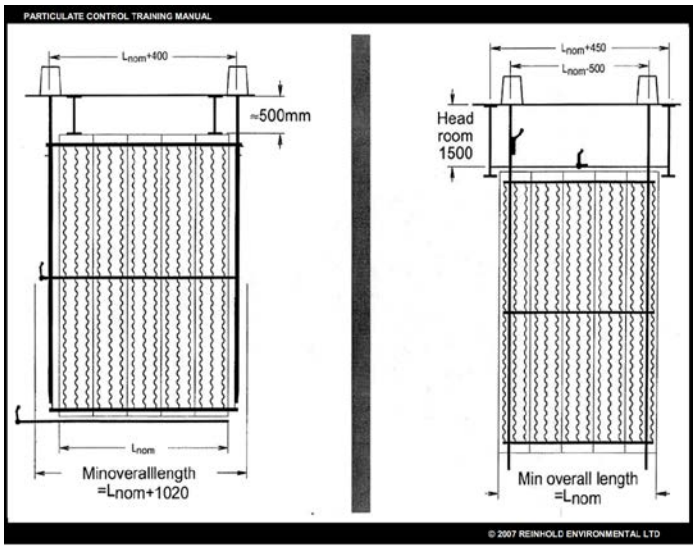
Unique Features From ABB.



Hopper Design with Heating

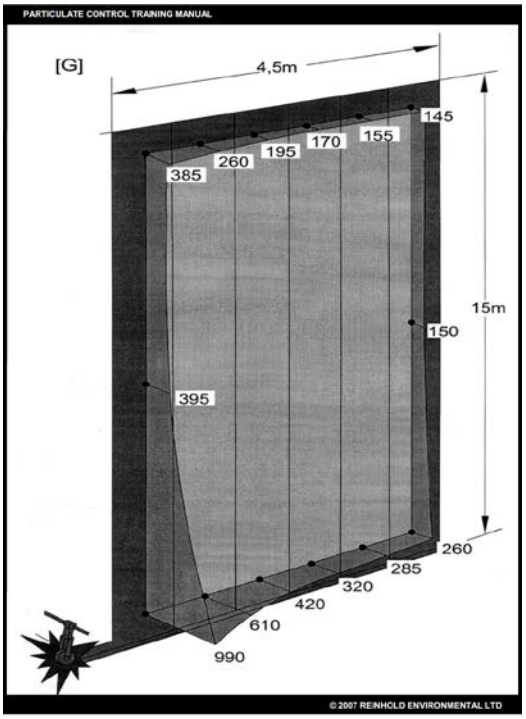


Electrode Configurations with/without Inspection Space between the ESP Fields

Tumbling hammer rappers are provided for both the collecting and discharge electrode systems. This system consists of a rotating shaft and a series of hammers that fall, by gravity, as the shaft slowly rotates, providing acceleration values on the collecting plates in excess of 120g. The hammers are staggered around the shaft so that only one hammer falls at a time. Only a minimal amount of collecting surface is rapped at any time, thereby minimizing particulate re-entrainment, electrical disturbance, opacity changes and overall mass emissions.

The hammer shafts are completely shop assembled and ready for installation. Each shaft is rotated by a gear motor specifically designed for this application. Since multiple hammers are operated from a single shaft, the number of casing penetrations is greatly reduced compared to that with electromagnetic rapper designs (MIGI).

In recent years ABB has provided electromagnetic



Typical Acceleration Pattern in g Obtained in the Laboratory during Long Term Fatigue Testing of Collecting Electrode Curtain

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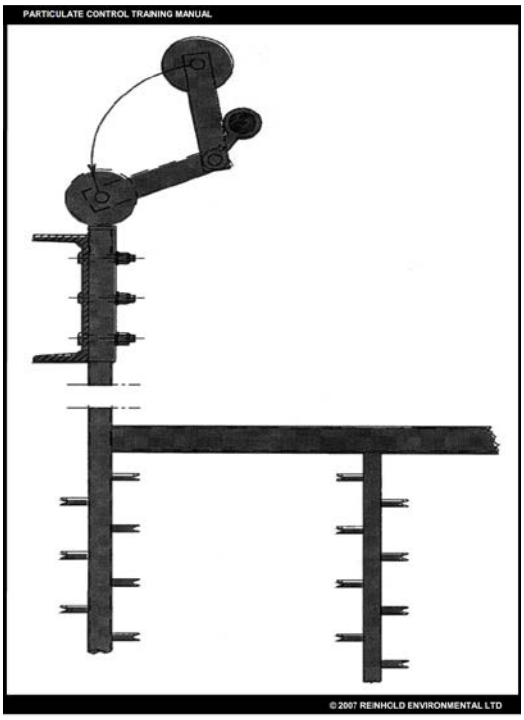
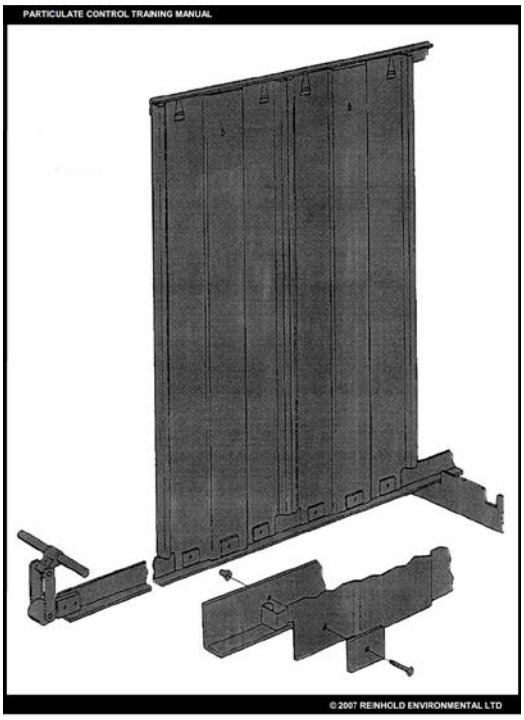
rapper designs.



Tumbling Hammer and Anvil Design for Top Rapped Rigid Frame



Collecting Electrode Curtain with Roll-formed Mild Steel Elements

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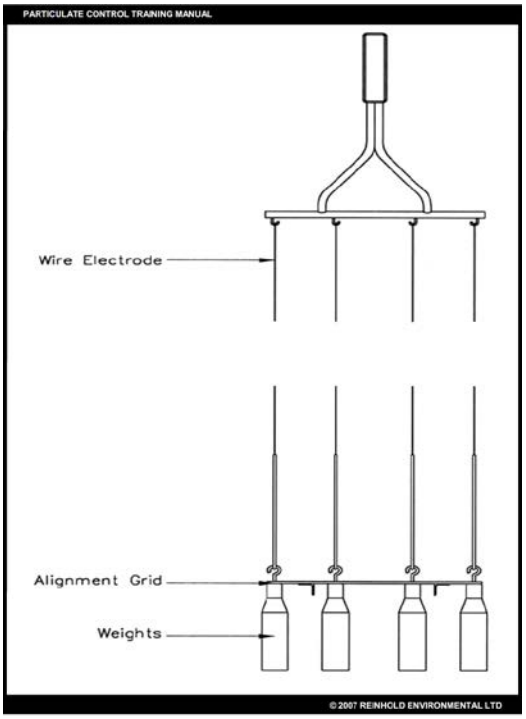
2.9 Buell, Envirotech, GEESI (Hamon Research-Cottrell)

The Buell Engineering Company was founded by Consolidated Goldfields of South Africa in 1934 for the purpose of designing and manufacturing mechanical collectors and particulate classifiers. From 1950 to 1965, Buell sold electrostatic precipitators first as a licensee of Flakt and later with its own rigid frame, rotating hammer rapping design (1960). Buell added fabric filters to its product line in 1958 with the purchase of Northern Blower Company. In the mid-1960s several key personnel left Research Cottrell and joined Buell.

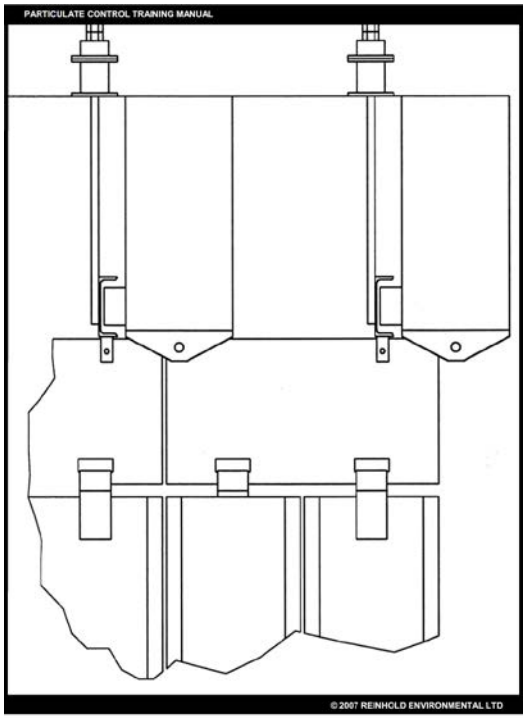
In the late 1960s Buell developed a weighted-wire, rollformed panel plate precipitator introduced as the 'B' design and later modified as the 'BA' design. The 'BE' rigid frame design using 3/16" twisted bar electrodes with 12" and 16" plate spacing replaced the 'BA' wire-weight in 1979. Throughout this precipitator design transition period, ownership of Buell changed from Consolidated Goldfields to Envirotech, then to General Electric Environmental Services, Inc. (GEESI) and finally in 1998 to Marsulex Inc, of Canada as Marsulex Environmental Technologies LLC.

Marsulex markets the full air quality control product mix as the former GEESI: Wet FGD Limestone and Ammonia scrubbers, Spray Dryer Dry FGD and Acid Gas Scrubbers, Pulse Jet (high pressure and long bag intermediate pressure) and Reverse Gas Fabric Filters, Electrostatic Precipitators, Mechanical Collector Cyclones, Particulate Classifiers, Dry Injection Technology, and an Activated Coke Process for NOX Control. Buell has been located in Lebanon Pennsylvania since moving from New York City in 1963.

The Buell wire-weight design precipitator is a socalled



"B" Emitting System



"B" Collecting Plate Support System

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modular precipitator, a multiplicity of three-foot mechanical fields in series. The three-foot fields could be separately energized or grouped together in series and/or in parallel. Typically two, three or four fields in series were energized by one transformer-rectifier (TR).

The difference in the 'B' and 'BA' designs to collecting plate design and collecting plate and emitting wire support details:

- The 'B' design used two 18" wide roll-formed plate panels hooked to a rectangular, slotted carrier plate as a three foot mechanical section.

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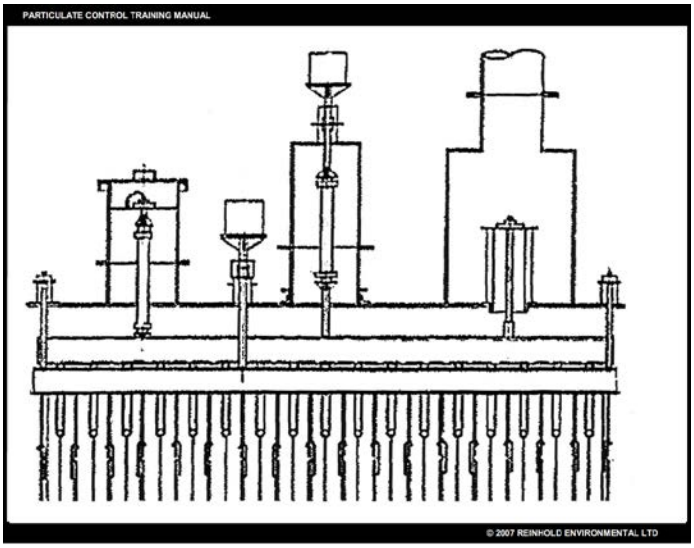
- The 'BA' design used a roll-formed three foot wide plate with center crimp supported at the top by a unistrut 'B'-line.

Groups of plates for the 'B' and 'BA' designs were supported at the top by bolting at one end to the bottom of roof box beams and the other end by a channel supported by two rods that penetrated the roof and were secured by a washers and double nuts. Rapping was provided by an electromagnetic impact rapper located above an impact rod between the two support rods on each channel.

Both the 'B' and 'BA' collecting plate systems used U-clips at 1/3 or ¼ points on the plate ends to hold the panels in line with each other in the direction of gas flow. At both ends of groups of three or four mechanical three foot sections, perpendicular to gas flow, sheet metal 'rakes' were installed at the midpoints of 1/3 points vertically to maintain plate-to-plate spacing of 9".

Collecting plate heights for both designs were typically 24, 30, or 36 foot. Bottom collecting plate alignment for the 'B' design utilized a pipe that connected plates in a series. Each pipe extended into a slotted angle which maintained



"B" Design Transverse Section

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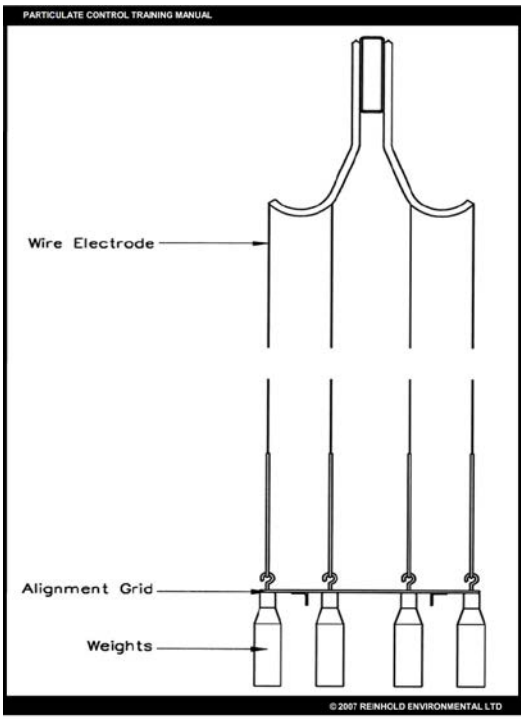
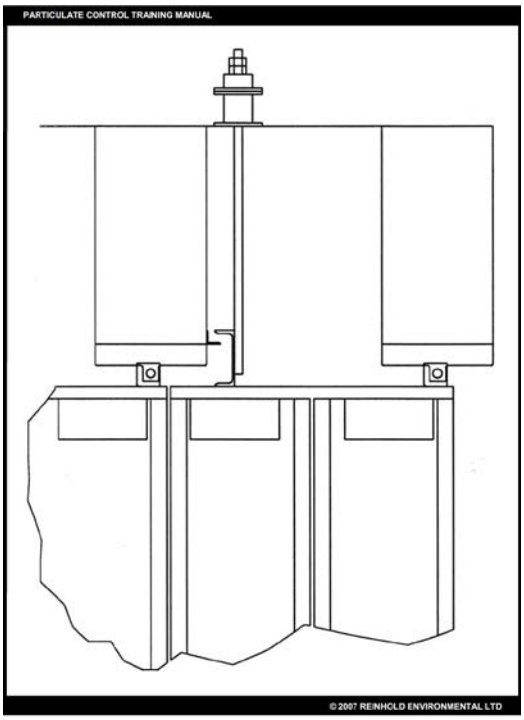
alignment of each plate row with respect to each other. The 'BA' design used the same bottom alignment scheme except that the pipe was replaced with a length of unistrut referred to as the lower 'B' line.

For the 'B' design the high tension frames were supported with two point suspension by a cylindrical compression insulator at one end and a shaft tension insulator on the opposite end. For dislodging particulate, a vibrator was located between the support points.



"BA" Emitting System



"BA" Collecting Plate Support System

The early version of the 'BA' high tension frame used the tension/compression insulator support approach. The later 'BA' design (1976) used cylindrical compression insulators on each end of the high tension frame which were housed within rectangular insulator compartment. A vibrator was used at each support insulator that was, in many cases, eventually replaced with an electromagnetic impact rapper supplied as a conversion kit.

Due to the inherent problem of wire breakage causing shorted fields, Buell, along with the other domestic ESP suppliers with wire-weight designs, switched to a rigid type electrode design. The

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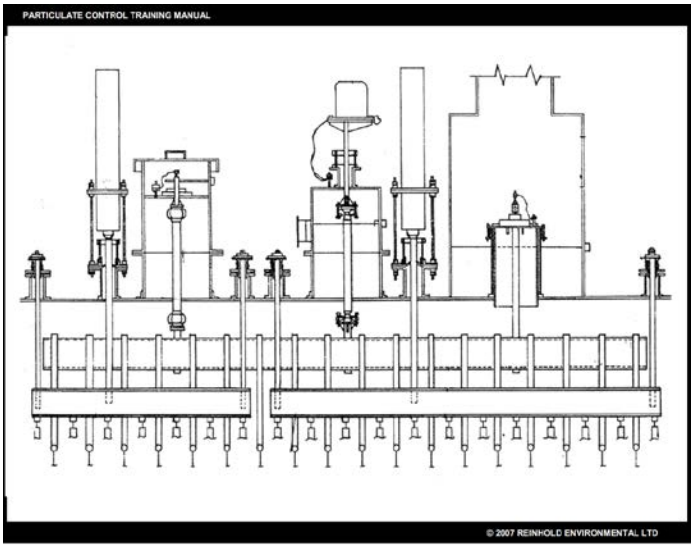
'BE' rigid frame precipitator design, which replaced the 'BA' wire-weight design, was introduced in 1979.

The BE emitting electrode system uses a rigid mast type emitter assembly available in 6 or 9 foot depth and up to 50 foot high. Each mast assembly consists of two 2" O.D. vertical tubes with horizontal supporting tubes. Each mast assembly contains eight, 3/16" square twisted bar electrodes for the 6 foot emitter and twelve twisted bar electrodes for the 9 foot emitter. Each twisted bar electrode is a continuous, extending the full height. Each electrode is pretensioned and welded to the top, bottom, and intermediate tubes. The rigid mast assemblies arrive at the job site ready for installation in the ESP casing. The two vertical 2" tubes are welded to the mast support system after final field alignment. The emitting mast system utilizes a four point suspension system with four alumina support insulators for each electrical bus section. The bottom of the two vertical tubes of each mast assembly is mounted in an anti-sway frame consisting of two channels per bus section. The bottom frame maintains spacing and alignment of the mast assemblies and prevents electrode swaying.

The BE collecting plate system is an assembly of 18", 18 or 16 gauge, rollformed plates with integral stiffeners. The 6' or 9' deep plate assemblies of up to 50' height arrive at the job site pre-



"BA" Design Transverse Section

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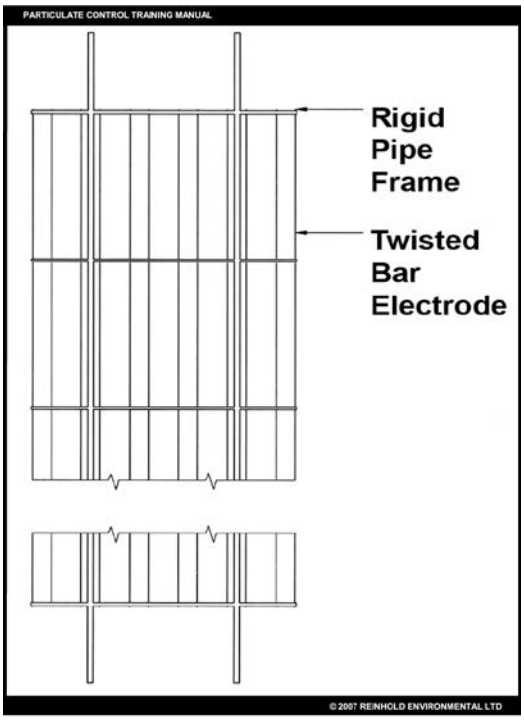
assembled and ready to load into the ESP casing. The plate assemblies are positioned on the top of the lower flange of roof plate girders. Three plate rapping is used with a rapper impact I-beam located midway between the plates girder structural supports. Rapping force transmission is through the impact beam, plate headers and shock bars that attach the individual 18" plates to the plate header support at the plate vertical stiffeners. The bottom plate alignment system consists of "finger" type tabs that have been welded to the bottom of the collecting plates. These tabs fit over a flatbar that aligns an entire row of collecting plates. The open bottom of the tabs allow for differing degrees o vertical movement and/or thermal growth of the individual collecting plate panels. A heavy flatbar for each row of collecting plates extends through a channel section on each end which aligns each plate row with respect to each other.

Particulate removal from the collecting plates and discharge electrode is accomplished by the use of roofmounted electromagnetic impact rappers.

The BE design does not require an insulator purge system for balanced draft PC fired boiler applications. Alumina support insulators are located out of the flue gas and enclosed in a common penthouse. The penthouse is externally insulated and designed to maintain an internal temperature in conjunction with the normal average flue gas temperature. Each



Type BE Rigid Mast Electrode

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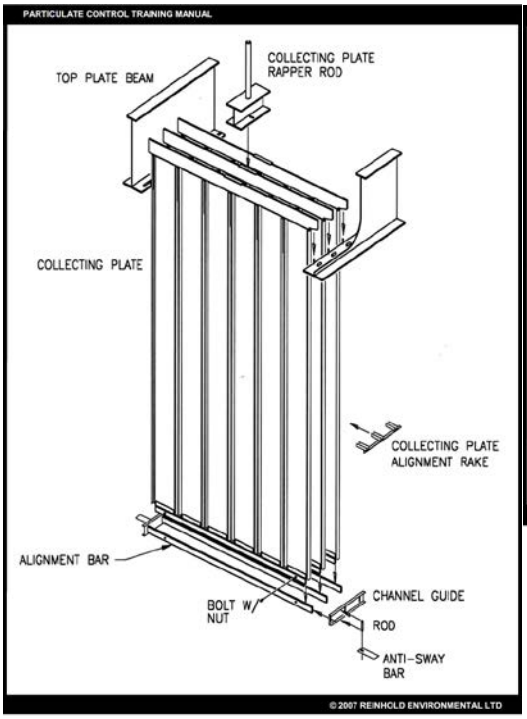
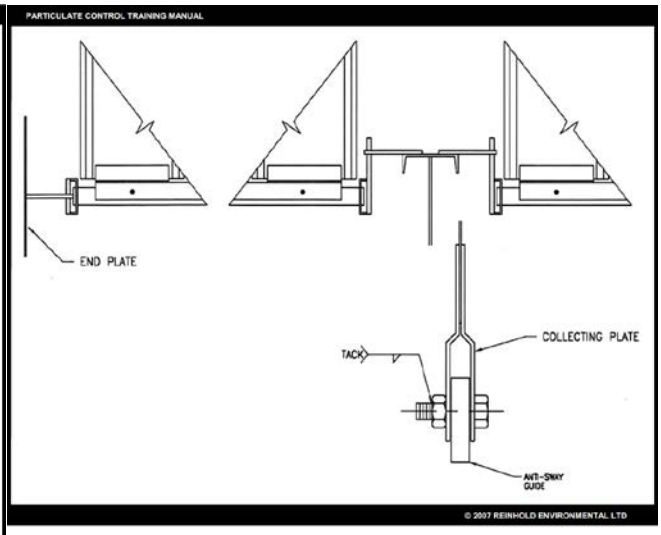
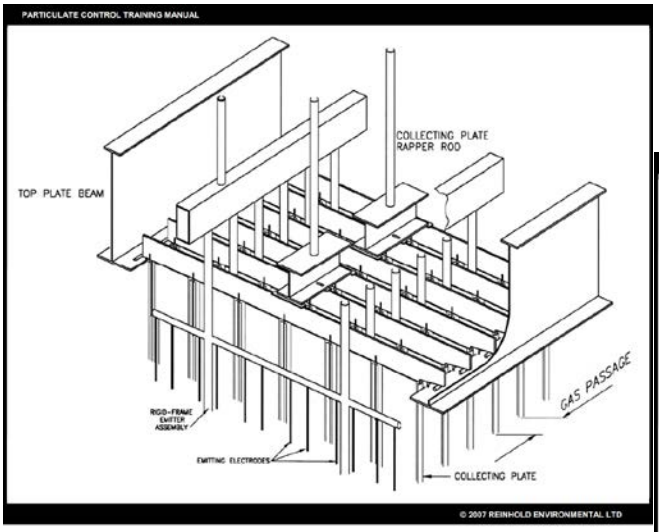
insulator has a gasketed cover plate, which isolates the penthouse environment from the flue gas flow and prevents flue gas from entering the penthouse. This prevents detrimental contamination of the insulator surface, which could lead to high voltage tracking. An individual tubular-type heating element is positioned around each support insulator. A combination of radiant and convective heating elevates the insulator and insulator compartment internal temperatures above the flue gas acid dew point.



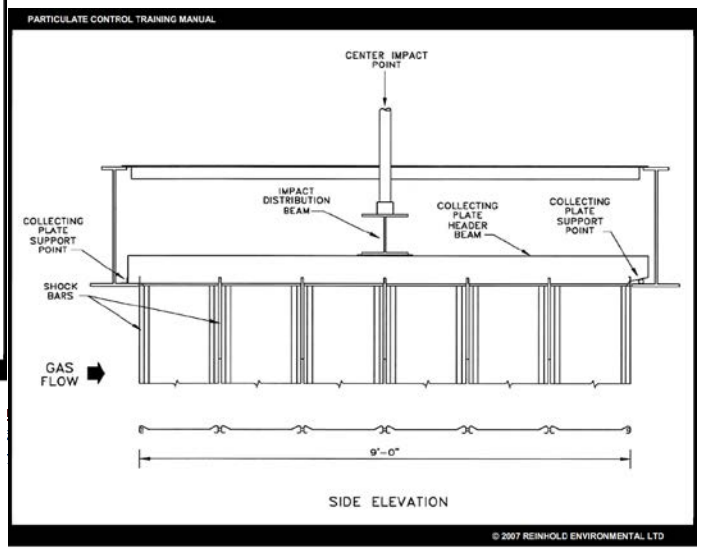
Type BE 9'-0" Plate Array



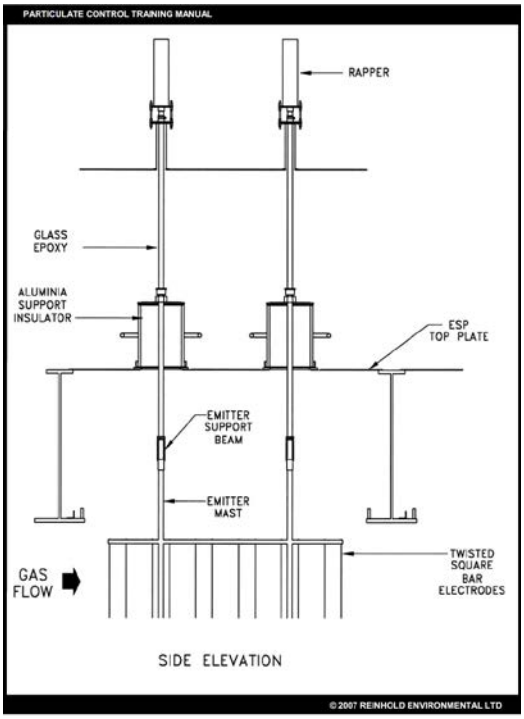
Type BE Collecting System Lower Alignment



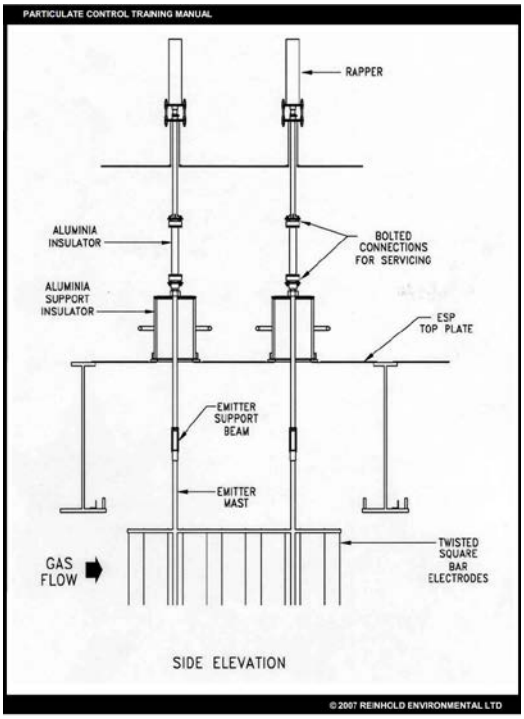
Type BE 9'-0" Plate and Rigid Mast Array



Type BE 9'-0" Collecting Plate



Type Rigid Frame Emitting System (Low Temperature Below 300)



Type BE Rigid Frame Emitting System (High Temperature Above 300)

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2.10 Belco Technologies (Lab SA)

Bogue Electric Company, shortly after World War II, formed Belco (contraction of Bogue Electric Co.), a water treatment company. Bogue in the late 1960's expanded into air pollution by forming Belco Pollution Control Corp. (BPC) via a stock offering. Water treatment was folded into BPC. In the early 1970's Foster Wheeler Corp. (FWC) purchased Bogue's portion of BPC, giving them controlling interest and eventually FWC became the sole owner of BPC. In 1989 FWC sold the assets of BPC to Lab SA, a French company. Lab SA, using the assets, formed Belco Technologies.

Belco Pollution Control Corp, prior to termination, offered the following air pollution control equipment.

- Multi-tube mechanical collectors
- Involute mechanical collectors
- Fabric Filters (AAF technology)
- Semi-dry SOX scrubbers (Deutsche - Babcock tech.)
- SO_3 dust conditioning (Ballestra Technology)
- Acid mist precipitation - lead pipe
- Tar precipitators - steel pipe
- Weighted wire, dry plate precipitator
- Rigid Frame dry plate precipitator (Ceca Tech.)
- RDE (pipe & spike) dry plate precipitators
- "Belcotrode" hybrid dry plate precipitators
- MIGR Rappers -electromagnetic
- "Merlin" digital precipitator controls

BPC had all of the above equipment in commercial operation in 1989.

The standard Belco weighted wire precipitators ancestry was mainly Research-Cottrell with a little UOP thrown in. Most of the Belco designers and managers had worked at Research-Cottrell.

The major deviation from the Research-Cottrell design was in the use of panel collecting plates instead of the one piece pre-fabricated opzel plates. This change was probably due to the large capital expenditure necessary to produce pre-fabricated plates.

Some interesting highlights of BPC are given below:

- Had a 20 inch plate to plate ESP in commercial operation
- Pioneered the digital (computer) ESP controls. In the late 1970s BPC via a modem controlled an ESP in Utah from New Jersey. The control had pulsing, pulse blocking, data storage etc.

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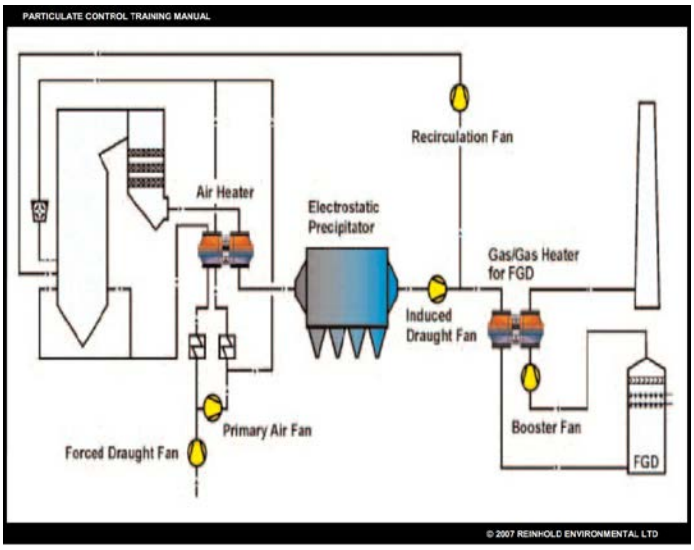
- The MIGR rapper was unique - 20 ft-lb. capability but very small in size. At higher intensities the slug rebounded from the top of casings, thus its downward velocity exceeded that obtained from gravity, although MIGR is "magnetic impulse gravity return".
- The "Belcotrode" used a strip plate and either an RDE or weighted wire discharge electrode. It was top rapped with either external MIGR rappers, external hammer rapping or internal (top) hammer rappings. A flexible economic design for new ESPs and also for rebuilds. Plate spacing varied from 9 to 12 inches.

BPC sold and installed about 200 new or rebuilt ESPs to both the industrial and utility market. Applications included acid mist, tar, wood firing, silver smelting, thermal oxidizers, MSW, cement, alumina, coal gasification, and fly ash. The majority of the business comprised fly ash collecting from P.C., cyclone, and stoker boilers.



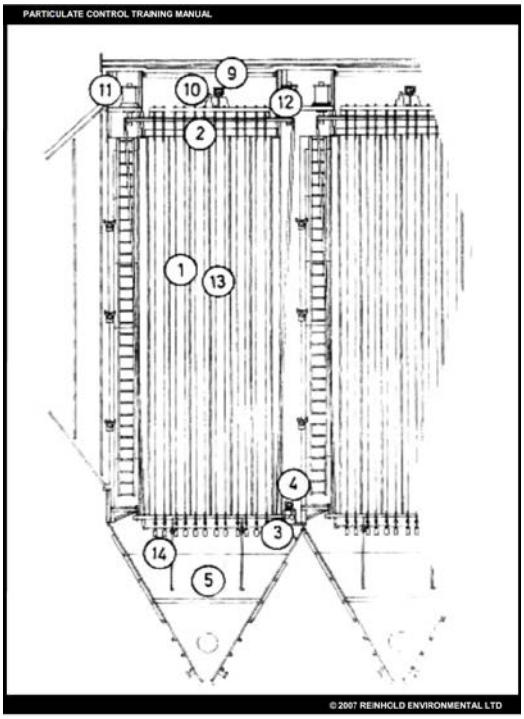
Rothemuhle Components in a Modern Power Plant

2.11 Walther (Balcke-Durr GmbH)

- In 2000, Hamon Group acquired 64% of the Apparatebau Rothemuhle Brandt & Kritzler GmbH and business will continue under the name of Hamon Rothemuhle Cottrell.
- In 1996, Rothemuhle acquired the majority of the Walther shares from GEC Alstom and all business continued under the name of Rothemuhle.

The Hamon Rothemuhle Cottrell ESP is highlighted as an example on the backend sketch of a modern power station (See **Figure:**

Rothemuhle Components in a Modern Power Plant



Rothemuhle Frame Mounted Discharge Electrodes

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).

Hamon Rothemuhle Cottrell (Walther) engineers have been designing ESP's since 1951 for all major applications such as: utility, cement, lime kiln and cellulose industries. At the beginning, Walther used a weighted wire design (See **Figure:**

Rothemuhle Frame Mounted Discharge Electrodes

), but in the mid sixties a change was made to the rigid frame design (**Figure:**

Rothemuhle Weight-tensioned Discharge Electrodes

), which allowed increased collecting electrode (CE) heights with comparably large bus sections, discharge electrode (DE) frames with significantly less wire breakage problems and electrode rapping with tumbling hammers for both, CE's and DE's.

Walther acted originally as a well established boiler manufacturer and started in the early fifties the ESP business in Cologne in cooperation with Simon Carves LTD. in England and with CECA in France. Their horizontal type ESP design was close to the European ESP design (**Figure:**

Walther Horizontal Type ESPs

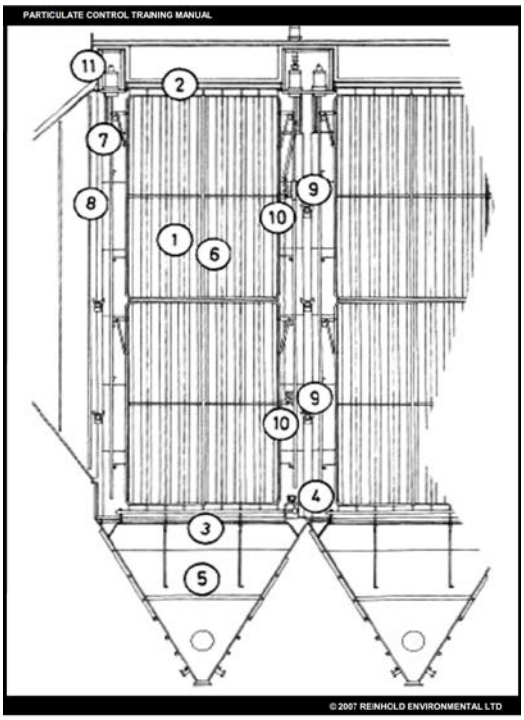
) and was used mainly for ESP's in the utility, cement and metallurgical industries. But included among nearly all industrial applications was also a vertical ESP's for cleaning vapor from coal/lignite drying and grinding processes, for gas de-tarring in coke-oven-plants and other off gas cleaning.

Walther and Rothemuhle started to extend their business with license agreements in the North American continent.

Walther's standard CE's, some different SIGMA profiles (**Figure:**

Typical SIGMA Collecting Electrode Panel Profile

) with a nominal width of 500, 875 and 1000 mm are generally in use, which allow, because of its stiffening edges and ducts, excellent particulate collecting and highly efficient rapping abilities.



Rothemuhle Weight-tensioned Discharge Electrodes

Since about 1993, Unbreakable Studded Tube DE's (**Figure:**

Unbreakable Studded Tube DEs Individually Rapped Tubular Frames

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) in individually rapped tube frames are in use also, especially in upgraded precipitators in the utility industries worldwide and behind iron ore sinter strands. The electrical VI characteristics can be varied by the amount and arrangement of the studs. This DE technology has its further advantages because of the high rapping effectiveness, since it is designed to avoid the settlement of particularly low dense dust on the DE tubes and studs.

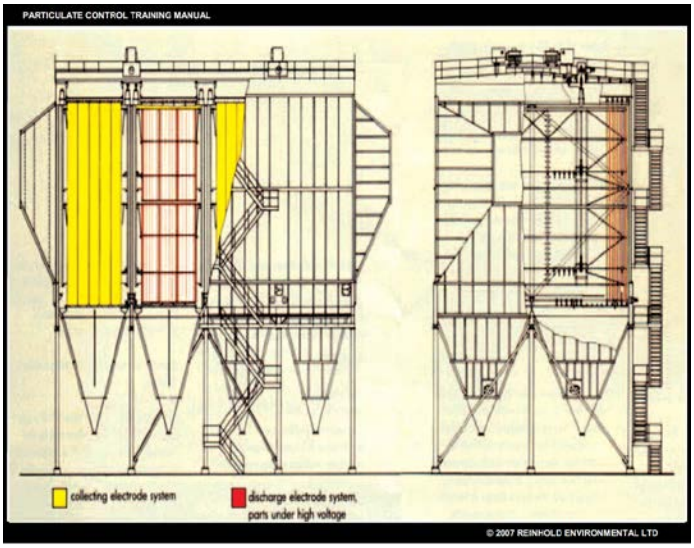
For nearly two decades, the plate-to-plate spacing in Europe was 12 inches (300 mm) with CE heights up to 46 ft (14 m) but after comprehensive studies and test work in the early eighties at EPRI's Arapahoe test facilities in Denver, Colorado together with SoRI, C-E/ESD and SHI, there was a strong tendency toward using the promising results.

Standard plate spacing was increased to16 inches (400mm) and CE heights to 50 ft (15m) and more. The consequences of the so-called Wider-Plate-Spacing had to be the adjustment of electrical insulation parts and proper mechanical clearances inside and outside the boxes in order to take profit of nearly proportional increased migration velocity. Since about 1984, Walther ESP's have been successfully installed with 16 ft (400 mm) plate spacing for practically all process applications. In some selected cases, ESPs are designed and in service with mixed spacing up to 500 mm.

Besides the above ESP, a Modular Type Electrostatic Precipitator (**Figure:**

Modular Type ESP Ready for Shipment

) for numerous industries with off gas volumes in the range of 3000 to 50,000 m³/h (about 1,800 to 30,000 acfm) was developed and marketed with tremendous success after the German Clean Air Act in 1986 has stipulated a reduction of particulate emission limits.



Walther Horizontal Type ESPs

In order to optimize the footprint effective ESP volume, DE top rapped Short Casing ESP's (**Figure:**

NT Type Short Casing ESP

) have been available since the early eighties and in use for several industrial applications for the range of 50,000 to 460,000 m³/h (about 30,000 to 275,000 acfm), but preferably for municipal and chemical waste incineration plants. As DE's, unbreakable Corostab- (**Figure:**

Corostab Discharge Electrodes in CE Electrode Arrangement of Modular Type ESP

) and / or Stud Tube - Electrodes (**Figure:**

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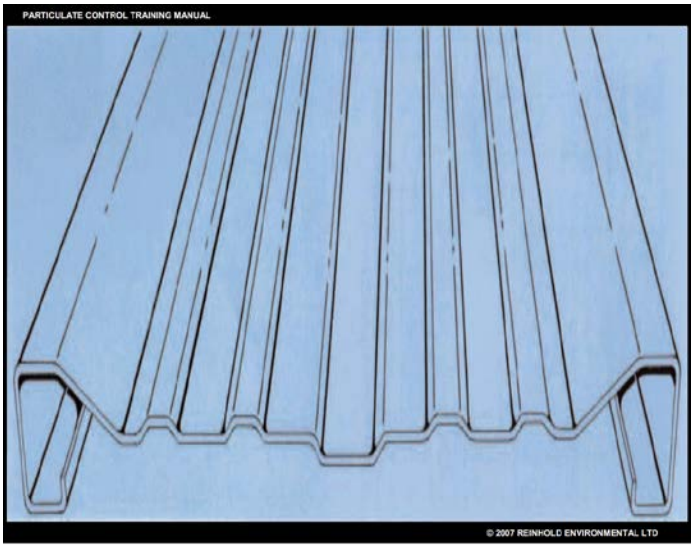
) are in use.

Consequently, after extensive and comparing real size acceleration testing, the latest development is the ready-to-go DE&CE Top Rapped Short Casing ESP type for unlimited gas volume treatment.

Regarding gas flow distribution in Walther ESP's, it was found that in most applications for the Walther ESPs, advantages for the overall collecting efficiency exist, if a certain flow maximum in the upper region over the whole ESP length can be maintained (**Figure:**



Typical SIGMA Collecting Electrode Panel Profile

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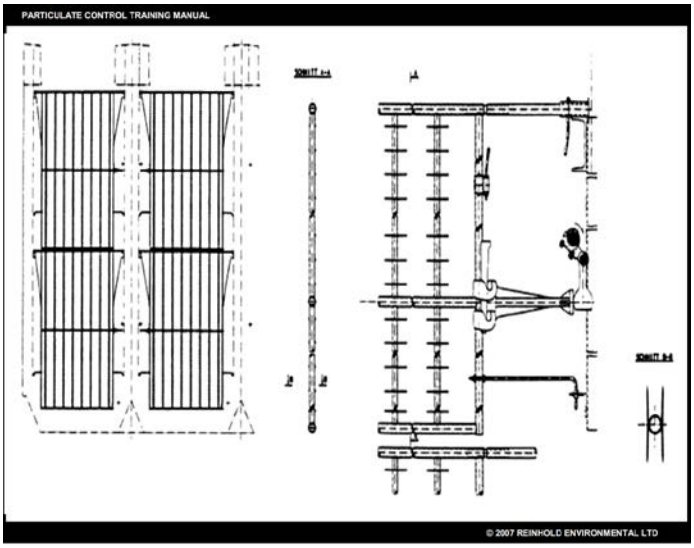
) contrary to recommendations of ICAC. This kind of flow distribution is obtained by means of appropriate fittings into the raw gas and clean gas ducts.

For electrical field energizing, Walther has cooperated worldwide with nearly all major suppliers for transformer/rectifiers and controls. The general control of Intermittent Energizing and/or Microsecond Pulsing for high resistive particulate collection is available.



Unbreakable Studded Tube DEs Individually Rapped Tubular Frames

Modular Type ESPs Ready for Shipment

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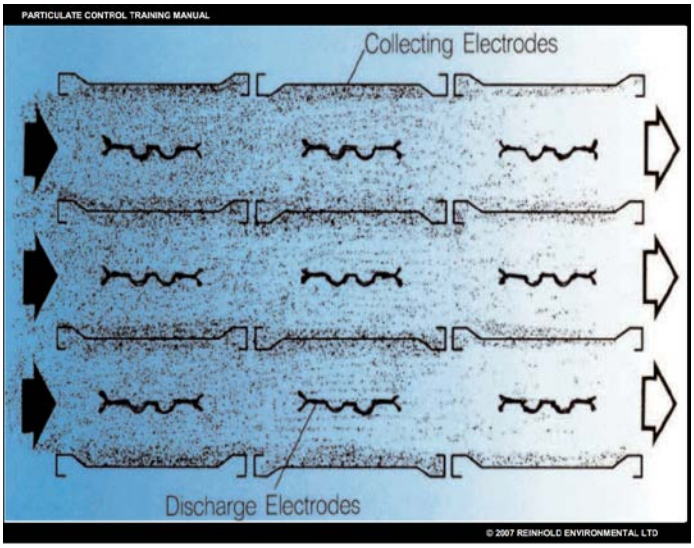
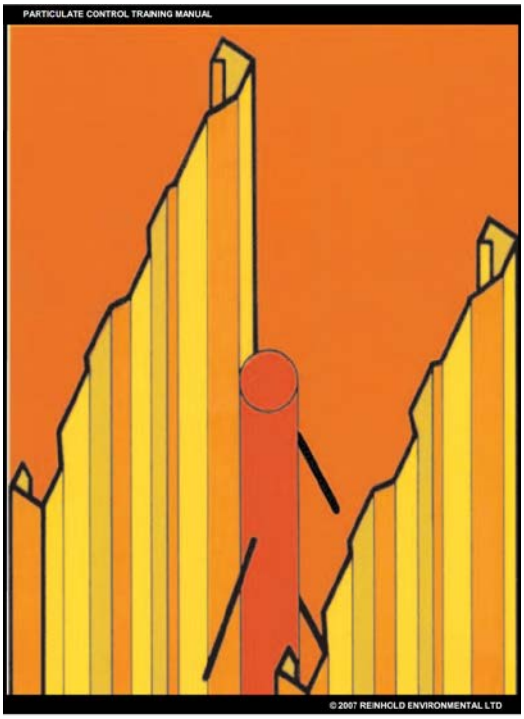


Corostab Discharge Electrodes in CE Electrode Arrangement of Modular Type ESP



Stud Tube Discharge

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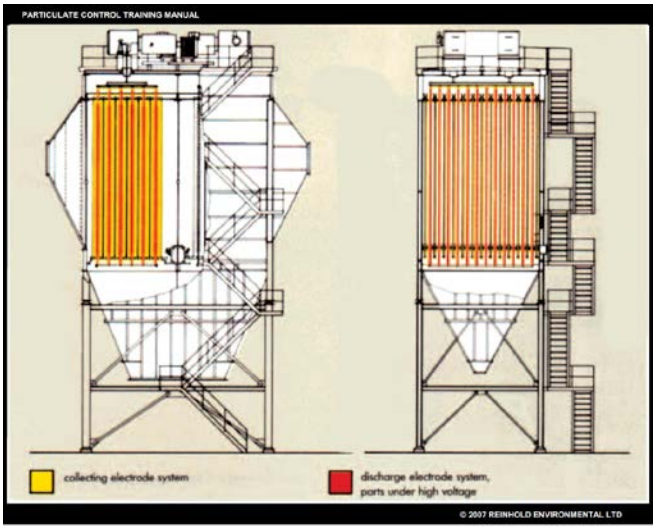
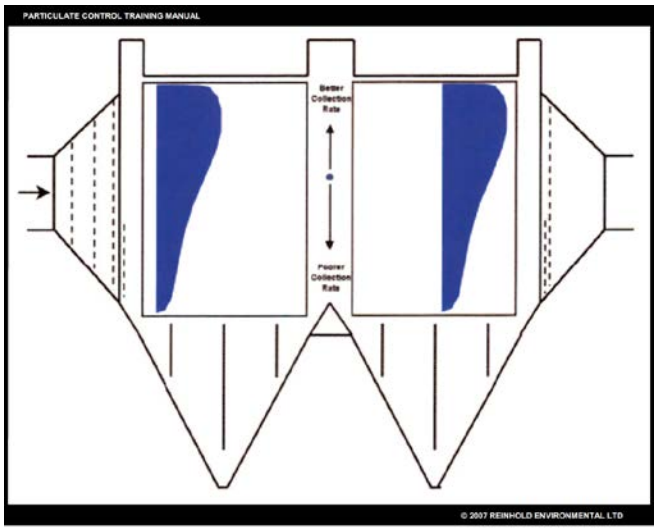


NT Type Short Casing ESP



In Principle, Recommended ESP Flow

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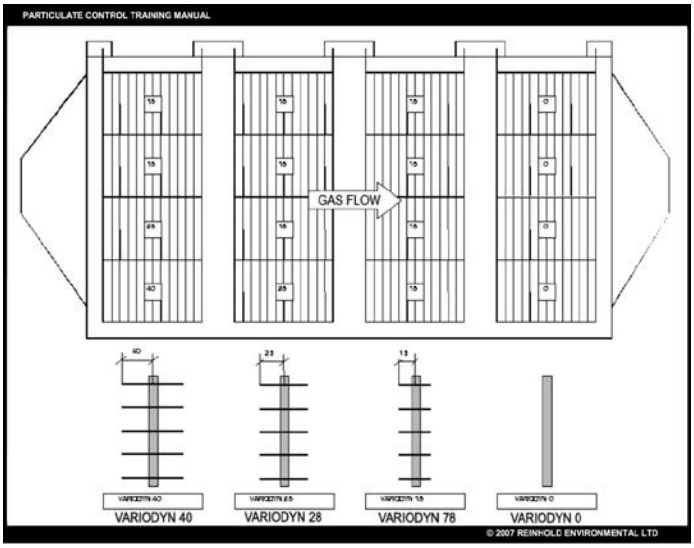
2.12 Lurgi (GEA Bischoff; Allied Environmental)

Lurgi is one of the oldest manufacturers of ESPs worldwide. Today, Lurgi's product portfolio comprises the full range of dedusting equipment needed in all kinds of process and industrial processes.

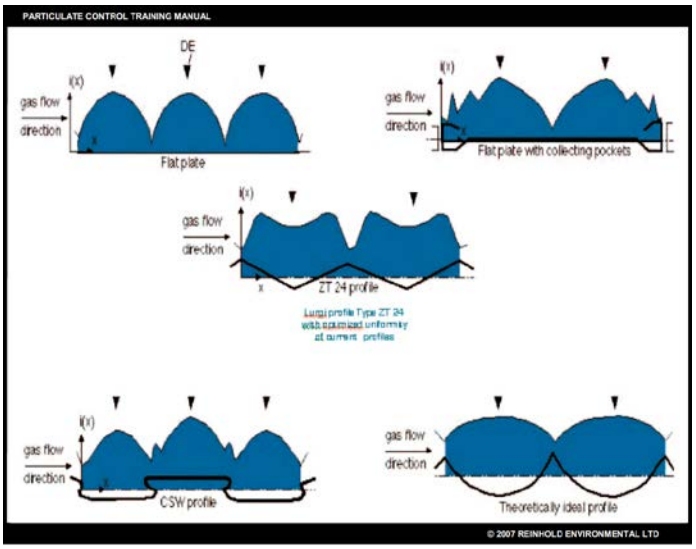
Apart from the traditional horizontal dry ESP, which is present in most applications, explosion-proof versions, wet and dry-type vertical ESPs with honeycomb or tube-type electrodes as well as wet horizontal type ESPs are built by Lurgi.

For many decades, the technology came out of its headquarters in Frankfurt, Germany. As a result of optimising the environmental activities within the Lurgi group, the Lurgi particulate control technology applied in power generation plants has been transferred to Lurgi Lentjes Bischoff GmbH (LLB) based in Essen, Germany in 1996. LLB, known for its Flue Gas Desulphurisation (FGD) and DeNOx-technologies, offers the complete range of flue gas cleaning technologies for the power generation sector.

Lurgi Bischoff GmbH (LB), also based in Essen, is responsible for the dedusting techniques in all other industrial processes such as cement and metallurgical processes, glass industry and others. R&D-facilities in Frankfurt are available to all companies of the group.



Theoretically Possible VARIODYN Configuration Throughout ESP



Current Profiles for Different Collecting Plates

Historical Development.

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Dedusting of industrial process and waste gases is one of Lurgi's oldest fields of activity. The very first unit was commissioned in 1913 at the Hoboken Metallurgical Works in Belgium.

From the very beginning, the activities were always aimed at optimizing the overall process including all its aspects from sizing to structural design and flow distribution as well as the energisation and controller systems.

The well known "Deutsch"-sizing formula was actually named after its developer, W. Deutsch, at that time in 1922 member of the Lurgi R&D-staff.

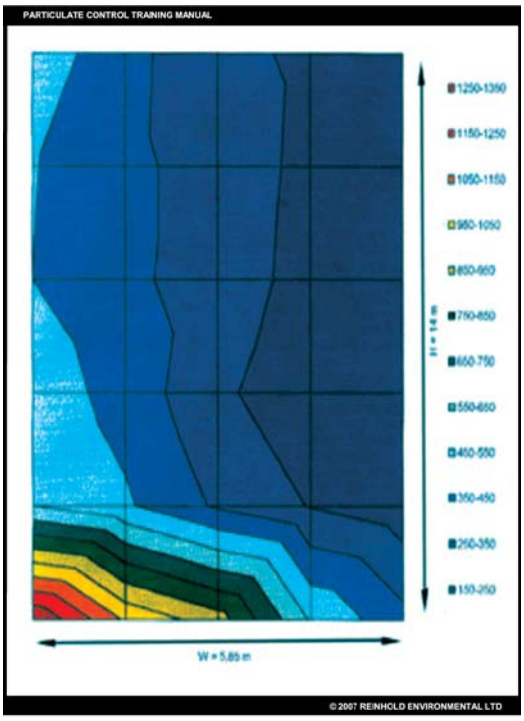
Substantial progress was made on the field of precipitator energization, when the first selenium rectifiers were introduced in 1951. Thyristor controllers were introduced in 1966.

In 1980 Lurgi implemented its vast process experience into the first edition of COROMATIC □ microprocessor controllers, which now has advanced to its current version, the COROMATIC □F, featuring fuzzy logic control algorithms and numerous remote operating and servicing functions.

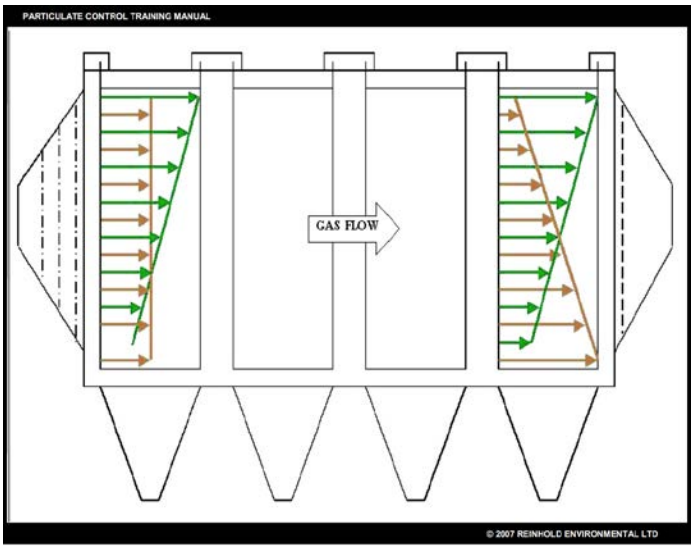
By 1997, more than 13,000 ESPs were built in various applications, among those more than 4,000 units for the power generation sector.

Increasing demands to protect the environment require a state-of-the-art product portfolio, which at Lurgi is ensured and backed by extensive research and development activities on all main aspects in Lurgi's own laboratories.

The following text gives an overview over the main features of the LURGI precipitator.



Distribution of Rapping Acceleration Values
(CE-height 14m, CE-length 5.85m)



Vertical Velocity (green) and Ash (brown)
Distribution Profiles

Design Base.

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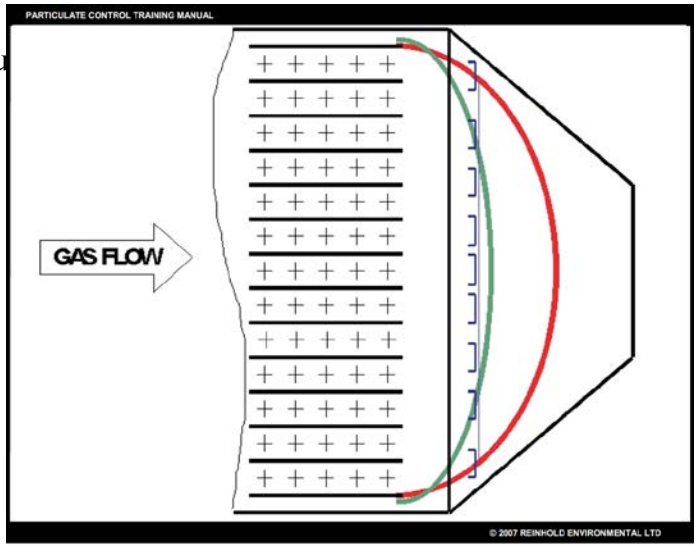
LLB can rely on a unique experience of more than 13,000 ESPs installed and commissioned by the Lurgi group worldwide. On the power generation sector, more than 4,000 ESPs have been built covering an enormous span of fuels and operating conditions. It's exactly this experience and knowledge of specific references, that makes LLBs sizing of new plants safe and reliable.

Adapted Discharge Electrode Design VARIODYN □.

Charging of the particles is the first step of actual particle precipitation. Therefore, the VARIODYN ÷Discharge Electrode supplies exactly the right amount of current where it is needed. Emission spikes with variable length allow to adapt the electrode emission characteristic to the ash concentration in the precipitator. Negative field charge effects in areas with high concentrations of ash and/or fine particles can be addressed with VARIODYN □ 25 or 40 electrodes, whereas increasing back corona tendencies towards the outlet fields will be limited by selecting a VARIODYN □ 0 configu

The VARIODYN □ is welded into a rigid tubular frame. For electrode heights in excess of 7.5 m, two separate frames with individual rapping systems are used. This design ensures lifetime alignment and tension of the individual electrodes, thus maintaining maximum efficiency.



Horizontal Velocity Profile with (blue) and without (red) Baffle Wall

Optimised CE-Electrode Profile ZT 24.

The proprietary Lurgi ZT 24 collecting electrode profile was developed with the next two of the main process steps of electrostatic precipitation - particulate migration to the collection plate and cleaning of the collector - in mind:

Uniform Current Density:

The ZT 24 provides a uniform current distribution in order to achieve a homogenous electrical field for maximum particulate migration rates. These superior electrical properties are maintained throughout the ESPs working life, as the single plates are interlocking over the total CE-height, thus ensuring permanent perfect alignment.

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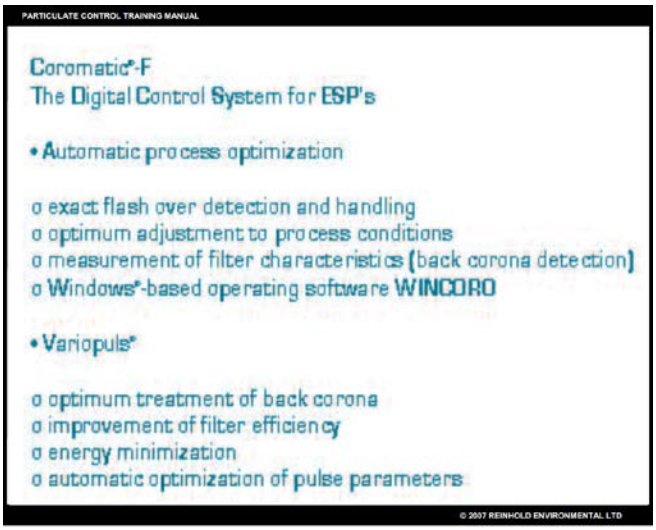
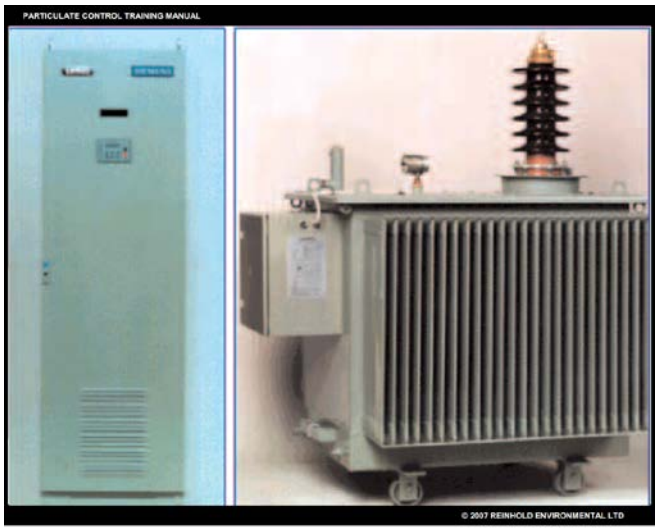
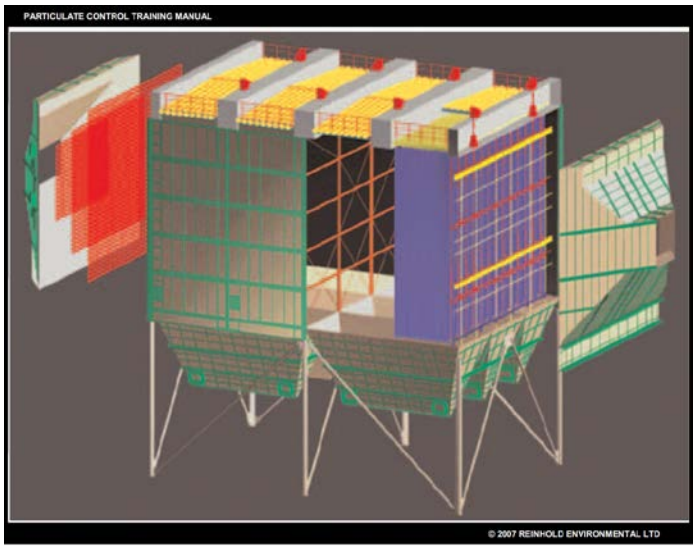


COROMATIC Features



COROMATIC Control Cubicle and T/R-Set

High Rapping Efficiency:



Casing and Suppoerting Structure Design of Lurgi Lentjes Bischoff BS 930 ESP

The ZT 24 enables efficient electrode cleaning through optimised rigidity and vibration properties. Rapping accelerations of more than 150 g ensure proper electrode cleaning and leave

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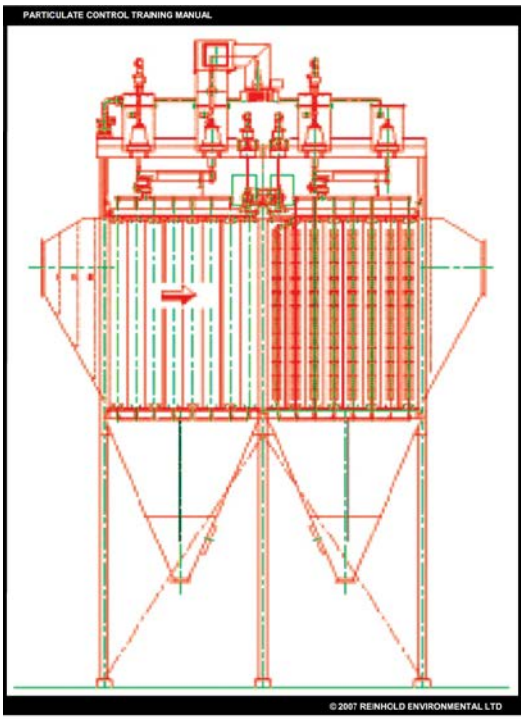
room for possible further extensions of electrode height. In all Lurgi-ESPs, mechanical hammer rapping systems are employed, since this technology ensures higher and more efficient cleaning than any other mechanical system.

Gas Flow Distribution.

One of Lurgi's main R&D-activities throughout the years was the optimization and standardization of gas flow internals. A suitable range of distribution screens was developed, which - in combination with the proper, also standardized inlet plenum configuration - minimizes, respectively eliminates the need for model testing for new plants.



Compact RDE-ESP with Rigid Discharge Electrodes and Top-rapping Systems

Recent discussions among both suppliers and users about the shape of the velocity profile - uniform or "skewed" - have not yet come to a final conclusion. However, it should be noted, that a certain "skewing" of the flow towards the ESP-outlet by positioning the outlet duct at a slightly higher elevation than the inlet duct has always been practised.

Nevertheless, it is advisable to leave this critical part of the process to the experience of the supplier, as he is the one to guarantee the performance of the plant and it is obvious that he will optimize the process in whichever way needed to achieve this goal with maximum reliability.

At Lurgi, each case is evaluated critically and the most suitable distribution is selected in accordance with the other process parameters.

The "skewed" flow concept as applied in several installations can be described as follows:

Vertical Distribution:

The mass flow of suspended ash in the precipitator decreases throughout the precipitator. However, due to rapping and gravity effects, the highest concentration of the remaining ash will be in the lower precipitator regions. Therefore it makes sense to have a slightly lower gas velocity in those areas in order to prevent increased ash carry out for higher efficiencies. In turn, a slightly higher velocity in the upper region can be accommodated without any detrimental effect.

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The distribution devices utilised include perforated plates, X-type walls, baffles, etc. - mechanically cleaned if necessary.

Horizontal Distribution:

The horizontal flow profile on the other hand has to be as even as possible in order to assure the same velocity and efficiency in every gas passage. Especially in the last field, a distortion of the horizontal distribution can be present with unfavourable outlet hood or clean gas duct configurations. A baffle wall with variable baffle spacing is installed in the clean gas hood, thus levelling horizontal gas distribution while maintaining a low pressure drop.

COROMATIC-ESP-Controller.

The LURGI COROMATIC - ESP-Controller is the mastermind of the precipitator. The COROMATIC control algori
installed. Specifically back corona detection and back corona treatment procedures have been optimised: The COROMATIC - operating when back corona VARIOPULS
is detected, it automatically selects the appropriate pulse parameters by using fuzzy logic control algorithms. This feature is a must when a wide span of difficult and high resistive ashes have to be collected.

Precipitator maintenance, data monitoring and data logging is made easy with the associated WINCORO - operating software, also offering easy remote access and system diagnosis tools.

Structural Design/Steelwork.

Lurgi's original ESP design can be referred to as what most people call "European Design", i.e. a casing with box-type roof-beams, which at the same time accommodate the support insulators for the high voltage system. Inlet and outlet plenums are equipped with gas distribution internals, the ash hoppers can be both pyramidal or trough-type, as required by the process.

The supporting structure of Lurgi Lentjes Bischoff ESPs is designed as a pendulum system. This means, that thermal expansion is compensated by pendular movement of the supporting pillars instead of using roller or slide bearings - completely maintenance free.

Furthermore, the number of required foundations is reduced by executing the lower ESP-casing section as a rigid frame. A supporting pillar is required only every 16 meters (approx.), thus reducing steelwork weight and civil work significantly.

The weights of the casing are optimized using a Finite Elements - method already in proposal stage.

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Compact RDE-ESP's.

Especially for smaller volume flows in industrial applications such as waste or sludge incinerators or small utility boilers as well as for the retrofit of larger, "traditional" ESP designs, the RDE-design was developed.

Other than in the traditional design, the discharge system is suspended from support insulators arranged above the electrical field, thus avoiding the extra clearance between the fields for the supporting frames and rapping systems. However, proven elements of the traditional Lurgi-ESP - the four point suspension of the electrical field, the reliable and long-lasting tumbling hammer rapping systems etc.- were maintained.

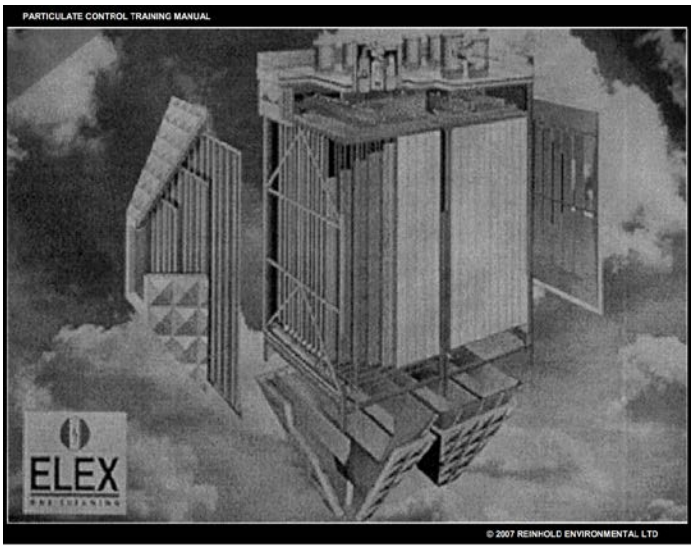
Optional top-rapping for both DE and CE-systems increases the available active volume in an existing casing, which makes this design ideal for retrofits.

A specific rigid pipe and spike-type discharge electrode was developed having in mind the same characteristics as the VARIODYN rigid frame el
of the welded-on emission tips, similar adaption of the corona current to the ash concentration in the ESP-casing is achieved.

2.13 ELEX

Basic Design.

In the ELEX-horizontal electrostatic precipitator, the collecting electrodes consist of profiled plates. These form a system of passages through which the exhaust gases flow. The discharge electrodes - type RS - are arranged along the central axis of the 400 mm wide passages. Mechanical rapping equipment cleans the collecting as well as the discharge electrodes by means of periodic rapping.



Typical ELEX Precipitator

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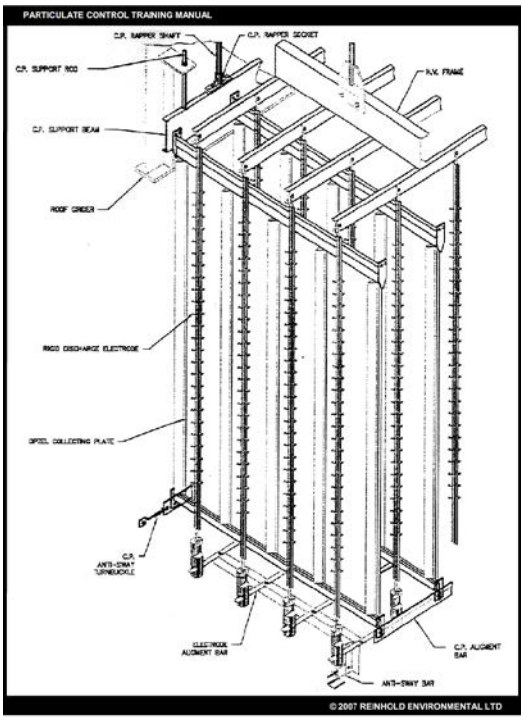
- Surfaces to be as smooth as possible to permit high flashover limits
- Good oscillation behavior to ensure that rapping produces high accelerations that will dislodge the dust as completely as possible from the plates
- Freedom of thermal movement for the collecting electrodes in the event of sudden temperature changes.

Discharge Electrode.

The ELEX discharge electrode is unique in present day practice. While similar devices have been used occasionally in the past in limited cases, ELEX has concentrated on it. The electrode is fabricated from independent stamped sheet metal stampings fastened by spot welding to a rigid body. By changing the design of the stampings, altering the spacing and changing their orientation, the aggressiveness of this electrode can be varied widely. The discharge electrode system comprises the actual electrodes and their supporting system. Criteria to be fulfilled are:

- Non-fracturing, so as to attain the same service life as the other components of the precipitator
- High impact strength, so that the discharge electrode can, during rapping, be given the same acceleration as the collecting electrode
- High disruptive voltage, in order to achieve optimum utilization of the installed collecting surface area
- Immunity from electro-erosion.



ELEX Electrode Design

Rapping System.

To attain high accelerations for dislodging the dust even from plates of considerable height each plate is rapped individually. An eccentric suspension ensures that each plate bears only a small force against the drive attachment on the rapping rod. When the rods are struck, the impact energy is thus transmitted undamped into each individual plate.

Electrical Equipment.

Electrical equipment must be adapted to the prevailing operating conditions to achieve the high dust removal efficiencies required today. The power supply system consists of:

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- Thyristor-controlled high voltage rectifier
- Control cabinet with automatic voltage control and thyristor with current limiting reactor
- Hand-operated disconnecting switches and, for certain applications, additional electromagnetically or pneumatically operated fast responds earh switches. (These components can be located with the high voltage equipment in the HV-room or on the roof of the precipitator)
- The low voltage switch gear cabinet for the auxiliary equipment (e.g. rapping mechanisms, insulators and hopper heating as well as dust conveying equipment).

High Voltage Rectifiers.

The following parts of a high voltage rectifier are built into a hermetically sealed oil tank:

- Current limiting coil
- High voltage transformer
- High voltage silicon rectifier set
- High voltage measuring resistance for voltage and current

High Voltage Control.

The objective of ELEX is always to achieve the technical and most economical optimum solution for each application. For that reason, stringent demands are placed on the high voltage controller:

- Accurate recording of the signal values, i.e. rapid and refined diagnosis of sparks and arks
- Control of signal values such that optimal suitability of the power supply to the continually changing electrical demands is guaranteed.
- Possibility of the modulation of one or several half-waves for the purpose of saving energy
- Easy-to-understand failure diagnosis
- Simple adaptation to new operating conditions

For control purposes, conventional relay systems are frequently being replaced by programmable logic controllers (PLC's) which guarantee efficient connection to the microprocessor controlled high voltage equipment.

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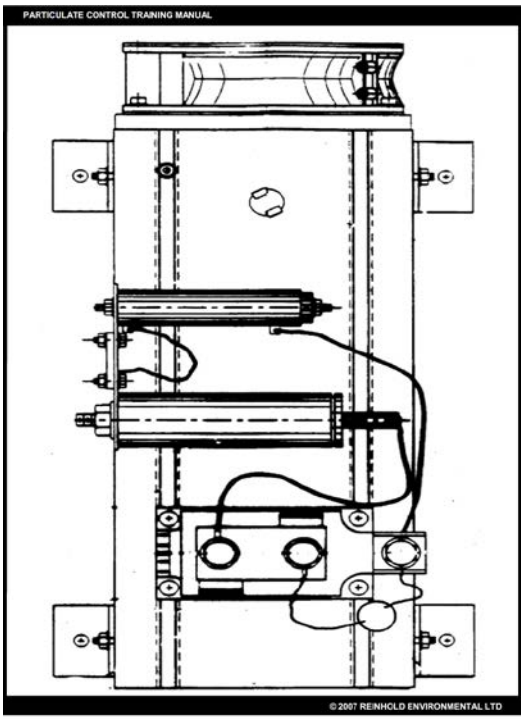
CHAPTER 3 - CONTROLS AND MONITORING

This chapter is a comprehensive review of ESP controls and monitoring systems including:

- ***ESP TRs (Transformer-Rectifiers)***
- ***ESP AVC Controls(Automatic Voltage Controls)***
- ***ESP AVC Control Troubleshooting***
- ***ESP Cleaning Device (Rapping) Controls***
- ***ESP Central Control Systems***
- ***Opacity***

A Troubleshooting Guide on ESP Controls and Electrical Systems is presented in the following reference prepared by NWL:

- ***Click to open NWL Troubleshooting reference***



An SCR Assembly
(Courtesy of Redkoh)

3.1 ESP TRs

General Description

Conventional Transformer-Rectifier (TR) units, operate from a pair of phases provided from an AC 3 phase source. As the quantity of TR sets increase on a power distribution system, the TR sets are split among the different phases. This offers the power distribution unit some semblance of balance.

The fundamental purpose of a Transformer Rectifier is to provide a suitable direct current voltage and current delivery capability that can be applied and drawn by an electrostatic precipitator. On application of this high voltage to the load (ESP in this case), certain things are expected to happen and so the design of the TR set is expected to be carried out with these in mind. This is typically how and why specifications for TR sets come about. The different ESP manufacturers and users have certain criteria that must be met by the TR set in order that it can fulfill its role in the electrostatic precipitation process. The equipment is manufactured as a

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number of sub-assemblies making up an operational unit. These are discussed later in this section.

TR sets are available in ratings to meet a wide range of voltage and current requirements for precipitator service. They typically have the following ranges:

- DC voltages ranging from 15 KV to 85 KV average
- DC currents ranging from 10 mA to 3000 mA average

Supply voltages and frequencies differ from country to country and continent to continent and must be accommodated by designers.

TR Components

The unit considered in this discussion example and certainly the type that is most frequently manufactured is complete in one tank and consists of:

1) A step-up supply transformer mounted either on the tank bottom and secured in place by guide bars welded to the tank wall or suspended from a frame welded to the top cover of the tank.

It is important to know which type you are using or buying because this plays a direct role in any maintenance procedure. Lifting a lid may be as easy as removing the bolts and sliding it out of the way as opposed to having a requirement for specialized lifting equipment.

The transformer is a step up device raising the voltage from the voltage applied to the primary to a level that when rectified provides the ESP with the ESP Manufacturers' specified levels.

2) The high voltage outputs from the secondary of the transformer are connected to a Bridge Rectifier assembly. Bridge rectifiers differ by manufacturer, and so to cover all the types would again not be something to attempt.

Most Transformer Rectifiers nowadays are of the "full wave type". This means applying a voltage to the load every half cycle of the supply. Many half-wave systems still exist and in this case, the voltage is applied to the load every 2nd half cycle. Most have two bushings to energize two separate electrical sections.

Most rectifiers supplied are designed with a certain safety factor in mind (Both in terms of applied voltage and current drawn). Safety factors of at least 10% can be expected from most manufacturers.

3) Most rectifiers are fitted with a certain level of RC (Resistor Capacitor) compensation, designed to promote sharing of the load over the entire rectifier and relief against the transients associated with the ESP application.

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4) An HF/HV choke (reactor) coil is fitted between the output of the rectifier assembly and the connection to the ESP. This choke sets about filtering out high voltage/frequency transients that are generated in the application. The secondary connection of the choke is connected to the underside of the high voltage bushing.

5) High voltage output bushing(s) are mounted either on the top cover of the T-R unit or on the sidewall of the tank.

6) Low voltage bushings for primary supply, metering, control and DC ground connections are also fitted to the outside of the tank. The location of these differs by manufacturer but most are fitted within a low voltage junction box mounted to the sidewall of the TR tank.

7) Gaskets used on TR sets differ by manufacturer and by fluid used. Some materials used would be neoprene rubber impregnated cork, neoprene rubber and Viton. Each has its advantages and the ability to withstand the environment in which it is placed.

Leaky gaskets are often more of an eyesore than a critical issue that needs immediate attention. A small amount of fluid seepage gives the observer a first impression of a large amount of fluid leakage. More often than not the amount of fluid that has leaked only represents a few cubic centimeters (ounces), but it has wonderful wetting abilities and so a small amount of fluid spreads over the tank surface to a large degree. The dust sticks to the oil and so a huge stain appears giving the impression of severe leakage.

8) TR Sets may be fitted with plain skid bases, unidirectional wheels or bi-directional wheels.

9) A drain valve - Hopefully you only ever need this for the purpose of taking fluid samples. Apart from this it's fairly obvious as to why they are fitted. The drain valve is often responsible for leakage. A plug and sealing tape is well worth the extra effort. This keeps the unit from leaking as well as keeping the threads clean. This makes is possible to take samples without contamination by grit from the threaded portion of the valve.

10) Ground connection - This is a super critical issue and relates both to the safety of the operational system as well as to the control of it. Good grounding is the most common oversight on TR sets. The fact that the TR may sit on the steel structure is not good enough.

11) Lifting hooks - How else would you expect to lift a 3000lb device that has some weird shape and no place to hold it?

12) Nameplate with schematic diagram - After many years in service, papers get lost. Details of the unit disappear. The only information on a Unit after 20 Years of operation is often the nameplate - Make sure the nameplates are permanent and of a material that does not corrode in your environment.

13) Liquid level gauge - It's always a good idea to check on the fluid level in a TR unit. Even

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though there are no signs of leaks, you can never be sure. There have been places where oil has been taken from one unit to top up another. Certain components within the TR insulation system require oil coverage to maintain their operational characteristics. These should not be jeopardized.

14) Pressure relief valves are spring-loaded devices, with the tension on the spring set to be overcome when the pressure in the TR unit exceeds the tension on the spring.

15) Dial type thermometer - Keep track of the temperature of the TR unit. Many different designs of thermometer exist. They may differ in quality and price, but all serve the same purpose. Watch the top oil temperature. The designer had an ambient design temperature in mind when he put the unit together. Exceeding this because of something that he did not know would not be fair.

16) Filling pipe on cover. This becomes useful if your oil sample indicates the presence of something "Not quite right" in the fluid. The re-circulation system gets connected here and on the drain valve allowing you to circulate and clean/dry fluid via the extremes of the tank.

17) Hand-hole on the cover for TRs (very useful for gaining access to rectifier assemblies and also disconnecting the HV bushing so the top TR cover can be lifted).

18) Junction box on the tank wall for connection of low voltage supply, metering signals, control and DC ground leads. The low voltage junction box usually contains a surge protector to protect the metering circuits and prevent surges from reaching the control.

Insulation and Cooling Fluids

Most TR Units are either types ONAN (Oil Natural Air Natural) in which case the cooling liquid is mineral oil, or LNAN (Liquid Natural Air Natural) in which case the liquid is either silicone fluid or R-Temp fluid. Other fluids are used in different countries, but those mentioned here are by far and away the most common.

Each has certain characteristics that give them a place in the industry. The most common reason for differentiating between the fluids in the ESP industry is that of the flash and fire points. Both R-temp and silicon possess qualities that make them superior in this respect. The down side of this is the additional cost and the availability of these over conventional transformer mineral oil. They also have superior operating temperature ranges, which allow the designers to run units at greater temperatures than one, would normally design for in the case of mineral oils.

Some interesting facts:

Mineral oil and silicone are not compatible. The presence of silicone fluid in mineral oil will cause the oil to foam severely when it is vacuum processed. A small amount of transformer

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mineral oil in silicone fluid will result in a reduction of the flash and fire points of the silicone liquid which renders the whole reason for the use of this expensive fluid useless.

R-Temp fluid is fully miscible and compatible with transformer mineral oil However small percentages of mineral oil in R-Temp fluid will reduce the flash and fire-points of R-Temp fluid causing the point of using the R-Temp to be missed.

TR Units are typically designed for a 55° C rise in a 40° C daily average air temperature. However there are numerous places where the ambient in which the unit is expected to work is higher and sometimes the temperature rise of the unit can be reduced by design.

Other Bits and Pieces

An ESP power supply system is made up of a number of assemblies. The following paragraphs refer to some useful and in some cases essential equipment.

1) A current limiting reactor CLR mounted on or in the TR tank or in a suitable enclosure. The CLR is a subject all of it's own. It fulfills a far greater function than simple current limiting capabilities. It interacts with the ESP, the TR set and the controls.

2) A 2-position ground switch for use on full wave units can be fitted inside the T-R unit or externally adjacent to the high voltage bushing. Switches typically have provisions for interlocking with the control system to prevent changing the position of the switch while the power is applied to the primary of the TR set. The oil immersed switches have caused problems due to poor electrical contacts in older designs.

3) A 5-position switch with provision for interlocking is typically used for older double half wave units.

4) Voltage divider network. The high voltage resistor allows the controls to sense what is happening within the ESP. Many controls provide ESP voltage feedback and typically detect sparks from the current signal and so very little attention has been paid to the quality of the secondary voltage feedback signal. But with the way things have gone in the past few years and the prevalence of more difficult fuels, state of the art controls can determine events within the ESP that cannot be derived from the current signal alone. Under these circumstances it is essential that a clean and accurate voltage waveform be obtained. Incorrect high voltage resistor placement causes interference with the signal and would corrupt the controls' capabilities in this arena.

5) Current monitoring resistors. These resistors provide ESP current feedback signals for the AVC. The current drawn by the ESP flows through a resistive shunt, generating a voltage drop for the controls to monitor. This gives data for display as well as fundamental control.

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3.2 ESP AVC Controls

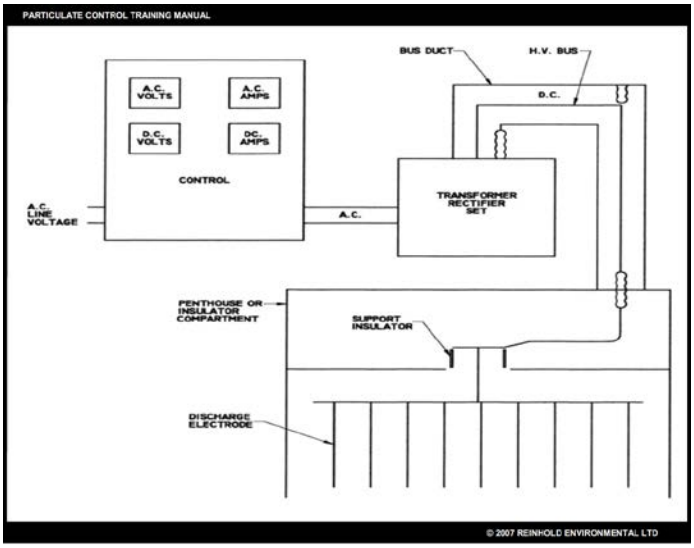
The aim of this section is to:

- Identify the global requirements of an ESP control system
- Identify and discuss the energization system
- Build and discuss a circuit that provides information on the function of each of the components associated with the circuit
- Discuss some of the different techniques that are available in the use of precipitator controls today.

The first part of the discussion involves the energization system.

Lets first look at an overall system identifying the control cabinets, the transformer rectifier sets, and the electrostatic precipitator (**Figure:**

Overall Energization System Diagram

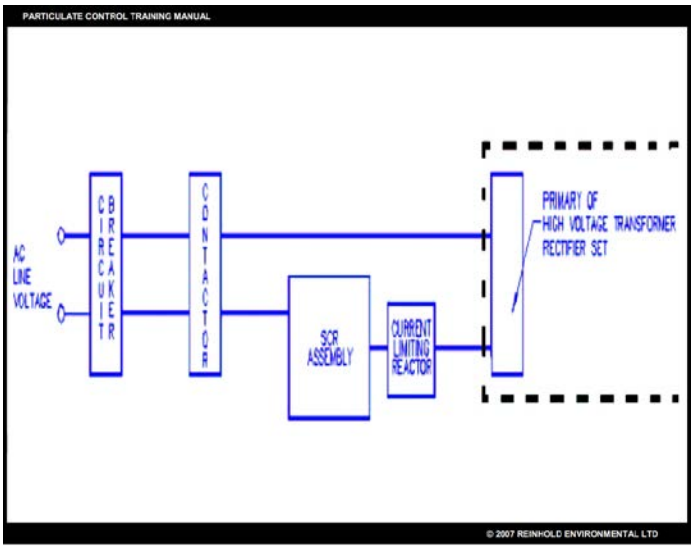


Overall Energization System Diagram

). It is a block diagram, and on our control cabinet you can see that the primary input is an AC line voltage entering into a control cabinet with some meters providing information. Leaving the control cabinet you see a supply going of f to the transformer rectifier set. Leaving the transformer rectifier set is the high voltage passing through the high voltage bus duct, supported by a series of high voltage insulators, down to a through bushing on to the high voltage grid of the electrostatic precipitator.

The block diagram of a power circuit (**Figure:**

Power Circuit Diagram



Power Circuit Diagram

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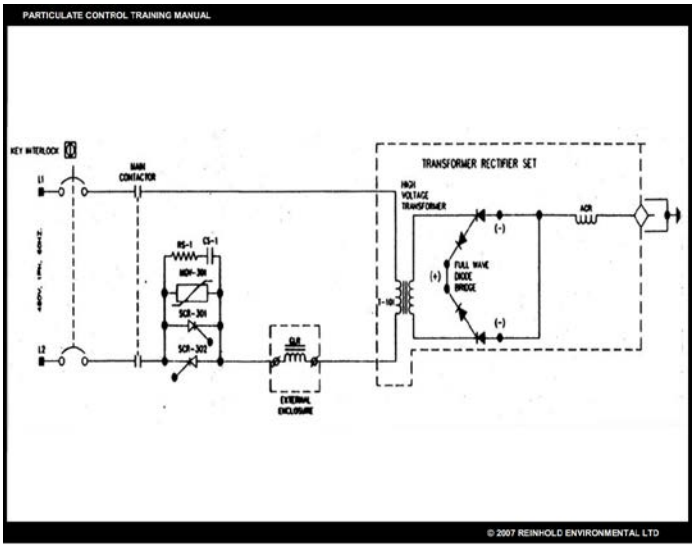
) provides you with the rudimentary information needed to get power from the line supply through to the transformer rectifier set. The ac line voltage, and depending on where you live, what country you are in, and what the level of supply that you have is, enters into the control cabinet and terminates on a main circuit breaker.

Passing through the main circuit breaker, the next point is a contactor. One side of the contactor goes off to one side of the primary winding of the transformer rectifier set, while the other side of the contactor goes off to a Silicon Controlled Rectifier (SCR) assembly. Leaving the SCR assembly the power then goes off to a current limiting reactor (CLR) where it meets up with the other side of the primary winding of the transformer rectifier.



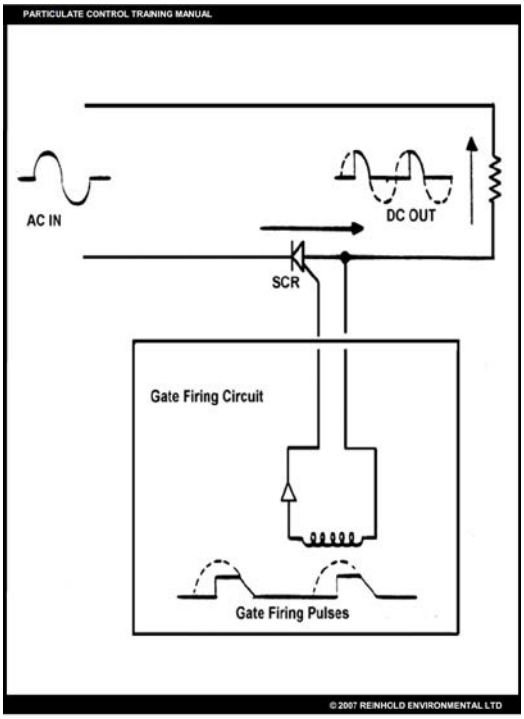
Control System Schematic

Putting this block diagram down onto paper allows us to produce a schematic from which you can build your control system (**Figure:**

Control System Schematic

). The information that is seen on the block diagram such as the main circuit breaker, the contactor, SCR assembly, current limiting reactor, and now the high voltage transformer rectifier, are put together in this fashion.

You can see that one of the requirements of the modern day control systems is to have an interlock associated with the main circuit breaker. This is a safety device and it prevents any unauthorized tampering with the circuit breakers and prevents people from energizing the precipitator while it is unsafe to do so. The part of the circuit that is perhaps the most interesting, and probably the most important with regards to control systems, is that of the SCR assembly.



An SCR is Very Similar to a Light Switch

As you look at this you can identify two SCRs, a surge suppressor and a snubber (RC circuit). Try to put the SCR assembly into perspective, as far as operation is

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concerned, by detailing how each of the SCRs works. **Figure:**

SCR is Very Similar to a Light Switch

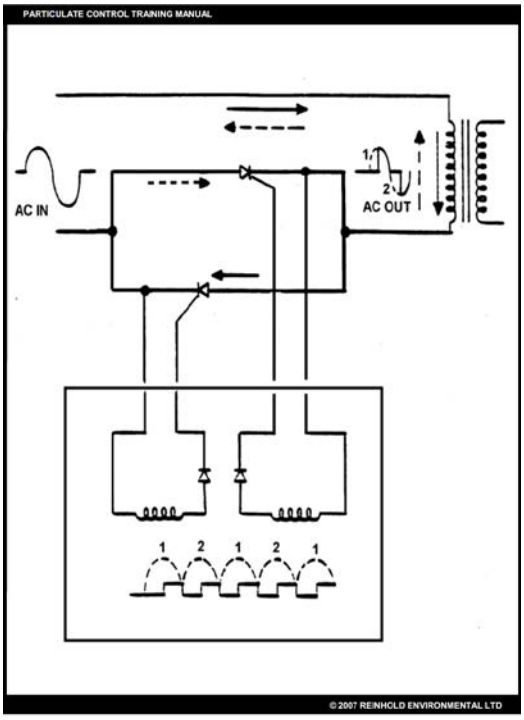
shows you that an SCR is very similar to a light switch, however the light switch in this particular instance will only allow current to flow in one direction at any one time.

The graphic details an SCR pointing in the negative direction and the SCR will only be conducting voltage and current during the negative half cycle of supply. Should you wish to conduct current and voltage in the positive half cycle of supply you will need an SCR that points in the forward direction. If you therefore put two SCRs in parallel (**Figure:**

Two SCRs in Parallel, One Pointing in the Forward Direction and One in Reverse

), one pointing in the forward direction and one pointing in the reverse direction, and providing you energize the SCRs in accordance with appropriate phasing of each half cycle of supply, the forward pointing SCR will conduct in the forward direction and the reverse pointing SCR will conduct in the reverse direction.

Therefore as you control the SCRs, so you can control the voltage applied to the primary of the transformer rectifier. Increasing the conduction on each of the SCRs allows you to increase the primary voltage on the transformer rectifier. Decreasing the conduction on each of the SCRs allows you to decrease the voltage applied to the primary of the transformer rectifier. As you regulate this particular voltage, that being on the primary of the transformer rectifier, the corresponding effect will be seen on the secondary of the transformer rectifier and the high voltage to the electrostatic precipitator will increase and decrease as a result of changes made to the primary voltage on the transformer.



Two SCRs in Parallel, One Pointing in the Forward Direction and One in Reverse

So, it becomes apparent from this discussion that the SCR assembly is the fundamental and most complicated requirement within the control system. The precipitator controls are therefore designed to provide accurate and speedy control of these SCR assemblies. A picture of an SCR assembly (**Figure:**

SCR Assembly

) is included to give you a feeling of what the modern day device looks like.

As you can see from the graphic, the SCR is a semi pack. This means that the forward and the

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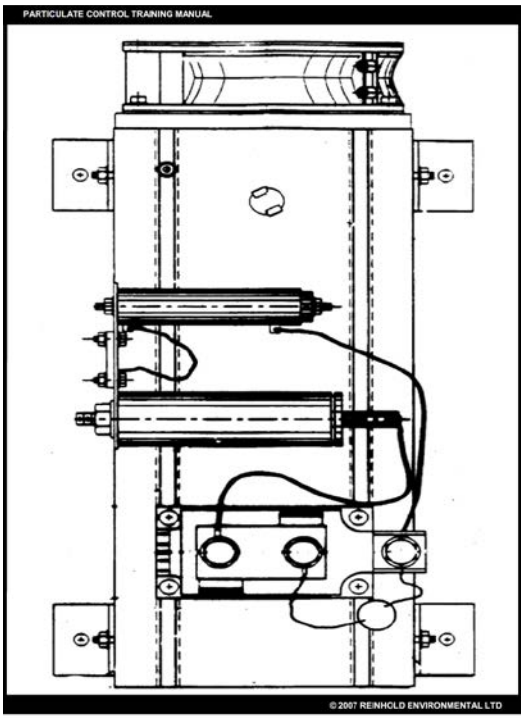
reverse facing SCRs are both mounted and encapsulated in a plastic casing. This is bolted to an aluminum heat sink. At one end of the heat sink we see that there is a fan. The purpose of the fan is to force air through the fins of the heat sink and to keep the entire device cool. With a semi pack assembly, the heat sink is at earth potential.

On older systems the heat sinks were at the main's potential, so the more modern systems are therefore much safer. In the center of the graphic you will see a resistor and a capacitor as well as a metal oxide varister.

The combination of these three components is often referred to as a snubber assembly. The snubber is a very important device in the world of SCR control. Because of transients associated with switching of SCRs, it is possible that an SCR may turn on by itself. High frequency transients associated with current and voltage can cause the SCRs to forward bias. This is not something that you would like to see when you are trying to control them form a high tech microprocessor or analog control system. The last thing you need is to be energizing the transformer when the application is dictating otherwise. The snubber, therefore, soaks up these transients and prevents this from happening, leaving all of the control of the SCRs down to the control system.



An SCR Assembly
(Courtesy of Redkoh)

On the secondary side of the SCR system you will see that you have included a CLR (**Figure:**

Current Limiting Reactor (CLR) Schematic

). CLR stands for current limiting reactor. The current limiting reactor has a number of functions within the circuit, but for the purposes of the control system, the CLR provides us with a smoothing of the waveform that is generated by the SCRs.

What this means is that the waveform generated by the SCRs is highly chopped, switching transients occur, and edges are sharp. The introduction of the CLR smoothes these edges down, and make the waveform that appears at the transformer rectifier significantly more rounded. The more rounded the waveform, and the closer the waveform is to a sinusoid, the greater the reliability of the system, and the greater the efficiency of the transformer rectifier. Adjusting the CLR to suit the system can make tremendous improvements, not only to the cost of running the system, but also to the electrostatic precipitation process.

Move on to a block diagram that shows you the transformer rectifier set (**Figure:**

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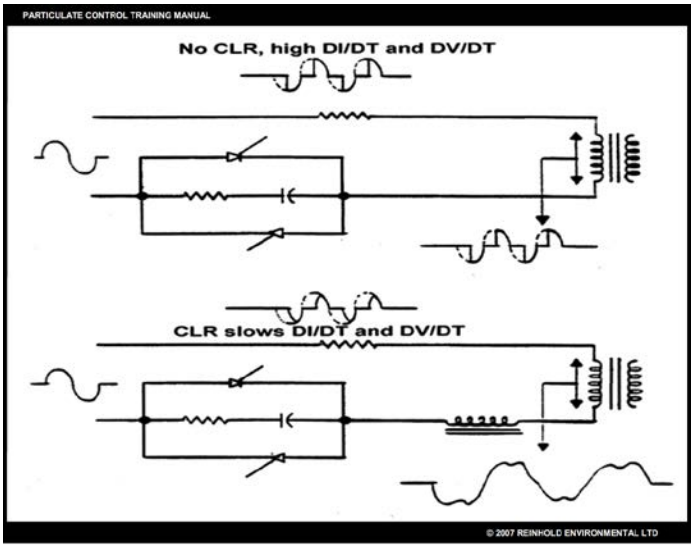
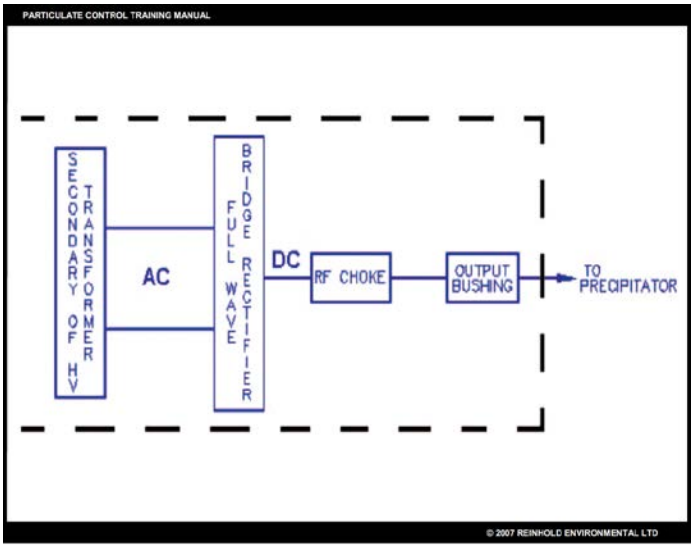
).



Current Limiting Reactor (CLR) Schematic

The transformer rectifier set sits at the far right hand side of the basic circuit diagram that you have looked at. Up until this time you have only looked at anything associated with the primary of that circuit. Moving through the transformer rectifier, you see that this low voltage that you have generated, and are controlling by means of the SCRs, is now stepped up to many thousands of volts. These many thousands of volts, and this value depend very much on the manufacturers of the precipitator. For the purposes of this discussion lets assume 55,000 volts just to give you a number to talk about. This 55,000 volts is applies to a high voltage rectifier assembly, the high voltage rectifier takes the 55,000 volts and converts it to a full wave DC. This full wave DC then passes through a high frequency choke, and out to the bushings for transmission to the electrostatic precipitator.



Transformer Rectifier Set Diagram

Now that you have dispatched this high voltage to the precipitator, you need to move on to an area that will allow you to determine the levels of this voltage, and provide more information associated with it as it arrives and is soaked up by the precipitator. A question that is often asked, and this is something that you will often hear on the phone when somebody is trying to assist you with fault finding over a long distance is: What are the feedback signals? Having passed this high voltage to the precipitator, you need to establish feedback information in order for the control system to operate correctly.

The four fundamental feedback signals associated with precipitator controls are easily defined and these are:

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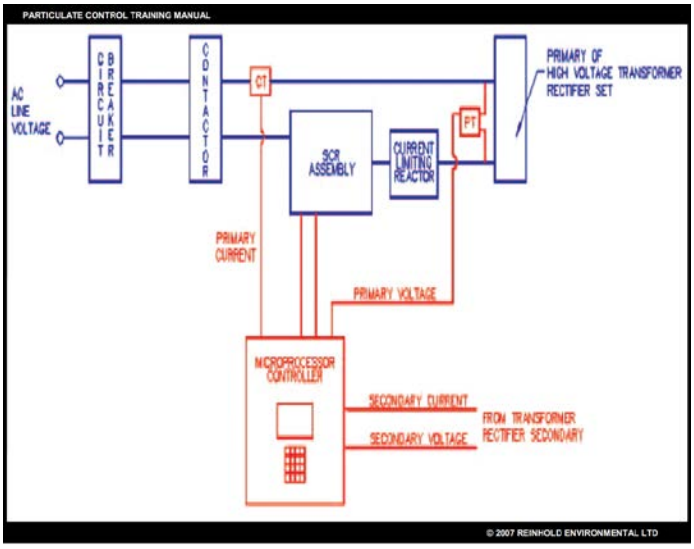
- Primary voltage- this is the voltage that appears across the transformer rectifier primary winding,
- Primary current- this is the current that is drawn from the line supply,
- Secondary current- is the current that is drawn by the precipitator,
- Secondary voltage- this is the voltage that appears on the precipitator as a result of the voltage that appears on the primary.

The feedback signals are derived from two sources, the primary side and the secondary side, of the control system (**Figure:**

Control System Feedback Signals

).

The primary side of the control system is the part that was discussed, that would be the main circuit breaker, the main contactor and the SCR assembly, along with the primary of the transformer rectifier. The graphic shows that on the low voltage line between the contactor and the primary of the transformer rectifier, you insert a current transformer. This current transformer is the instrument that is used to provide information on the current flowing in to the low voltage line, from the mains, through the primary of the transformer rectifier. Across the primary of the transformer rectifier you insert a potential transformer. This is typically a small very low VA rated voltage transformer that steps the voltage down from 600 volts or 480 volts (whatever your supply voltage is) down to a low voltage that is safe and readable by the control system. This varies from vendor to vendor and is typically between 20-120 volts.



Control System Feedback Signals

As you move over to the secondary side of the transformer rectifier (**Figure:**

Control System Feedback Signals

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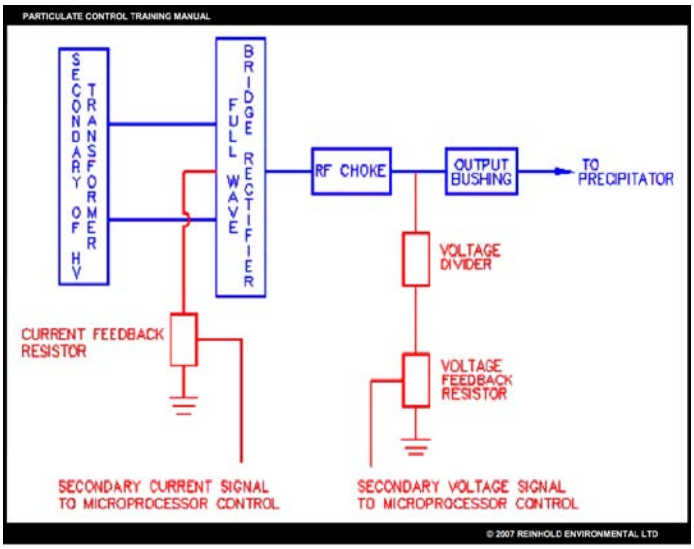
) you need to establish feedback signals associated with the voltage on the precipitator and the current drawn by the precipitator. Two methods of note, are that of establishing voltage on the precipitator via a high voltage resistance network, and the current on the precipitator as it passes through a shunt resistor.

What are feedback signals? Feedback signals are the signals that provide the control system with all the information that they need in order to produce output for the transformer rectifier to feed the precipitator with the voltage that is demanded by the precipitator, and hence for the ultimate current to flow and ions to be produced. Having listed these four signals, you now set about determining exactly what they are used for.



Secondary Side of the Transformer Rectifier Feedback Signals

Primary voltage signal

The primary voltage signal is one of the most important. In all of the older control systems, only the primary voltage and the primary current signal were available. The primary voltage allows you to assess the voltage being applied to the primary of the transformer rectifier. If the primary voltage is high enough you can determine that the voltage on the precipitator is following suit, and is also high enough. As the primary voltage reduces, you run the risk of going into what is called an under voltage level. The under voltage level is where the voltage on the precipitator, and hence the voltage on the primary of the transformer, fall below a predetermined level. When you fall below this predetermined level, what happens is the control system makes certain decisions that are guided by operators and may well suggest that the voltage on the precip is no longer useful and trip the control system.

Primary current signal.

The second is the primary current signal. You monitor the primary current in an effort to determine the amount of current that not only flows from the supply through the primary of the transformer rectifier, but also the amount of current that is being drawn by the electrostatic precipitator.

Secondary current

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The secondary current is the current that is drawn by the load, the load being the electrostatic precipitator, and as the voltage is applied and ions are produced, the current that is drawn by the precipitator is representational of the amount of gas cleaning current. And the current that is being drawn by the precipitator is representational of the ionic emissions. The greater the current typically is a result of greater ionic emissions. Greater ionic emissions result in greater gas cleaning.

Secondary voltage

The secondary voltage is the voltage that is applied to the precipitator from the secondary of the transformer rectifier. Greater voltages give you a greater opportunity to draw current; so the goal, in this particular instance, is to produce as high a voltage as possible.

These four feedback signals are now taken by the control system and used to determine the best way to operate the system. Building these feedback signals into your circuit a current transformer is inserted in the low voltage line between the contactor and the transformer rectifier primary.

Now, this particular place shown on the graphic is not necessarily the place where the current transformer has to be mounted. The current transformer can be mounted in either leg and or either side of the SCR assembly. It is preferred that the CT or current transformer is mounted after the SCR assembly. The only real reason for this would be that if ground occurred in the primary winding of the transformer rectifier, and in the right place, it may be possible to limit the current flowing to earth by phasing back the SCRs.

Deeper into the circuit and on the primary of the transformer rectifier winding, you see a potential transformer. The function behind the potential transformer is to step the voltage down, from the main voltage that appears across the transformer rectifier, to a level that is readable by low power electronics. The step down ratios vary from vendor to vendor, but typically they are between 20-150Volts. These two signals are referred to as the primary feedback signals, fed back to the controller, and we now have the fundamental for control.

In years gone by these were the only two feedback signals that were available and fairly high levels of precipitator operation and control was available by using just these two devices. On more modern systems, you have the opportunity of using secondary feedback as well as primary feedback.

Secondary feedback signal

The secondary feedback signals, with in the system, provide us with the ability to measure the voltage applied to the precipitator as well as the current drawn by the precipitator. The voltage

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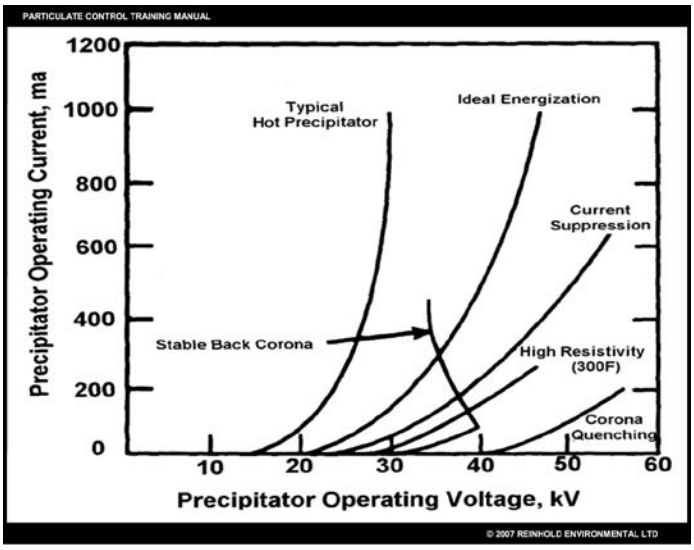
applied to the precipitator is typically measured by utilizing a high voltage resistor network. This consists of two resistors. The first being of high voltage resistor, which varies between vendors, but typically in the United States, is 80-120 megohms, with a low voltage resistor at the low end of that. The low voltage resistor is then set to calculate the ratio between the high voltage that exists on the precipitator and the amount, or the level of voltage, that the control system intends to read, to a scale, so that in one instance, perhaps 80, 000 volts on a precipitator, would yield a 10 volt feedback to a control system or perhaps a 5 volt signal to the control system. This is purely vendor specific and so anything that is mentioned in this manual should be cross referenced to a vendor's O & M manual before taking it as the gospel's truth.

Having taken these two block diagrams, now you insert them into a schematic showing the overall feedback system, and looking closely at the electrical schematic you see that the current that flows in the primary, through the CT, transfers into the secondary winding of the CT, and then passes through a shunt resistor. In this particular instance, the reason that this is done is that the control system is required to read a voltage level rather than a current signal. The same applies to the secondary current.

The secondary current from the transformer rectifier, which is exactly the secondary current that is drawn by the precipitator flows through a sensing resistor and produces a voltage. These two provide the closed path from the high voltage discharge electrodes across the gas, or the airspace to, collecting plates to ground. Passing this current through that space and closing a loop through a shunt resistor allow you to measure the voltage across that shunt resistor, and to determine by virtue of the fact that you can read the voltage across the shunt resistor, and you know the resistance of that shunt resistor, the exact amount of current that is being drawn by the precipitator. Feeding this current back into the control system allows us to make important decisions.

The following are some of the parameters that one is able to use as a result of having these feedback signals available to you. The control systems, and this is almost without exception, even from vendor to vendor, will include some or all of these points.

- Max Primary Current
- Max Secondary Current
- Max Secondary Voltage
- Primary Voltage Limit
- Primary Under Voltage Trip
- Primary Current Limit
- Secondary Current Limit
- Secondary Voltage Limit
- Secondary Under Voltage Trip



Precipitator Voltage Current Curves

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You are able to determine the maximum primary current that you can allow to flow through the transformer rectifier. And you are able to limit this. You are able to determine the maximum secondary current, and you are able to limit it. The same applies with the voltage on both the primary and the secondary of the transformer rectifier.

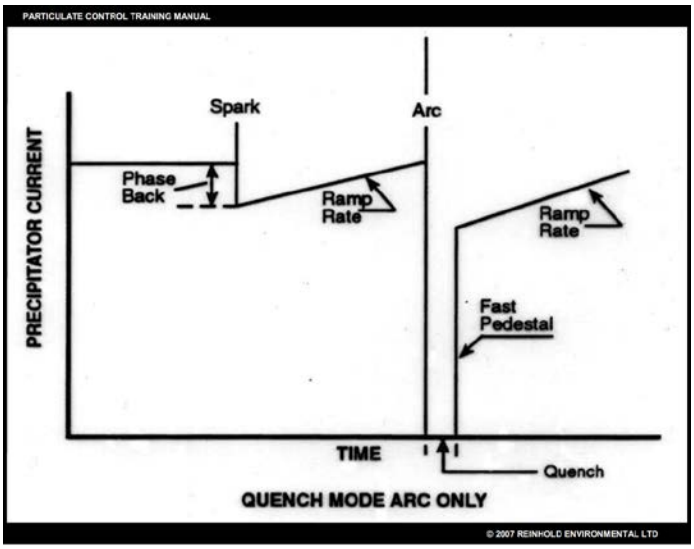
Comparing set points to actual levels allows you to protect not only your equipment but the precipitator as well. Having these signals allows you to protect not only the precipitator but the equipment as well. You are also able to set up trip levels, alarm levels, and response levels.

All of this backs up onto feedback. In the world of precipitous and precipitator experts, operations, maintenance, operators, feedback is probably one of the most significant requirements. The fundamental behind assessing a precipitator's operation can not be achieved without these signals, and to sum up this particular section, one of the most important pieces of data that can be assembled as a result of having this feedback available, is that of the production of voltage/current curves (**Figure:**

Precipitator Voltage Current Curves

).

It is absolutely necessary that the system, or the operators who use the plant, are able to read these signals through either panel mounted meters, or digital readouts, or transmitted data, and to assemble that data into tables and hence produce graphs, where the voltage and the current applied to the precipitator can be monitored to see the shape of the curves.



Arc Detection

The goal of this particular figure is simply to show that unless you have accurate and reasonably high technology level feedback signals, the data that you are providing to the engineers and operators who will make assessments as to how well your precipitator is operating, may be inadequate or false. Poor decisions will be made and your precipitator may not operate at the expected level.

The following will help you understand how the control utilizes all these signals. **Figure:**

Arc Detection

is a typical control waveform. Now, this is not a microsecond or millisecond-by-millisecond waveform. This is more like a second by second analysis of the waveform that is applied to the

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precipitator and represents an average output current envelope.

Looking at this typical controlled response, the graphic is one where the output voltage is applied to the precipitator, and is actually limited by one or another factor, in this particular case it could be any limit associated with the transformer rectifier or the control system and, for purposes of the discussion let's suggest that it is limited by the primary voltage. The line is flat showing that if no further increase in voltage is occurring at the precipitator. The charge on the precipitator is building up and after a certain time a spark occurs. A control system detects the spark and produces a response.

Following the response, the voltage is reapplied to the precipitator and increases again until a second spark, or another event actually occurs. The second event could easily be the limit is once again reached. The event could be another spark, or an arc. Each of these events results in a response from the control system.

Now, what you should do is have a look at these events and see if you can understand why they occur and how they occur, and once that is done, what do you do about it?

A spark

The first one that you should look at is that of the spark. First of all, what is a spark? A spark is a precipitator disturbance which causes a depression in the electrode voltage for not more than one half cycle of supply. One half cycle of supply at 60 Hz is 8.3 millisecond. This particular event which, is determined or defined as being a spark, actually will last for no more than 8.3 milliseconds. Now you also know that typically a spark doesn't start at the very start of a half cycle. It starts towards the peak of the voltage, and the peak of the voltage occurs at about the middle of the half cycle. A spark is a very short duration event, and most likely will not last a great deal longer than 4 milliseconds. Spark detection is one of the fundamentals of any control system associated with electrostatic precipitators. The ability to detect a spark and to make a decision what to do following detection is absolutely crucial.

Sparks can be detected by a number of different methods. These methods vary from vendor to vendor, but ultimately provided the control system you have accurately and reliably detects sparks, you should have no problem.

Here are some of the methods that are used:

- Looking for transients on the current signal
- Looking for substantial and instantaneous rises on the primary and secondary currents
- Looking for sharp falling edges on the secondary voltage.

Provided your control system can achieve one or more of these on a moment by moment, or an instant-by-instant basis, you shouldn't have trouble detecting the spark and carrying out the appropriate action.

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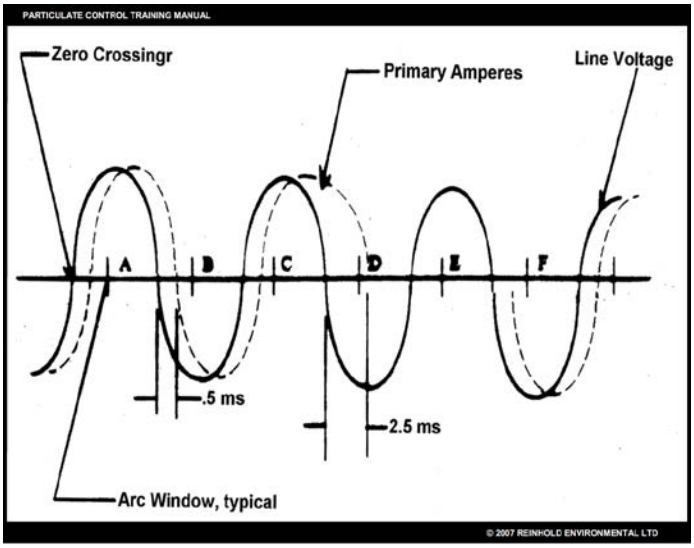
Arc detection

The second one that is of importance is arc detection. But first, what is an arc? An arc is a precipitator disturbance that causes successive or a continued depression of the electrode voltage. Now the electrode voltage is actually the kilovolts applied to the precipitator. If the kilovolts applied to the precipitator falls and remain at zero, or close to zero for an extended period of time or longer than the half cycle of supply or two half cycles of supply, depending on the manufacturer, then this situation should be detected as an arc.



Typical Control Response

Again, different vendors and different manufacturers have different methods of detecting arcs. Some utilize the fact that the KV signal stays at zero for an extended period of time in order to determine that an arc exists, others use the fact that two sparks occur extremely close together to determine that an arc exists, and others use a method whereby a phase shift between the primary voltage and the current drawn from the supply is created as a result of the arc occurring. In this particular instance, you can monitor the current and from the time that the voltage falls through 0 on the half cycle of supply, you begin to measure the time that it takes for the current to fall through that same zero (**Figure:**

Typical Control Response

). Should the time between the voltage fall and the current fall exceed certain set points then under these circumstances an arc is detected.

Having now learned the difference between arcs and sparks and what is an arc and what is a spark, what do you do with it? Going back to your diagram of your typical control response (**Figure:**

Typical Control Response

), you can now put into practice what you have learned. The voltage on the precipitator is increased at a reasonable rate, until an event occurs. The event again, just to recap could be a limit, hopefully it won't be a limit, hopefully it will be a spark or an arc.

This is the closed loop method of controlling precipitators, and ensures that you are always

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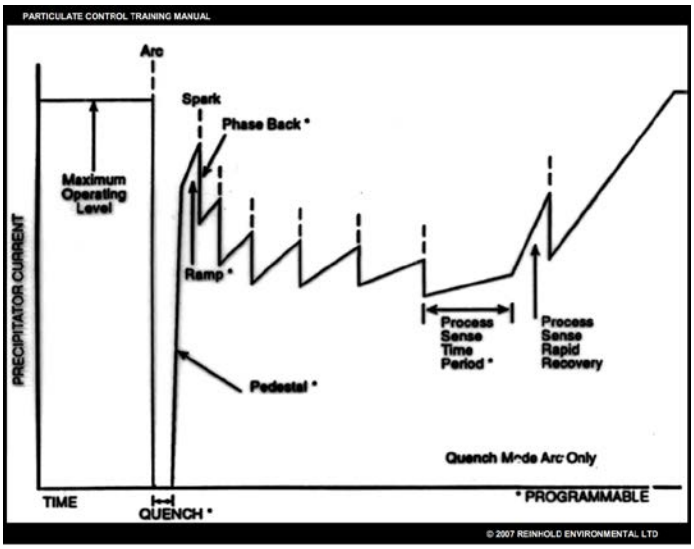
applying the maximum voltage to your precipitator, that is, keeping the voltage up as close to the spark over level as possible. Increasing the voltage until a spark occurs, you detect a spark then you institute a portion of your software, or an algorithm, that would result in the voltage being reduced from the precipitator and then reapplied a very short time later at a slightly lower level. This particular parameter or set of events that occurs is called a step back, or a phase back. Once a spark is detected the controller executes a step back or a phase back. The conduction angle on the SCRs, and you remember this because all of the control that you can achieve is on the primary side of the transformer, is reduced and the voltage is reapplied at a level below which the original spark occurred.

A ramp

Once the conduction angle is set to this new level, the control then increases the output voltage to the precipitator in accordance with the predefined rate. And this rate is most commonly called a ramp. It is fairly self-explanatory. A ramp is really a rise time, it is a rate of rise. The output voltage of the precipitator ramps, up or rises up, until the next spark or arc is detected.

There are different responses that one can expect, depending on whether a spark is detected or an arc is detected, and these are application specific. Some manufactures, on detection of a spark, choose to turn the voltage off for an extended period of time, typically 20 milliseconds or two half cycles of supply at 50 Hz. Others choose just to reduce the voltage by the predetermine amount, a single step back. Under circumstances when an arc is detected, the most common set of events is that the voltage on the precipitator is removed completely for an extended period of time. This allows any buildup of locally ionized gas, or whatever had caused the arc in the first instance, time to disperse before reapplying the voltage.



Control System High Sparking
Courtesy of Redkoh

Sometimes, the application of the voltage after having simply taken a small step back is inadequate because the gas is not dispersed and so the voltage is reapplied to the precipitator back into the area where the initial problem occurred, so a follow-up spark occurs. To prevent this, the event is detected as an arc, and the voltage is removed all together and held at zero for a period of time. After this period of time, the voltage is then reintroduced to the precipitator at a predefined rate. All of these rates and amounts are values that most control systems allow the operator to make adjustments to. So, a ramp time may be controlled by setting the rate of rise from the time of the first spark until the level at which the

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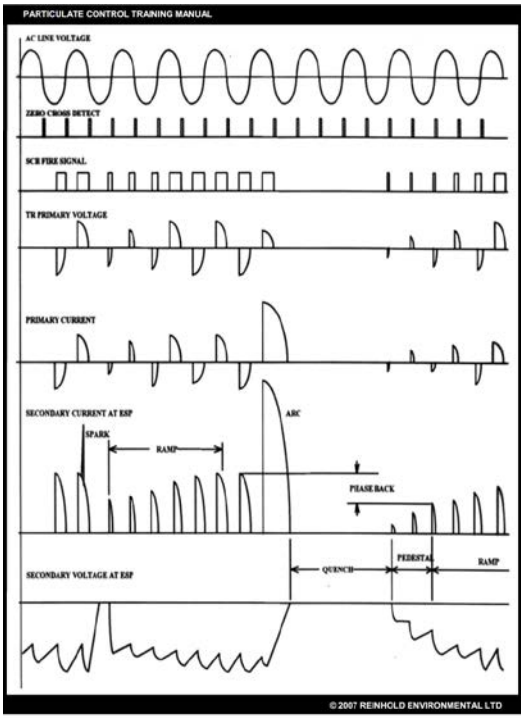
second spark may occur, in seconds. The amount of voltage that is pulled back from the precipitator may be reduced by a certain number of KV. If an arc is detected, the amount of time that the voltage is held at zero may be controlled in half cycles or in milliseconds. And then the rate of recovery may also be controlled in terms of milliseconds or half cycles. Typically, the goal behind your control system is to continue doing this ramping, sparking, stepping, and the occasional arc quench, throughout its entire life. Always with the goal of keeping the voltage applied to the precipitator as high as possible and as close to the spark threshold as can be achieved. If for any reason there is a high area of sparking, or a significant number of sparks occur at any period of time, the control system will make a significant reduction in power (**Figure:**

Control System High Sparking

).

At the ramp rate that was preprogrammed it may take a long time for the voltage to recover, and return to the level where it is considered to be efficient. Most control systems provide a parameter such as process sense, that rapidly increases power after a period of no sparking.



TR Waveforms during Sparks and Arcs

What happens is, if the control system does not detect a spark for a period of time, it institutes what is called a fast ramp. And instead of ramping up at the same ramp rate used following a spark, the control initiates a fast ramp, and the output climbs rapidly trying to achieve the level that it was at prior to the upset condition. Hopefully it will get there, if it does not it may reach a limit or it may spark on the way up. In which case, the original set of operating conditions is returned, following a spark a step back is carried out and a ramp, and so the control system carries on. The typical control waveforms or the controlled response that is shown in the graphic indicates exactly how this happened with information that shows how the feedback is fed back to the transformer such that a phase back can be calculated, a ramp rate can be calculated, the response that the control system takes once an arc is detected, and there are other parameters, that are identified and defined in this particular waveform.

Figure:

TR Wavefroms during Sparks and Arcs

identifies how our control system achieves these goals of ramping and stepping, as they occur.

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The top line shows the AC line voltage with positive and negative half cycles. The second line shows the zero cross detector. The function behind the zero cross detector is to accurately and reliably detect when the main voltage falls through zero. This is one of the most fundamental portions of electronic circuitry that you will have in your control system. It is absolutely necessary that the control system knows and understands where the start or the end of every half cycle occurs, in order that it can determine which SCR has to fire and which SCR has to fire in which half cycle. From those zero crosses all of the delays are calculated, the delays being the time from the zero cross from the time the SCR begins to conduct.

The third line shows the difference in conduction angle as applied to the firing circuit of the SCR assembly. Following each one of these firing signals you see the primary current and the primary voltage. The primary current and the primary voltage are both AC signals, therefore, when testing, one should always check that the signal occurs on both sides of the zero line. Should the signal only appear on one side of the zero line, in either the primary voltage or the primary current signal, it is fairly safe to say that one of the SCRs is not operating. This may be as a result of the failed firing circuit, or as a result of the failed SCR.

Down towards the bottom of the graphic, you see the current signal. The current signal is a DC signal and results from the current flowing into the precipitator. Along with the control response, you see the increasing current on the half-cycle by half cycle basis, you see the transient associated with the spark that has occurred, and following the spark you see the current signal is reduced. It is reduced by virtue of the fact that the control system has detected the spark and has phased the SCRs back, so you start again with a relatively small current pulse, and the current pulses increase on a half cycle by half cycle basis. You see that an arc has occurred, and the size of the current pulse is significantly larger than those that are in front of it. The control system detects the arc, the voltage and the current are pulled to zero, and held at zero for the predetermined rate, and then slowly fed back in.

The final trace on your control waveforms show the voltage and what happens to the voltage as these changes occur. During the time that the spark occurs you see that the voltage falls rapidly to zero. During the time that the arc occurs you see that the voltage is pulled to zero by the arc and then held there by the fact that the control system ceases to fine the SCRs until the end of the period, that is set, which would determine when it is safe to feed the voltage back into the precipitator.

Continuous vs. Intermediate Energization

So far, all of the discussions that you have had have surrounded what you call "continuous energization". The two fundamental methods of energizing an electrostatic precipitator are continuous energization and intermittent energization. Both have a time and a place for use. You should make the effort to understand the difference between the two, and to try and understand when they should be used.

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The first one is continuous energization. The control seeks to maintain a high average voltage, and hence powered to the ESP, by firing the SCRs every half cycle of supply, unless a recognized event within the ESP determines otherwise. By all accounts, the ESP is continuously energized.

The second method of energization, intermittent energization, is achieved by alternatively firing, or energizing the transformer rectifier set, with a high firing angle for a specified number of half cycles and a low firing angle for a specified number of half cycles. Typically the low firing angle will always be an even number of half cycles, which results in a period between on times of full cycles. This is done unless there is an event in the precipitator that which determines that SCRs should not fire.

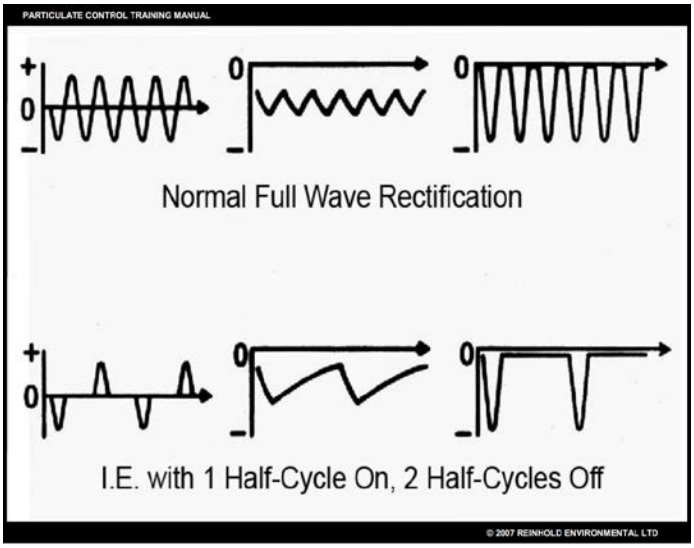

Figure:

Difference Between Waveforms under Continuous and Intermittent Energization

Difference Between Waveforms under Continuous and Intermittent Energization

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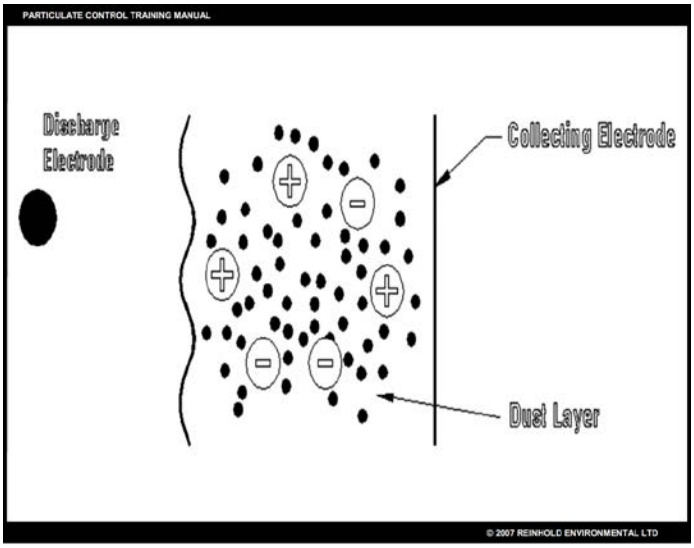
shows that there is a significant difference between the waveforms applied to the precipitator under continuous energization and under intermittent energization.

The top line shows normal full wave rectification under a continuously energized system. You see that the AC is rectified, fed to the precipitator, and that the high voltage is negative. Your precipitator has a negative high voltage electrode system and it is capacitively smoothed. You see that there is a half cycle for every half cycle of supply. The second line down shows intermittent energization, and this the graphic shows, has one half cycle of supply being fed through to the precipitator with two cycles of supply being withheld, and so you see that the time between pulses was significantly longer. The precipitator charges, and then waits two full cycles. A discharge occurs in that time and then another peak of voltage.

Associated with intermittent energization, you have a specific set of control parameters that you need to understand. These are IE charge time, IE discharge time, IE background power, and various optimization parameters. The charge time would be the amount of time that the SCRs are energized, or that the transformer rectifier is energized, and the SCRs are fired. The IE discharge time would be the amount of time between the firing of the SCRs. The IE background power would be a sublevel of power upon which these pulses could be superimposed. During the time that intermittent energization is in service very few of the parameters that would normally be used under continuous energization are used. So, the fundamental limit that is used in intermittent energization is that of peak secondary current limit.

A peak secondary current limit allows the control system to protect the transformer rectifier diodes from an over current or an over voltage situation. Because the average during the time that intermittent energization is very low. The averaging circuits, or the averaging algorithms with in the control systems, would not pick up these high current peaks. A second circuit, or a second set of algorithms, which strictly monitors the secondary peak current would be used to protect our overall system.



Buildup of Dust on the Collecting Electrode Surface
Courtesy of Redkoh

When do you use intermittent energization? Intermittent energization is most commonly used to combat a set of events within the electrostatic precipitator known as back corona. Therefore, to understand why you should use intermittent energization you have to understand what back corona is. **Figure:**

Buildup of Dust on the Collecting Electrode Surface

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shows a collecting electrode, a discharge electrode and a buildup of dust on the collecting electrode surface.

Back corona

Under the condition where back corona exists, the voltage across the dust layer becomes excessive. The reason for this excess voltage is that the resistivity of the material is high. And as the resistivity of the material collected on the collecting plate increases, so does the voltage dropped across this dust layer increase. As the voltage across the dust layer increases the layer becomes more and more stressed. ithin this stressed dust layer there comes a point in time where the layer must break down. As the layer breaks down an explosion occurs within it, blowing dust from the layer back out into the gas stream.

Once this portion of dust is removed, a small pinpoint of collective plate surface becomes available to the gas stream. This pinpoint of collecting plate surface begins to omit ions of the opposite polarity of those being emitted from the discharge electrodes. The ions traveling from the discharge electrodes to the collector electrodes collide with ions traveling from the collector electrodes to the discharge electrodes. The ions have opposite polarity, so therefore on collision they neutralize one another. The net result is the neutralization of charge within an area of the precipitator. This is very self-defeating.

The following is a list of a few of the detrimental effects of back corona.

- Oppositely charged particles collide and cause charge neutralization. The back corona may have with sufficient strength to cause the particles to collect on the discharge electrodes.
- Excessive dust to build up on the DEs causes poor current distribution which reduces ionic emissions.
- The DEs may now need more frequent rapping and so increased mechanical wear and process instability may result.
- The dust layer on the collector plates does not discharge completely by virtue of the retained potential so the rapping efficiency is reduced. Reduced power rapping may become required.
- The current from the supply often increases and power consumption increases.

Under the circumstances where you are faced with problems of back corona you can use intermittent energization to intermittently energize the precipitator with bursts of power, and then wait times. This allows you to provide power for only long enough to charge the gas within the gas stream but not sufficiently long enough to allow any charge to build up on the dust that has collected on the plates. If you can do this you can limit the power into the precipitators to being effective power, with no charge being built up on the dust that is collected on the plates, then the rapping efficiency on the collecting plates is considerably better. You are not faced with these explosions that occur within the dust layer, and back corona ceases to exist.

This is all highly idealistic in that often precipitators are not sized sufficiently well enough to

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allow intermittent energization to be as effective as the theory suggests it might be, but it provides us with a tool that under many circumstances is actually a lot more effective than one would think, especially when considering the fact that you are providing less power to the precipitator and achieving the same emissions as if you were throwing all the power you could possible throw at it. Some of the other useful control parameters that you have available to us would be the ability to have displays on our control system that would allow us to see these various effects and their causes.

During times that back ionization exists you are able to see that the peak readings or peak minimum of the voltage tends to fall below that at which it would be during continuous energization when back corona does not exist. A peak reading, or a peak reader output from the control system, is a valuable tool. A pre-spark reading is an interesting tool. This allows you to determine exactly from the display, or from our metering system, the level of voltage at which every spot is occurring.

Power savings

Intermittent energization whilst providing the user with a tremendous tool for solving the problems of back corona, also allows one other valuable area, or issue, to be entertained. This is in the area of power reduction and power savings. There are certain plants that under certain circumstances find that their emissions are sufficiently low that they can afford to reduce the power applied to the precipitator and reap the benefits of low cost operation. Should the precipitator be amply sized, it is possible at this point to institute intermittent energization as an energy management routine. Instead of firing the SCRs every half cycle of supply, portions of this can be blocked out using the intermittent energization technique so that the average power of the precipitator is reduced.

While doing this, one monitors the opacity for the emissions levels, and depending on the level of emissions, one takes away more and more of the applied power, or lengthens the IE discharge time between applied pulses. In doing so, one allows the precipitator peak power to remain high while the average, or RMS power, reduces and a certain level of power savings, sometimes quite significant numbers have been thrown around 70% or 80% power reduction depending on the size of the precipitator, the application, and the events on the day can be achieved.

This pretty much covers the fundamentals that you would need to understand how and why your control system works, and how to correctly interpret its operation. A few more useful bits of information for today's high tech control systems would be things like tumble hammer rapping. AVCs nowadays have the ability to actually drive the tumble hammer rapper right out of the AVC. This allows us to easily achieve power down, or reduce power rapping, during the time that the rapper motors are running. Something that is a little more difficult to coordinate with an external rapping system because this would then require communications between a PLC, or some other piece of equipment, that was in fact carrying out timing or the control for the rapping system.

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Wet ESP controls

Controls specific to wet precipitator applications exist. Wet precipitators operate marginally different from dry precipitators in terms of the energization techniques, further to this they also require wash downs as opposed to rapping, so where rappers would be used under one instance a wash down system with wash down time, as in wash down intervals, would be more appropriate.

Operator interface

One of the most important features of the modern control system is that of a global communications system. What is communications as far as precipitator controls are concerned? Communications fall into a number of different levels. Primarily, if you have a microprocessor base controller, you most likely require some form of operator interface terminal or remote terminal unit. In order to communicate with your AVC to extract the parameters and the information one would require a fairly high level of communications for that device. One could institute communications between your AVCs and essential coordination systems, which might be a PC mounted near to your precipitator control room, or up in your main boiler control room.

This PC would then transmit data backwards and forwards, giving the operators and the maintenance engineers information about the control, about how well the controls are operating, about the events within the precipitator, allowing people to focus their energies on optimizing the efficiency of the system rather than trying to understand exactly what is going on in the microprocessors brain.

DCS interfacing

One of the more common communication systems on the market today, and one of the more vital requirements, is that of allowing the precipitator controls to be connected to the plant DCS. The communications links in all of these instances are far too slow in order that the actual control can be carried out at any of the remote ends, whether it be a PC or a DCS, but the monitoring and the date storage, and the date of logging, and the day to day data gathering that needs to be done to satisfy plant engineers, maintenance engineers, and the EPA, can be effectively achieved by feeding data of a serial communication linked back to a DCS, or some other form of storage device.

Remote monitoring

Finally, communications in this day and age is at the sophisticated level whereby your data can

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be shared with the outside world. A good quality control system, and one of the highlights of a great control system, is the ability to have your vendor analyze the system that they have supplied, and the application under which you are operating. A control system, being a computer of one variety or another, should have the ability for specialists outside of your own company to dial in, on request, to extract information and data, and to provide you, the user, with useful information and information that will assist you in running your control system.

3.3 ESP AVC Control Troubleshooting

Problems

The following AVC and TR problems are addressed in this section. Please also see Appendix 3 for more troubleshooting information.

- No or incorrect Primary Voltage Reading (all other readings okay).
- No or incorrect Primary Current Reading (all other readings okay).
- No Secondary Current Reading (all other readings okay).
- No Secondary Voltage Reading (all other readings okay).
- Under Voltage Trip (Low or no primary or secondary voltage, high or rated primary or secondary current).
- Over Current Trip
- SCR Imbalance Trip
- Main Circuit Breaker Trips
- No Primary or Secondary Current (high or rated primary voltage).
- Low Voltage and Low Current
- No Power After Performing Electrical Repairs in Cabinet.
- No Sparking is Occurring and No Electrical Limit is Being Reached

Solutions

Problem:

No Primary Voltage Reading (all other readings okay) - If an Analog meter is fitted, this may be driven from a different circuit and may read different from a digital readout or an AVC display readout.

Course of Action:

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a) The primary voltage signal is typically taken from the secondary of a potential transformer (PT) whose primary is across the primary of the transformer rectifier (TR).

b) The PT is a step-down device. Therefore a reduced ac voltage can be expected at the secondary of the PT that is proportional to the voltage on the primary of the TR.

c) Measure the voltage at the primary of the TR (after the CLR), Measure the voltage at the secondary of the PT. The Ratio of the 2 numbers should be the same as the turns ratio on the PT (Use a true rms reading meter to measure these values).

d) If the expected voltages are not present start tracing the voltage back through the PT. Either the wiring/connection between the PT and the AC input board is bad, the PT is bad or the signal to the primary of the PT from the TR primary is missing.

e) Some controls have fuses in series with the primary of the PT. These fuses may be either in the control cabinet, the low voltage junction box on the TR, or in the CLR enclosure mounted on the TR. Don't forget to check the fuses.

f) If the correct voltages are present at all the above points, then there is most likely a problem with the board handling the signal from the PT. This may be a simple calibration issue or at worst, a failed board.

Problem:

No Primary Current Reading (all other readings okay)

Course of Action:

a) The primary current signal is most likely a voltage-referenced signal derived across a shunt resistor that is located across a current transformer (CT).

b) When the control is initially calibrated this resistor is set using a formula supplied by the AVC manufacturer. Once adjusted, the signal across the resistor will be scaled corresponding to 0 to current rating.

c) Check the current with a true RMS ac clamp-on ammeter.

d) Using the CT ratio and formula supplied, determine the voltage that should be across the resistor. (V = Isec x R) That voltage should appear across the current input on the rms current (AMP) inputs to the AVC.

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e) If the voltage is not present, start tracing the voltage back to the resistor. If the voltage is present at the resistor, the wiring or connections between the resistor and the primary current terminals of the AVC unit are defective.

f) If the voltage is not present across the resistor, the CT or the resistor could be defective. Replace these items, re-calibrate the resistor, and recheck the signal at the AVC Unit.

g) If the proper voltage signal is present across the primary current terminals at the AVC unit, there is a malfunction in the AVC. This may be a simple calibration issue or at worst, a failed board.

Problem:

No Secondary Current Reading (all other readings okay)

Course of Action:

a) The secondary current signal is a voltage referenced signal derived across a circuit on a TR signal-conditioning panel or a set of shunt resistors mounted either at the TR set or in the main control cabinet.

b) Resistors at the TR may be located in the low voltage junction box or TR ground switch enclosure.

c) Resistors are calibrated during initial set-up to provide a dc voltage to the AVC that is representative of the dc current into the ESP Unit.

d) Measuring the voltage across the shunt resistor, and dividing it by the value of the resistance of the shunt will determine the value of the current that the AVC displays.

e) Note that a definite relationship between primary current and secondary current exists.

f) If no primary current is flowing, then there will be no secondary current flowing. This is an acceptable situation. If there is primary current reading, but no secondary current reading, then investigation is warranted.

g) Start the trace at the signal conditioning or shunt resistor unit in the TR or Cabinet and work toward the AVC. If no voltage is measured across the shunt resistor, then it may have failed.

h) The safety spark gap may be shorted in it's protective mode and be shorting the signal directly to ground.

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NEVER RUN THE TR SET WITH THE SHUNT RESISTOR DISCONNECTED.

Turn the TR set off; replace the shunt resistor and the spark gap.

i) If the signal is still not present there is probably a fault within the transformer tank. (Most likely an AC leg of the high voltage rectifier has failed to a short circuit and current is circulating in the secondary high voltage winding. At this point call the manufacturer of the TR for help.

j) If the proper voltage signal is present across the AVC secondary current input terminals, there is a malfunction in the AVC. This may be a simple calibration issue or at worst, a failed board.

Problem:

No secondary voltage signal (all other readings are okay). Okay in this case is relative. Beware of ESP problems being diagnosed as controls problems.

Course of Action:

a) The secondary voltage signal is a reference voltage signal derived across a circuit on a TR signal conditioning panel or a set of resistors in the TR set or control cabinet.

b) A voltage divider provides a reduced voltage to the AVC that is proportional to the voltage applied to the ESP. The supplier determines this ratio.

c) Calculation of the secondary voltage is very much dependant on the value of the high voltage resistor and the secondary average voltage rating of the TR set. The following is an example: If the high voltage resistor is 80 Meg Ohms, and the Transformer Rectifier is 55 kV average, the current that would flow down through the voltage divider network, at rated voltage, would be 55,000/8,0000,000 = 0.6875 mA.

d) The value of the other resistors in the network should be small enough that the error is insignificant.

e) The voltage across a known resistance of say 10K ohms (one of the resistors in the voltage divider network) is 0.6875 mA x 10,000 = 6.875 volts.

f) We can therefore conclude that if we measured 6.875 volts across the 10k resistor, then the ESP would be receiving 55,000 volts from the TR. If we measured 4 volts across the 10k resistor, the ESP would be receiving (55,000 x 4/ 6.875) = 32,000 volts.

g) If the approximated voltage (in this case, the voltage across the 10k resistor) is not present at

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the AVC unit, trace the voltage back to the signal-conditioning panel or the sensing resistor.

h) If the voltage is present at the signal conditioning panel or the resistor, the wiring or the connections between the conditioning panel and the AVC unit are defective.

i) Before going further, it is wise to run an open circuit test on the transformer rectifier. See the section on under-voltage faults in this document.

j) If after having done this, the voltage is still not present at the conditioning panel or resistor, replace the panel/resistor, re-calibrate, and recheck the signal.

k) If the signal is still not present there is probably a fault with the voltage divider resistor or the connection to the voltage divider resistor.

Problem:

Under Voltage Trip (Low or no primary or secondary voltage, high or rated primary or secondary current)

Course of Action:

a) If the primary voltage drops below the setting of the Under Voltage trip limit while the primary current continues to flow, the control should trip.

b) The cause of this condition is either a resistance ground or a dead short to ground downstream (on the ESP side) of the high voltage transformer.

c) In weighted wire type precipitators, a broken wire is the common cause. Additional causes could be a full hopper or high voltage insulators that have electrically tracked.

d) To isolate the problem, disconnect the precipitator load from the high voltage transformer rectifier (TR) and reenergize.

e) If primary and secondary voltage is now present (there should be no primary or secondary current) the ground is located within the precipitator. If the voltage is still low or zero the problem is within the TR tank or ground switch mechanism.

f) For problems within the TR tank consult the manufacturer. For problems within the precipitator perform a complete internal inspection.

Problem:

Over Current Trip

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Course of Action:

a) If the AVC control system is operating properly, the only way an over current trip should occur is if one or both of the SCRs are shorted or miss firing.

b) Start troubleshooting by disconnecting the gate and cathode leads of both SCRs at the electronic firing unit.

c) Tape the leads individually so they cannot touch other components. Re-energize the control and note the current and voltage levels.

d) With the SCRs disconnected the current and voltage should be zero (or very low, around 20 volts and 5 amps). If significant amounts of current and voltage are obtained one or both of the SCRs are defective (either shorted or leaking).

e) For reliability sake, replace both SCRs, or the single power pack, based on the existing arrangement.

f) If after disconnecting the SCRs and re-energizing the control the current and voltage are zero, the SCRs are most likely okay and the problem probably lies within the AVC unit or the snubber/surge suppressor network.

g) Replace the AVC control. Be sure not to accidentally swap the SCR1 leads with the SCR2 leads. If they do get switched you will not get any power when it is re-energized.

h) If after replacing the AVC unit the control continues to trip on over current, replace the snubber/surge suppressor network.

Problem:

SCR Imbalance Trip

Course of Action:

a) The SCR imbalance trip initiates when the amplitude of the primary current positive and negative waves differs by more than a predetermined percentage.

b) This difference could be caused by defective SCRs, defective firing unit, or gradually

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deteriorating snubber/surge suppressor network.

c) Replacing the firing unit is the first step.

d) If this does not solve the problem replace the SCRs then the surge suppressor.

e) If the problem still exists, and you have a double half wave output on the TR operating in the half wave mode, place a full wave jumper between the output bushings.

f) If the imbalance trip continues, follow the TR manufacturer's troubleshooting instructions to determine if the diodes in the bridge rectifier have failed.

g) If the imbalance trips stop with the full wave jumper in place there is a major difference in the loading between the two frames. An internal ESP inspection should be performed.

Problem:

Main Circuit Breaker Trips

Course of Action:

a) If the AVC control is operating properly it should de-energize the control and display an over-current trip message without tripping the breaker. Therefore, if the breaker is tripping:

- The AVC Unit is defective and not regulating the conduction angle of the SCRs
- The breaker is incorrectly sized, set, or is defective
- One or both of the SCRs are shorted or defective
- There is a short to ground between the breaker and the SCRs

b) To eliminate a short to ground in the control cabinet as the problem, disconnect the field wiring going to the primary of the transformer rectifier. Connect four 110 volt incandescent lamps in series across the output of the cabinet.

c) Since the cabinet no longer has a substantial load, reenergizing the cabinet should produce line voltage and very low current.

d) If moderate or high current is present, a short exists. Keep disconnecting components in-route back to the breaker until the defective device/wiring is found.

e) If after disconnecting the TR load the current goes to zero, the problem probably lies with the SCRs, the AVC Unit, or the breaker. Reconnect the wiring to the TR.

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f) Re-energize the control and watch the primary current display. If it goes above the rated current for that cabinet recheck the control and breaker settings.

g) If the settings are correct, disconnect each SCR gate and cathode lead (and tape them individually to keep them from contacting anything) from the Interface Unit.

h) Re-energize the control and again watch the current, it should be zero. If there is any current, or one or more of the SCRs are shorted or leaking.

i) Replace the defective SCR or SCR block.

j) If after disconnecting the SCRs the current is zero, the problem lies within the AVC unit. Replace the unit with a known working one.

k) If after performing all the above checks it is determined that all components are in proper working order yet the breaker continues to trip, replace the breaker.

l) As a double check, place a recording amp meter on the line feed between the breaker and the contactor. If the current does not exceed the control rating, yet the breaker keeps tripping, the breaker is definitely defective.

Problem:

No Primary or Secondary Current (high or rated primary voltage)

Course of Action:

a) This condition occurs when there is no load on the control and/or the TR.

b) The first step in determining the cause is to place a temporary ground on the high voltage bushing of the TR.

c) If the TR is a double half wave configuration (two output bushings) make sure the two bushings are tied together for full wave operation.

d) With a ground on the secondary of the TR, the control should reach the primary or secondary current limit programmed into the control, and no voltage should be present.

e) If rated current is present the problem lies in an open circuit between the TR output bushings and the support bushing tie in point on the high voltage frame.

f) If after grounding the TR high voltage bushing(s) the current is still zero, the problem lies

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between the control and the output bushings.

g) Verify that the wiring between the TR control and the primary input to the TR is not open.

h) If it is open, replace the defective wiring. If it is not open the problem is within the TR tank.

Problem:

Low Voltage and Low Current

Course of Action:

a) When both the voltage and current are low it usually means that either excessive sparking is occurring in the precipitator or electrical noise is entering the control cabinet.

b) Electrical noise can enter the control through the electrical line feed or through the feedback signals from the secondary of the TR.

c) Usually, the only noise that affects the control through the line feed is fast rise time transients generated by variable frequency drives or SCR type motor speed controls.

d) An Oscilloscope will be necessary to detect these transients. If they are present, adding inductive filters to the feed of the offending motor control will usually solve the problem.

e) The common entry of noise is through the TR secondary feedback signals. In particular, the secondary current signal. Electrical noise on this line can be interpreted by the control as sparking, and cause the control to back down on power in an effort to maintain a reasonable spark rate.

f) At this point it is strongly suggested that expert help be sought.

Problem:

No Power After Performing Electrical Repairs in Cabinet

Course of Action:

a) This condition occurs most often after SCRs or the control transformer have been replaced. The SCRs are synchronized to line phase. Therefore, if the SCR1 and SCR2 gate and cathode

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leads get switched or the wiring to the new control transformer get switched, or the new transformer is wound differently, the SCRs will be out of phase and no or an uncontrolled voltage will occur.

b) To fix this problem, either swap the SCR1 and SCR2 gate and cathode leads, or swap the wiring on the secondary of the control transformer that provides the phase reference to the AVC or the firing card.

Problem:

No Sparking is Occurring and No Electrical Limit is Being Reached

Course of Action:

a) If the control is not under Energy Management Control, not in manual mode, and there is no sparking or arcing, at least one of the electrical parameters should be at a limit. This limit could be one of the ratings of the transformer, or it could be a lower value programmed into the control.

b) Regardless of what the limit is, some limit should be reached.

c) If a limit is not being reached when there is no sparking, find a way to measure the SCR conduction angle.

d) If once measured, this is at or close to full conduction the current limiting reactor may be defective (usually due to shorted turns) or the transformer rectifier may have the full voltage applied across the primary.

e) Measure this with a true rms meter and if this is the case it is not possible to do any more from an electrical control standpoint. (The reactor impedance can be re-assessed; the size of the TR set can be re-assessed. Or if there is no issue because the emissions are extremely low…Leave everything alone and go and have coffee.)

f) If the control is not operating at full conduction the AVC unit is probably defective. Replace it with a known working unit.

3.4 ESP Cleaning Device (Rapping) Controls

Cleaning Device Control

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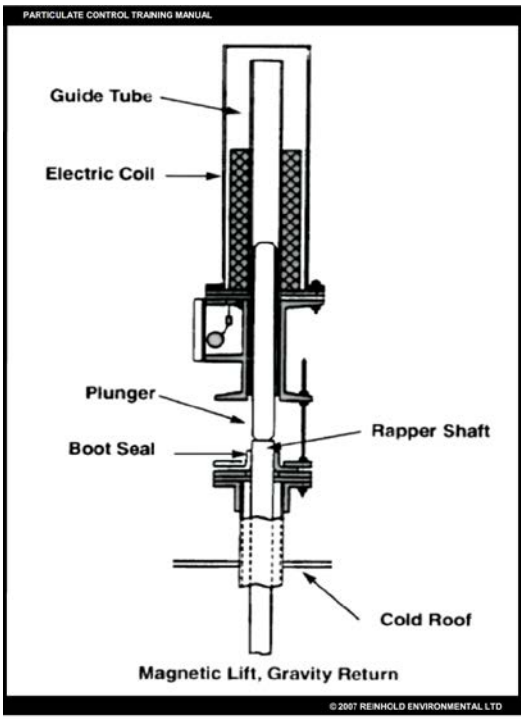
Precipitators that collect dry particulate require a means of removing the collected particulate from the collecting and discharge electrodes. This is necessary because excessive accumulations of particulate on either of these electrodes can lead to the following problems:

- Reduced sparkover distance between the electrodes that results in increased spark rates and operation at lower than desirable electrical power levels and lower collection efficiency.
- Suppression of the formation of negative corona on the discharge electrodes and a reduction of free ions resulting in decreased particle charging and lower collection efficiency.
- Unbalanced electrical fields within a bus section causing reduced collection in local pockets within the precipitator.



Magnetic Impulse Rappers

Devices such as magnetic impulse rappers (See **Figure:**

Magnetic Impulse Rappers

), electrical vibrators, pneumatic vibrators, and tumbling hammer rappers are the most common devices used for cleaning precipitator electrodes. These devices, except for the tumbling hammer rappers that are always internal devices, are located outside of the gas stream on the top (or side of older units) of the precipitator.

A dedicated controller typically provides the energization power for these cleaning devices. However, some automatic voltage controls have the ability to control rapper devices. The controller must have the flexibility to allow an operator to adjust cleaning intensities and frequency to the lowest levels that produce an acceptable opacity level without cleaning "spikes". Under-cleaning of the electrodes leads to particulate buildups that result in problems above, and over cleaning can result in particulate being forced off the electrodes back into the gas stream (reentrainment) that results in opacity spikes (See **Figure:**

Opacity Spikes due to Reentrainment

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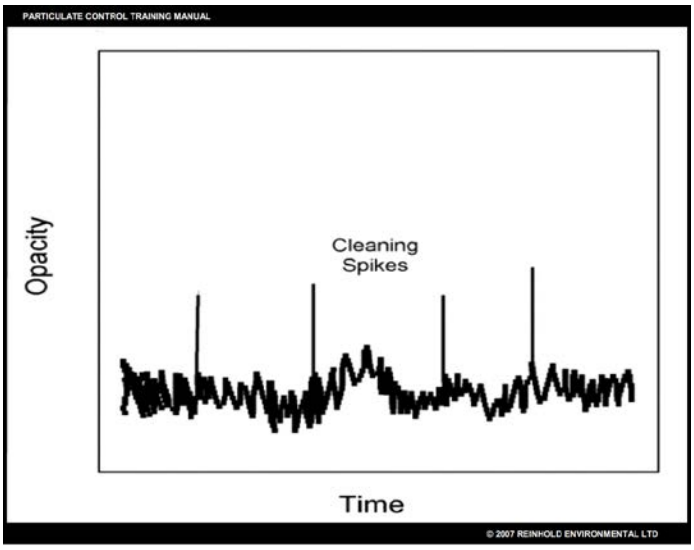
). When the cleaning intensity and frequency are properly adjusted the collected particulate should release from the collecting electrode in agglomerated patches heavy enough to fall into the hopper for removal.



Opacity Spikes due to Reentrainment

Modern cleaning device controllers are microprocessor-based or PC computer based systems. The main components usually include a keyboard or keypad for entering security code and programming information, an LCD or CRT display to show parameter settings, device energization, alarm conditions, etc., output cards, power components, and a cabinet to house everything.

Two different modes of adjusting the intensity of magnetic impulse devices are used among the different manufacturers. One mode is cycle chopping, where the intensity of the impact is determined by the number of half cycles that that are sent to the device. The higher the number of half cycles the greater the intensity, and conversely the fewer half cycles the lesser the intensity. The other mode is phase angle adjustment, where a constant number of half cycles are produced but the SCRs are fired at various conduction angles to produce more or less power to the device (similar to the operation of a TR control). With the cycle chopping mode, each half wave produces a given amount of intensity, intensity requirements between the half cycles cannot be obtained. The SCR conduction angle mode produces an infinite number of intensities and is the more accurate operating mode.

As a minimum, a cleaning device controller should have the capability of allowing an operator to easily change the following:

- The cycle time of a device
- The intensity of a device
- Fault detection and cause identification
- Manual device energization

Other desirable features are:

- Anticoincidence energization (prevents to devices from operating at the same time to minimize cleaning spikes)
- Multiple energization (allows a device to operate more than once before the next device is energized aiding in cleaning of very sticky materials)

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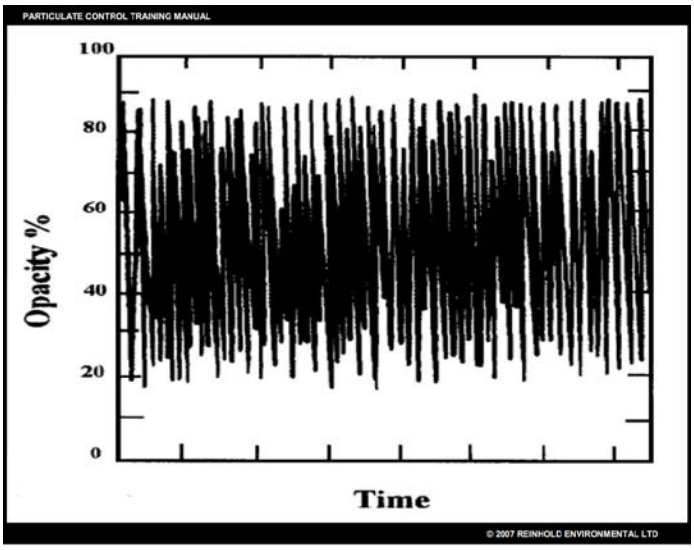
- Power off rapping (reduces, or turns off, the power to a TR associated with the cleaning devices being energized to ease particulate removal - usually used on precipitators collecting high resistivity particulate)
- Central control system capability (allows all operating parameters to be viewed and changed remotely, allows multiple operating programs to be selected based on process conditions, and monitors/displays alarm conditions and causes of alarms)

Optimizing the Cleaning Device Control and Precipitator Operation



Opacity Before Optimization

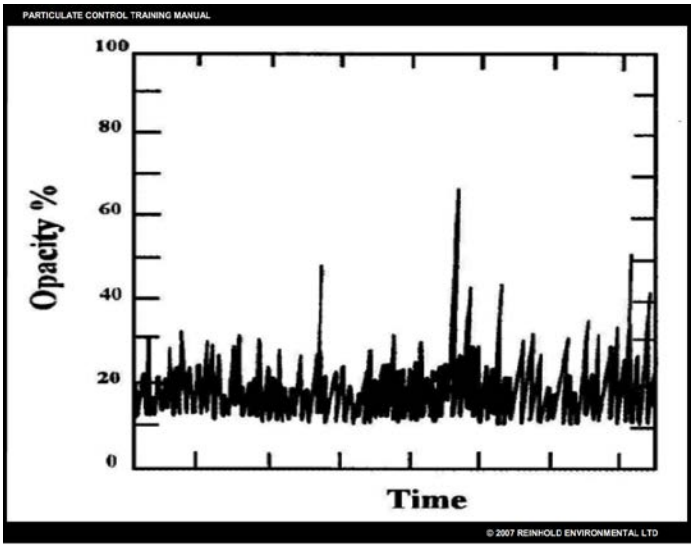
The best way to optimize cleaning device operation, and thus precipitator efficiency, is to perform programmable parameter changes while observing the instantaneous readings obtained from the flue or stack opacity meter. If a strip chart that displays the instantaneous reading is not presently in use, it is recommended that one be installed.

If an opacity meter is not presently installed on the stack or outlet flue, it is strongly recommended that one be installed. Without an opacity meter it is extremely difficult to judge when the devices are optimized.

Note: Where two or more precipitators feed a common stack it is recommended that separate opacity meters be installed in the outlet flue from each precipitator.

What to Look For

The optimum control program will produce the smoothest opacity strip chart reading, at the lowest opacity level, with the fewest "spikes".



Opacity after Preliminary Optimization

Figure:

Opacity Before Optimization

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shows what an opacity strip chart might look like prior to optimizing the control. **Figure:**

Opacity after Preliminary Optimization

shows how an opacity strip chart might look like after the cycle clocks and general device intensities have been optimized. The spikes shown in **Figure:**

Opacity after Preliminary Optimization

can most likely be reduced in amplitude, or eliminated, by further optimizing individual device intensities.

Note: **Figures:**

Opacity Before Optimization

and

Opacity after Preliminary Optimization

are for illustrative purposes only. Actual opacity strip chart recordings will vary from precipitator to precipitator, and from process to process.

Where to Start Optimizing

The following is an example for optimizing the rapping system of a gravity impact rapped ESP. There are many other tumbling hammer rapped ESPs that can be optimized in a similar manner.

Initially, set the lifts for all rappers, except the outlet field rappers, at a 4 inch lift. The outlet field rappers should be set for a 3 inch lift. For electric vibrators, set the intensities for 85%. And for pneumatic vibrators set the air pressure for 30psi.

Program the Cycle Clocks for longer and longer cycle times from the inlet field to the outlet field. A typical initial setting for fly ash would be as shown in the chart below. Processes with sticky particulate or high moisture contents will need cycle times of shorter duration.

Inlet Field Cycle Time - 3 minutes
2nd field Cycle Time - 10 minutes
3rd field Cycle Time - 25 minutes
4th Field Cycle Time - 45 minutes
5th Field Cycle Time - 90 minutes

If the opacity level initially drops but starts to climb back up with time, the cycle times are probably too slow. If the opacity initially increases and does not come back down, the cycle

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times are probably too fast.

The main point to understand when setting the cycle times, is the cycle time should be long enough to allow particulate collection to occur to a nominal buildup, that will not promote sparking, before the particulate is cleaned off the electrodes.

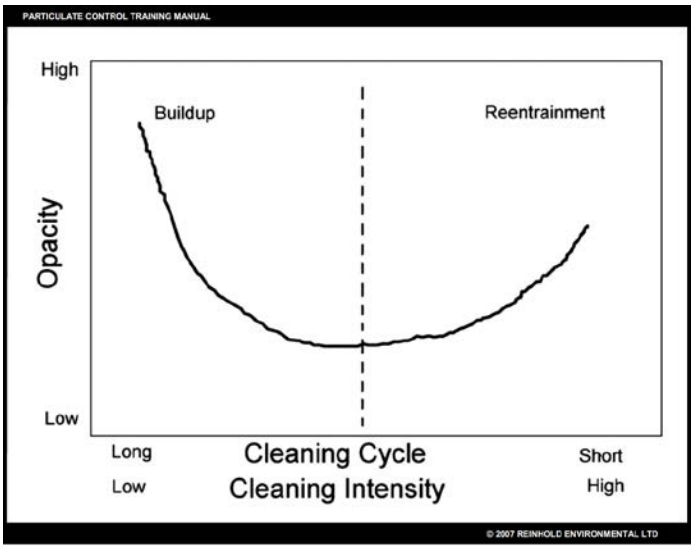
If the cycle time is too slow, opacity will initially decrease because long periods between raps means long periods between re-entrained particulate, which will lower opacity. However, the collected particulate will soon become thick enough to promote increased sparking at lower voltage levels causing the transformer-rectifier controls to reduce power. As power is reduced, the efficiency of the precipitator decreases and opacity rises.

If the cycle time is too fast, opacity may rise and stay at an increased level because the particulate is being re-entrained into the gas stream at a fast rate. Transformer power may also rise but will never compensate for the amount of re-entrainment taking place. (See **Figure:**

Opacity vs. Cleaning Cycle Intensity

)

Optimum cycle time settings are obtained by trying longer and shorter cycle times on each precipitator field until the lowest opacity that remains constant over time is reached. Once the lowest opacity base line has been established, any rapping spikes can be reduced in size or eliminated by optimizing individual device intensities.



Opacity vs. Cleaning Cycle Intensity

By careful observation of the timing of the opacity spikes, the device(s) that caused the spike(s) can be identified and its lift can be reprogrammed.

Optimization of the control is a trial and error game where the opacity level is judged against long-term power levels until the highest power levels that produces a desired opacity is reached. If the optimum setting of the control is done at maximum process load the control should not have to be readjusted for lower loads.

Make changes slowly and allow the precipitator to reach equilibrium before making another chance. You cannot rush this process or make large changes quickly. It may take several days for the effects of some change to become apparent.

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Although this section has focused on gravity impact rappers, the optimization process is similar for other rapping devices. Typically, for tumbling hammer rappers, only the frequency of rapping can be adjusted, not the intensity. In cases of lift and drop hammer rapping, both frequency and intensity can be adjusted.

3.5 ESP Central Control Systems

Central Control Systems

With the advent of electrostatic precipitator microprocessor controls for transformer rectifiers (TRs) and cleaning devices, sending data between controls, and between controls and a central computer system, has become possible. It is no longer necessary for an operator to physically go to each control cabinet to collect electrical data and/or check the alarm status, or to make operating adjustments. Each control now has the capability of communicating, using a number of different protocols, amongst its own family of controls and with other outside devices.

There are three basic levels of communication:

- Communication only between TR and cleaning device controls for initiating such things as power down cleaning and automatic cleaning program changes.
- Communication between the TR and cleaning device controls, and a central control system consisting of a PC and printer.
- Communications between the TR and cleaning device controls, and a distributed control system (DCS) or programmable logic controller (PLC).
- A combination of the above.

In the case of the TR and cleaning device controls talking amongst themselves, the communications capability simply provides a closed loop system that reacts to locally programmed parameters and instructions.

The communications system to a Personal Computer allows for automatic logging of data and alarms (both hard copy and magnetic storage), remote reprogramming of control parameters, energy management, and automatic special operating modes based on process conditions. When a PC is provided as part of a control system it is typically preprogrammed based on a user's requirements for screen colors, layout, and content. All the time consuming programming has already been performed by the manufacturer, however if changes to the system screens are desired the supplier must be contacted and arrangements made for changes.

With communications directly into a DCS or PLC the user is free to integrate the data directly into existing reports, and display the data on existing monitors. Any additions to the content of reports or displays, or any new control parameters that are desired at a later date can be performed within the DCS/PLC by plant programmers.

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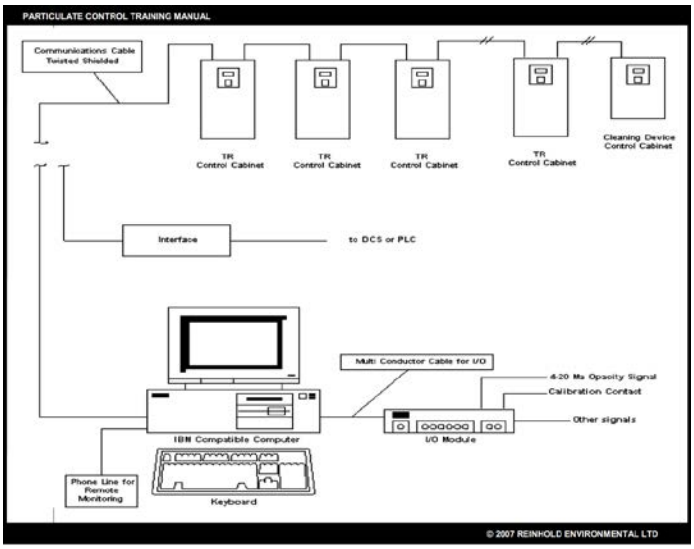
A typical communication loop is shown below.



Typical ESP Central Control System Communication Loop

Electrical communication between the various controls are usually RS232, 422, or 485 protocol and carried over 16 gauge shielded twisted pair communication cables. In some instances, where the electrical noise of the environment is very high, fiber optic cables and associated cable modems may be required to insure data integrity.

Typically, all electrical readings as well as operating parameter changes that can be made at the local controls also can be made from a central computer system or a DCS. This affords the operator the opportunity to investigate how process control changes and upsets affect the precipitator. The operator also can determine what changes to the precipitator electrical operating parameters are helpful in correcting any performance shortfalls.

Colorful animated graphics aid in locating and troubleshooting system failures. Computer display screens can show such things as:

- Precipitator layout showing transformer and rapper locations
- Electrical energization equipment showing On/Off status and half wave/full wave operation
- Electrode cleaning equipment showing energization patterns, intensities, cycle times, and alarms
- Auxiliaries such as hopper level indicators, hopper heaters, and blast heater systems
- Process parameters such as steam flow, boiler load, feed rate, etc.

On line tutorials on theory of precipitator operation, preventive maintenance, and troubleshooting are also available through context sensitive help screens.

The use of magnetic media for data logging and storage, coupled with graphing capabilities, allows historical electrical readings to be displayed graphically. Compared to tabular data, this graphical format makes relationships between process conditions and precipitator operation much more evident. Trending of data permits changes in operating modes to be made before emissions degrade to unacceptable levels. It also points to areas where preventive maintenance may be needed.

Today's central computer systems also permit automatic precipitator start-up and shutdown procedures. For example, where moisture is a problem, the precipitator can be energized in

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various steps of both the number of TRs that are energized and their electrical levels. This allows time for insulators to dry before they receive full electrical energization, reducing insulator breakage. This automatic operation can be based on inlet or outlet gas temperature, steam flow, MW load, feed rate, or any other reference. This type of staged startup (and shutdown) also can be used for operations that become unstable during these periods. Using absolute minimum electrical levels to maintain opacity can stabilize precipitator operation.

Energy management is one of the cost-saving features of a central control/DCS type system. Using an opacity signal brought back to the central system, the power levels can be automatically kept at the lowest level possible while maintaining the lowest opacity possible (or a chosen opacity level). The energy management feature typically saves between 40 and 60 percent of the total precipitator installed power. This feature alone has allowed the cost of the central system to be paid back many times over. Other cost-saving features include automatic logging of electrical readings, alarm indicators that pinpoint the cause of the alarm condition, and the use of a modem to transmit operating information for remote analysis and correction.

Remember that in a multi-field precipitator there is an interaction between fields. Adjustment to an inlet field may cause changes in following fields requiring adjustment to these. Always make changes slowly in small steps and wait until equilibrium is reached before making additional changes. Take your time.

Features and Functions

Some of the typical features and functions of these systems are:

- Control and monitoring of individual AVCs
- V-I curve generation
- Data acquisition and trending
- Historical archiving and retrieval
- Control of and/or interface with rapping systems
- Control and/or status of auxiliary electrical equipment
- Remote access and monitoring via modem
- Power consumption calculations
- Energy management
- Troubleshooting advice
- On screen user help
- Plant DCS interface

Where large numbers of transformer rectifiers (TRs) are to be monitored, multiplexing technology is employed to poll the individual TR controls on a rapid cycle without having to hard wire each set to the monitor.

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3.6 Opacity

Relationship of Mass Emissions, Particle Size, Particle Physical Properties and Stack Diameter To Opacity

Visible Emissions (Opacity)

Aerosol particles scatter, due to reflection, refraction, and diffraction, and absorb light causing that component of the emissions to be visible to the human eye. Some gaseous emissions, specifically NO_2, also absorb light, but concentrations at the point of emission are rarely high enough to be of significance, relative to the obscuration or opacity caused by typical particulate levels. Certain gaseous components in the vapor state such H_2O and H_2SO_4 can condense into fine liquid droplets which effect opacity.

Since visible observations of emissions by the human eye are rapid, convenient, commonly available, and inexpensive, this method is commonly used to monitor particulate emissions by means of the opacity. Also, in-stack and out-stack techniques and instruments exist for measuring stack and plume opacity. However, opacity depends upon several complex factors, which prevent it from being applied in general as a quantitative measure of particulate emission levels. Visible emissions or opacity regulations are maintained across the nation at federal, state, and local levels with varying degrees of independence from particulate mass emission regulations.

Intent of an Opacity Standard

Since opacity relates to several different considerations, an opacity standard can in effect be utilized for multiple purposes. Some consider this standard important for aesthetics as well as for its role in controlling particulate and gaseous emissions. Others want it applied stringently because of its greater sensitivity to fine particles, which are believed to be more detrimental to our environment than large particles (>10 microns). The U.S. EPA has clearly stated the intent for its opacity standard in the Federal Register as a method of insuring "proper operation and maintenance of such control systems (best adequately demonstrated system of emission reduction) on a day-to-day basis, but not require the design and installation of a control system more efficient or expensive than that required by the concentration/mass standard."

The U.S.EPA has relaxed its permitted opacity level in some circumstances where it was clearly demonstrated that the source was emitting below the level required by the concentration/mass

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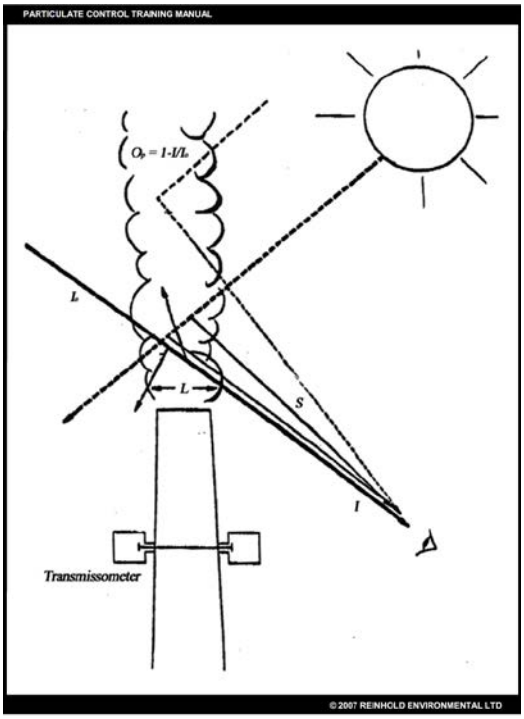
standard.

The federal, state, or local government can limit opacity based on those considerations established as important. However, an opacity standard should be applied with a clear policy statement of the intent of the standard. Once the intent of the standard is clear, then questions concerning how to comply, permitting, and enforcement can be readily addressed.

If the intent is to limit mass emissions on a continuing basis, then the policy assumed by the U.S. EPA is appropriate considering all issues relevant to environmental protection:

"Opacity of emissions is indicative of whether control equipment is properly maintained and operated. However, it is established as an independent enforceable standard, rather than an indicator of maintenance and operating conditions because…the time and expense required to proved that proper procedures have not been followed are so great that the provisions of 10 CFR 60.11(d) by themselves (without opacity standards) would not provide an economically sensible means of ensuring on a day-to-day basis that emissions of pollutants are within allowable limits."

Opacity as an independent enforceable standard is judicious because, while being a good indicator of mass emission rate, rates inferred from it are subject to substantial, fundamental errors for reasons beyond the control of operators of sources. Opacity cannot be considered as a definitive method of measurement of mass emissions. However, the unique advantage of inexpensive monitoring, which opacity provides, is utilized through the opacity standard.



Factors Involved in Measurements of Visible Emissions

Measurement of Opacity

According to the Federal Register the visual determination of opacity from stationary sources (Method 9) is obtained by an observer who has been qualified by demonstrating agreement between his values of opacity and values from a standardized transmis-someter. The qualification tests are performed with a smoke generator on 25 different plumes. The observations are made viewing a contrasting background scene through the plume with the sun at his back. The observer is instructed to avoid including condensed water in his observations. Methods for avoiding the effects of condensed water in the observation of opacity are specified.

The parameter measured by the transmissometer, and thus, that sought by the observer is the

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fraction of the light removed from a beam due to scattering and absorption by aerosol particles (Opacity = $1-I/I_o$ where I_o is the incident intensity). Some light scattered from directions other than from the background scene and sensed by the observer tends to interfere with the determination. The position of the sun is important for that reason. Other important variables are the stack diameter, the position and elevation of the observer relative to the plume, and spreading of the plume.

Criticism has been directed at the observer method (Method 9) of measuring visible emissions due to the potential interferences listed in **Figure:**

Factors Involved in Measurements of Visible Emissions

. Several studies have been conducted to establish the uncertainty of visual opacity measurements relative to transmissometers. The U.S. EPA has concluded that the maximum uncertainty in Method 9 is +/- 7.5 percent opacity. It is important to note that this does not necessarily mean that observer measurements of plume opacity will always be within +/- 7.5 percent of values from a transmissometer mounted in the stack. Also, aerosols existing in stacks can have much lower opacities than those in the plume due to condensation and chemical reactions which tend to occur with the cooling of some process gases.

Therefore, caution must be exercised when deducing visible emission levels as defined by Method 9 from in-stack transmissometers.

Some regulatory agencies require continuous measurements of in-stack opacity to demonstrate compliance with the standard. Many devices for measuring in-stack opacity are available commercially, which satisfy U.S. EPA requirements specified in the Federal Register (1976). **Figures:**

Transmissometer Schematic

and

Typical Double Pass In Situ Transmissometer Design

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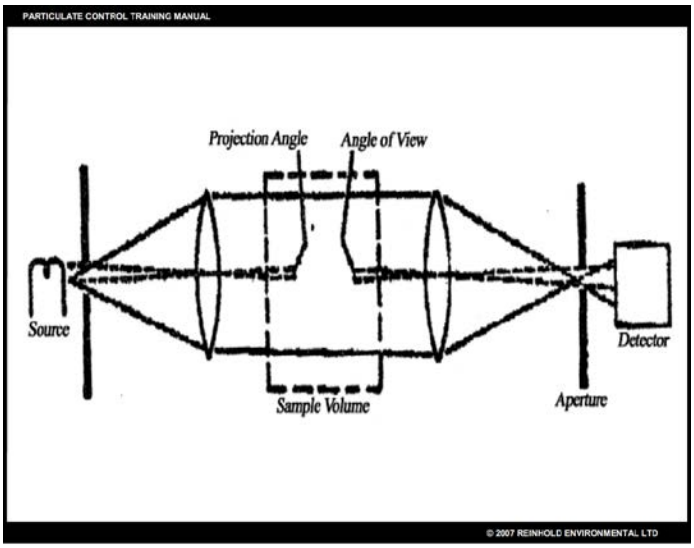
depict two such devices referred to as single and double pass transmissometers because they measure the transmitted light. The use of visible light as a light source is required because the response of the instrument is supposed to match that of the human eye (photopic response). The angle of view and the angle of projection is specified, for compliance, as no greater than 5 degrees. To obtain true transmittance data the collimation angles (angles of view and projection) for the transmitter and receiver must be limited to reduce the sensitivity to stray light scatter. All transmissometers require purge air systems to protect the optical windows or reflectors. Still, regular cleaning is required with the accumulation rate varying widely from one location to another. Most commercial instruments have automatic zero and span checking capabilities to verify proper functioning and calibration between cleanings.



Transmissometer Schematic

Methods for measuring plume opacity also exist; some are available in commercial devices. Some methods, utilizing sunphotometers and telephotometers, are passive like the visual determination in that sunlight, direct or reflected, is the light source. Others are active in that a laser beam is projected through the plume. Lidar (Light Detection and Ranging) is the most widely known method of this type. It measures the intensity and time of flight of light, which is scattered backwards from points along the laser beam by atmospheric molecules. The opacity of a plume is inferred from the intensities of back-scattered light from in front of and from behind the plume.

Relationship of Opacity to Aerosol Parameters

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Particles suspended in an aerosol will scatter and absorb radiation from a light beam passing through the aerosol; the remaining portion of the beam is transmitted. The transmittance (T) of an aerosol is defined as the ratio of the transmitted light intensity (I) to the incident light intensity (I_o). The parameter T is also given by the Beer-Lambert law as

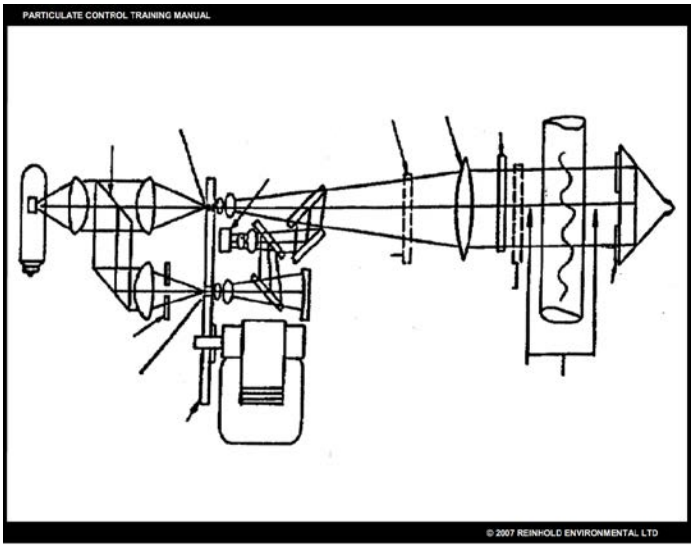
$T = I/I_o = \exp(-EL)$ Equation (1)

where L is the path length of the beam through the aerosol medium and E, the extinction coefficient of the medium, is a complicated function of the size, share, total projected area, and refractive/absorptive indices of the particles and the wavelength of the radiation (light).

The measured transmittance may be expressed in terms of optical density (O.D.) defined as

$O.D. = \log(1/T) = \log(I_o/I)$ Equation (2)

instead of the transmittance itself. Based on the above, it is seen why the in-stack opacity monitors which were described earlier and make an aerosol measurement based on light transmission principles were referred to as transmissometers.



Typical Double Pass In Situ Transmissometer Design

From equation (2),

$T = 10^{-(O.D.)}$ Equation (3)

The opacity (O) is defined as the ratio of the light attenuated from the beam by the aerosol to the incident light:

$O = (I_o - I)/I_o = 1 - I/I_o = 1 - T = 1 - 10^{-(O.D.)}$ Equation (4)

For general insights and applications regarding opacity, it must be determined based on a mathematical solution to Maxwell's electromagnetic equations. The theory using this type of development is that of Mie which yields, among other parameters, the extinction efficiency

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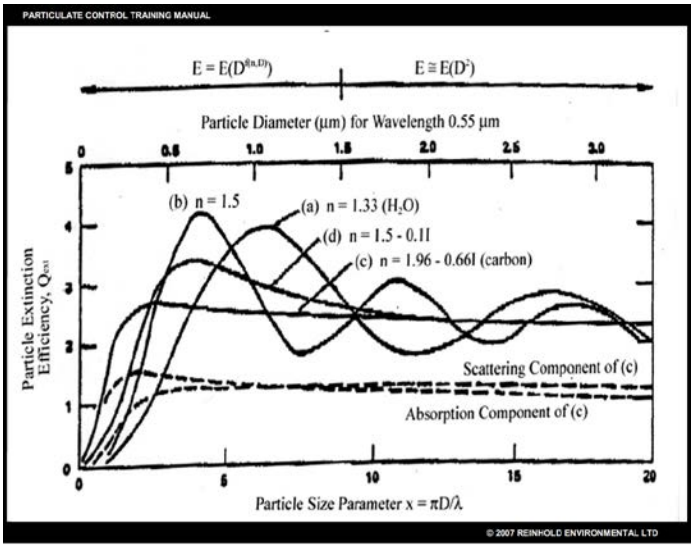
(Qext) in terms of the particle refractive index (n) and particle size parameter ($\pi D/\lambda$) for isotropic, homogeneous spheres. D and λare the particle diameter and the wavelength of the light beam, respectively. Qext represents the effective projected area of a particle for removing light from a beam compared to the particle's geometrical projected area (A). Opacity is related to Q_{ext} by:

$O = 1\text{-}\exp(-EL) = 1\text{-}\exp(-NAQ_{ext}L)$ Equation (5)

where N is the particle number concentration and $Q_{ext} = Q_{ext}(n, \pi D/\lambda)$.

Equation (5) shows that the reduction in the transmission of light passing through an aerosol due to scattering and absorption by the suspended particles is a function of particle concentration, path length through the aerosol, particle size, and particle composition (index of refraction). **Figure:**

Particle Extinction Efficiency as a Function of Particle Size Parameter



Particle Extinction Efficiency as a Function of Particle Size Parameter

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shows Qext as a function of the particle size parameter ($\pi D/\lambda$) for four refractive indices of interest. A value of n = 1.5 is typically used as representative of fly ash particles. For particles greater than about 1-2 microns, the extinction of light is essentially determined by the total projected area of the aerosol particles. For smaller particle diameters, particle composition or index of refraction becomes important. Also, the peaks in Qext are greatest for particles less than about 1 μm in diameter. For a polydisperse aerosol, the total effect of the suspended particles on opacity must be determined by summing the contributions to opacity must be determined by summing the contributions to opacity due to the various particle sizes with their possibly different concentrations and compositions (indices of refraction).

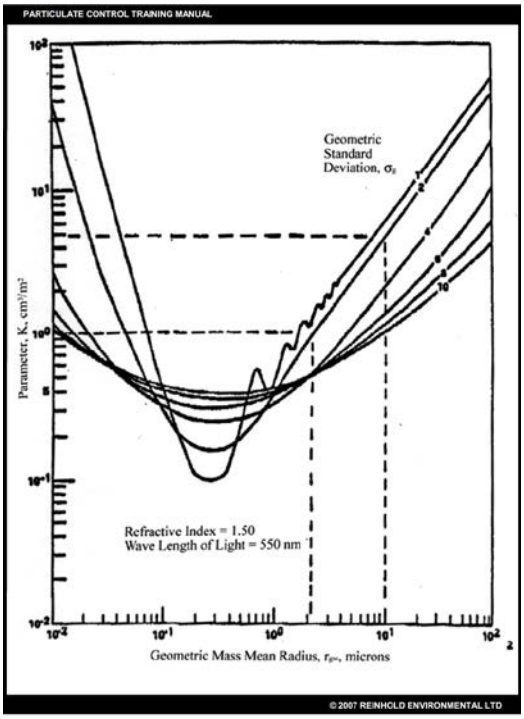
Since there is an interrelationship between mass concentration, particle size distribution, particle composition, and opacity, it is possible to meet the mass emissions standard and not the opacity standard or vice versa. Emissions from electrostatic precipitators (ESPs) which are high in re-entrained particulate matter or unburned carbon and contain larger particles may exceed the mass emissions limit while being well within the opacity limit. It is also possible to improve boiler efficiency resulting in reduced mass emissions and increased opacity due to a finer particle size distribution and reduced unburned carbon content. The above analysis can be illustrated further by examining the opacity expression given by Ensor and Pilat:

$O = 1 - I/I_o = 1\text{-}\exp(-WL/pK)$ Equation (6)

where:

W = Total particulate mass concentration, (gm/m3),
L = Illumination path length or diameter of plume, (m),
p = Particle density, (gm/cm3),
K = Specific particulate volume/extinction coefficient ratio (cm3/m2)

The parameter K, related to the volume/surface ratio of the aerosol, is determined by the particle size distribution and refractive index. Illustrative calculations of K assuming log-normal distributions for two values of the refractive index are given in **Figures:**



Parameter K as a Function of the Log-normal Size Distribution Parameters

Parameter K as a Function of the Log-normal Size Distribution Parameters

. It can be seen that K and thus opacity is very sensitive to mass median diameter (MMD), geometric standard deviation (σ_g), refractive index. Since opacity increases as K decreases, the minimum occurring around 0.5 to 0.1 micron in diameter is of particular interest. The extent of the variation of opacity with particle size may perhaps be more easily visualized from the presentation in **Figure:**

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where (pk)-1 is plotted on a linear scale.

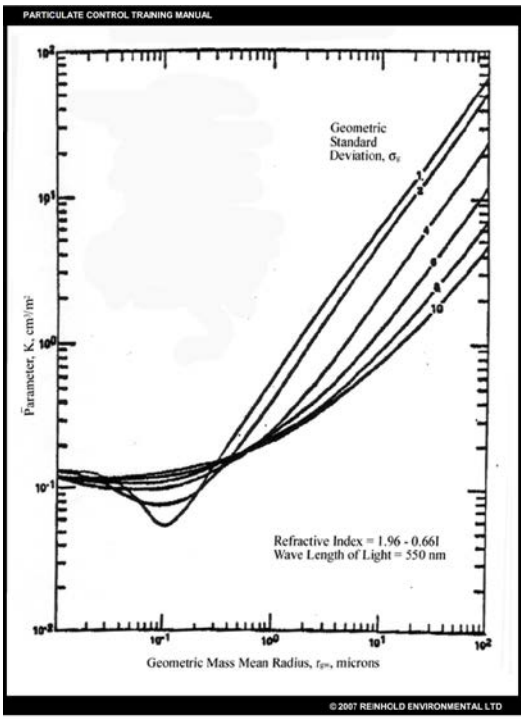
Equation (6) can be expressed in another from which can be utilized to demonstrate the several factors which can affect the use of opacity as a predictor of particulate mass emissions. Consider

O = 1-exp[-W/(1/pK/L] = 1-exp[-E/Q)/A/L] Equation (7)

where:

W = E/Q (gm/m3)
E = mass emissions per heat produced (gm/J),
Q = gas volume flow per heat produced (m3/J)
A = 1/pK = specific attenuation coefficient, (m2/gm)

Based on equation (7), the opacity increases or decreases when the product (E/Q)/A/L) increases or decreases, respectively. For a given stack, if A and Q remain constant over time, then a useful relationship exists and simultaneous measurements of mass emission rate and opacity make this relationship known. However, variations in Q and A for the same value of E can be expected due to variations in coal and ash properties, boiler operation, and ESP operation. The discussion above can be evidenced in work in the literature to correlate opacity and particulate mass emissions at coal-fired plants.



Parameter K as a Function of the Log-normal Size Distribution Parameters - 1

Summary. An opacity standard can be used for the purposes of aesthetics, control and/or enforcement of particulate and gaseous emissions, control of fine particle emissions, and/or an indication of proper operation and maintenance of the particulate control equipment.

Stack opacity can be determined by visual observations of the plume exciting the stack (USEPA Method 9) or by an in-stack transmissometer, which measures the light transmitted through the aerosol.

Stack opacity depends on the particulate mass concentration, particle size distribution, particle composition (index of refraction), and the stack exit diameter.

Stack opacity may or may not be a good indicator of particulate mass emissions depending on

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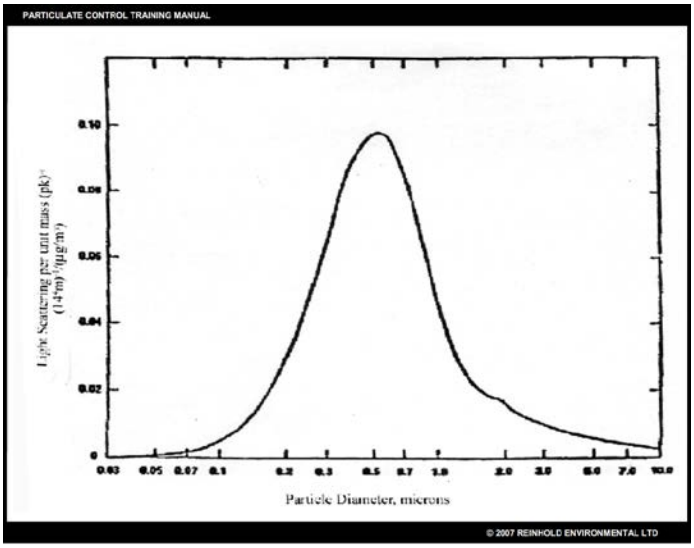
the constancy of factors such as coal and ash properties, boiler operation, and particulate control equipment operation.

Method of Opacity Determination

Opacity may be determined by the following formula or closely approximated using the curves found on the following pages. It the geometric mass mean diameter of the particles in the system is known, a corresponding parameter "K" may be found for white or black aerosols, and for various geometric standard deviations.



Normalized Light Scattering by Aerosols as a Function of Particle Diameter

Procedure 1: Approximation of Opacity

Once the appropriate K has been determined, the opacity can be found directly from the graphs, knowing the stack diameter and outlet particulate concentration.

Procedure 2. Calculated Opacity

Determine K from the appropriate graph, based on the geometric mass mean particle diameter and the appropriate geometric standard deviation. Opacity can then be calculated by the following formula:

OPACITY (decimal percent) = 1 - e [-0.7WL/pK]

where:

W = outlet particulate concentration (grs/acf)
L = diameter of stack outlet (feet)
p = particulate density (gm/cm3)
K = a parameter determined from graphs, and is a function of particle size and color

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CHAPTER 4 - ESP OPERATIONS AND MAINTENANCE

Bent Plates - Gas Passage Explosion

This chapter discusses the fundamentals of ESP Operation and Maintenance, including:

- *Cycling*
- *Startup & Shutdowns*
- *The Dirty Inspection*
- *The Clean Inspection*
- *Air Load of ESP*
- *Precipitator Electrode Alignment*
- *Structural Problems in ESPs*
- *Maintenance of Mechanical Equipment*
- *Mechanical Problems and Solutions*
- *Fundamentals of Troubleshooting an ESP with an Oscilloscope*
- *What the Meters Tell You*
- *Low NOx Burners Effects on ESP*
- *Replacement Parts for ESPs*

4.1 Cycling

General

In the march to deregulation, it is uncertain as to the effect on cyclic operation. Much of the cycling may take place using simple-cycle and combined-cycle natural gas plants. A lot of forecasts have been made, and they differ greatly. A great deal will depend on the price and availability of natural gas over the next two decades.

Cyclic operation of coal-fired plants will still be practiced to a certain extent in smaller systems.

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While cyclic operation can be disruptive to precipitators and fabric filters, it can offer some benefits which to date have been little used.

With the advent of more sophisticated precipitators, rappers and fabric filter control systems, we can now easily take advantage of these potential benefits.

By integrating pollution control equipment systems with boiler systems, operators can take advantage of low load periods and lower gas temperatures. To clean the equipment without causing emission excursions, operators can also reduce rapping or cleaning disruptions during unit up ramping and down ramping. Users can save substantial quantities of electric power by reducing electrical input during low load periods. They can completely empty hoppers during low load operation.

Development of procedures, computer software and addition of hardware can result in substantial improvement in overall performance and substantially reduce excursions. The benefits available from cyclic operation may substantially outweigh the drawbacks. Users must, however, invest in developing procedures, software and hardware to take advantage of this opportunity.

The only major problem with cyclic operation involves maintaining temperature above the dew point and the excursions, which occur during up ramping and to a lesser extent during down ramping. During load ramping, the combustion process is changing and results in changes in the flue gas and particulates. This may lead to upsets in the control equipment, resulting in increases in mass emissions and opacity.

4.2 Startup & Shutdowns

General

Both precipitators and fabric filters are adversely affected by the disruptions due to startup and shutdown of the boilers associated with them.

Most of the problems are caused by periodic episodes of dew point or below dew point service. Precipitators tolerate this better than fabric filters, but it is a problem for both types of collectors. There are some measures, which can be taken to mitigate these difficulties to some extent, depending on the circumstances.

Units, which undergo a yearly or twice yearly shutdown present problems associated with moisture condensation from a cold startup. Keeping insulators hot and dry and paying close attention to hopper discharges solve most of these problems. Cleaning the unit during the shutdown eliminates almost all of the other problems.

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The most destructive startup and shutdown situation involves units, which come down every weekend, or worse yet, every night. Some of the things, which can be done in these cases, involve the following:

- For nightly, or even weekend shut downs, bottle up the boiler to preserve temperature.
- Always keep insulator vent fans and heaters and hopper heaters in service.
- On the way down, increase rapper frequency and intensity to clean fly ash from the internals. De-energize rectifiers while rapping. Operate bag cleaning on an accelerated basis.
- Get hoppers empty and keep them empty. Keep ash handling system running for 1 to 2 hours after boiler shutdown. Start ash handling an hour before boiler startup. Start rappers or bag cleaning cycle before startup.
- Do not open precipitator, baghouse or flue doors unless absolutely necessary.

In dealing with the problems, operators must feel their way and do what works for them. Your own experience is your best teacher.

It should be pointed out those units, which startup and shutdown frequently, are also frequently subject to dew point conditions and acid dew point corrosion.

Each year the roof, sidewalls hoppers and collecting plates should be checked for metal thickness, and the readings taken at the same spot with readings recorded so that corrosion rate can be established and repair or replacement dates established.

Gas and Oil Startup

Natural Gas Startup for coal-fired boilers.

Natural gas is an ideal startup fuel for solid fuel-fired boilers. If the startup burners are of proper design and are operated properly, little particulate matter is generated, and it is usually possible to leave the collector out of service until the furnace is hot and the flame absolutely stable.

The only problem with a gas startup usually occurs due to condensation of the water of combustion of the natural gas on the cold parts of the electrostatic precipitator or fabric filter. If the equipment is not cleaned of fly ash, mud may form on the metal surfaces and on the fabric. It is best to get through this condensation period as quickly as possible and to have the collector as clean as possible, especially the hoppers. Hoppers should be closely monitored to prevent hardened mud deposits from plugging the outlet.

The only other problem is generally quite rare, but in the event of combustion control or unsensed flame failure, an explosion or fire is possible in the electrostatic precipitator. Close monitoring is necessary.

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Propane Gas Startup for coal-fired boilers.

A few boilers use this fuel and the same precautions apply as in natural gas startup. The fuel is however three times as energetic as natural gas and has a lower flammable limit.

4.3 The Dirty Inspection

Preparation

In order to properly perform a precipitator dirty inspection certain preparations must be made.

- Take an up to date set of electrical data on the precipitator rectifier controls including a set of V-I readings on each set. Be sure to identify the corona starting voltage, the secondary voltage at which current just starts to flow. This should be done just before shutdown procedures begin. Examination of this data will indicate poorly operating areas, the ones where the inspections, both clean and dirty should begin.
- As soon as the coal mills are stopped and/or coal is taken off the unit or other particulate generating activity stops, shut off the rappers.
- Leave the rectifiers in service until the fans, forced and induced draft, are shut down.
- Only after fans are down, shut off rectifiers, locking them out and proceed through the interlock system to prepare for opening the doors
- Move the inspection equipment up to the selected access door, don protective gear and open the door slowly and carefully perform required confined space procedures and gas tests. Be careful of hot dust. Have camera ready.
- Attach portable grounds and enter precipitator disturbing as little as possible. Be sure to comply with plant confined space entry requirements.

Inspection

Be careful of deep dust deposits. The surface may be cool, but the interior may retain sufficient heat to cause burns. This is especially true in hot (over 450°F (230°C)) units.

Deposits not compacted by electrostatic forces tend to be quite fragile. Make observations on perforated plates, flue and nozzle floors, turning vanes, flue struts and hopper corners before the evidence is dissipated. Use camera.

After making general observations as above, begin a ductby-duct precipitator inspection noting the depth of deposits on plates and their character (light & fluffy, compacted, muddy,

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cementlike, etc). Examine discharge electrodes and note diameter and character as above as well as nature (donuts, smooth, pointy, etc). Note if deposits are confined to certain wires or plates to certain sectors (outboard, inboard, 8th through 12th plate etc.)

If time permits, examine sectors with heavy deposits to determine if plates are jammed in spacers, stuck against wall-ways, rapper bars are broken, welds failed etc. If time does not permit, note areas for special attention during clean inspection.

Inspect insulators, rapper, support and anti swing for evidence of tracking, moisture and carbon deposition. Often this is better seen when dirty.

Inspect insulator compartments and bus ducts for evidence of inadequate purging, or poor boiler draft control. Look for water in-leakage.

In flues or precipitator casings particularly in corners and under roof, look for evidence of water leakage or air infiltration.

In measuring dust deposits, use your ruler. Measure, don't guess.

Always look down into the hoppers in an attempt to locate buildups in corners where grounding or clinkering has occurred.

Photographs

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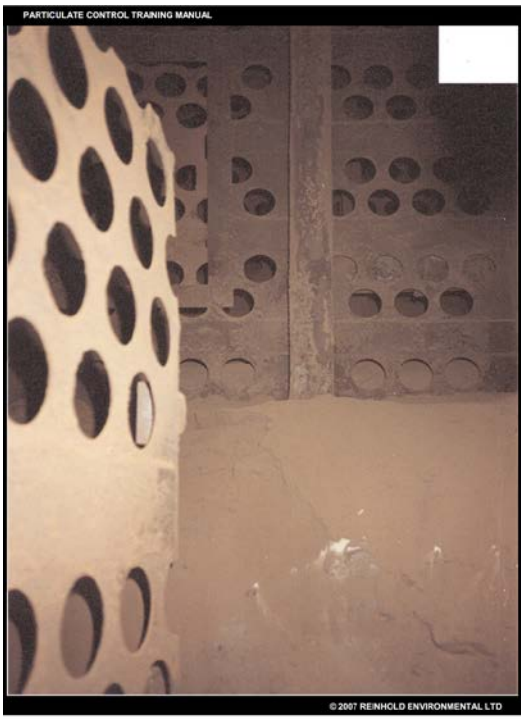
The following series of pictures shows the type of evidence you can gather in the dirty inspection. Photographs should be taken. Remember, you will be showing what you have seen to people who have no intention of going



Buildup in Inlet Flue between Perforated Plates

Buildup on Inlet Flue Floor

into a dirty precipitator. The best way to explain is with a photograph.

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Buildup in Inlet Flue - Perforated Plates and Floor

Flyash Buildup on Turning Vanes

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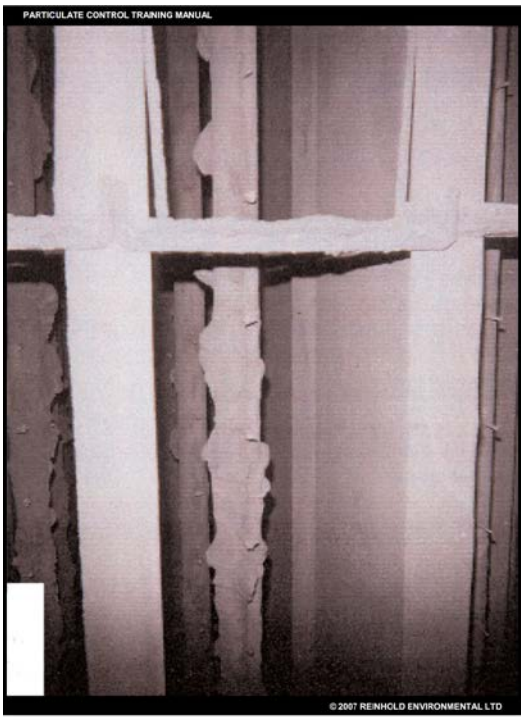
Buildup on Turning Vanes



Badly Fouled Pipe and Spike

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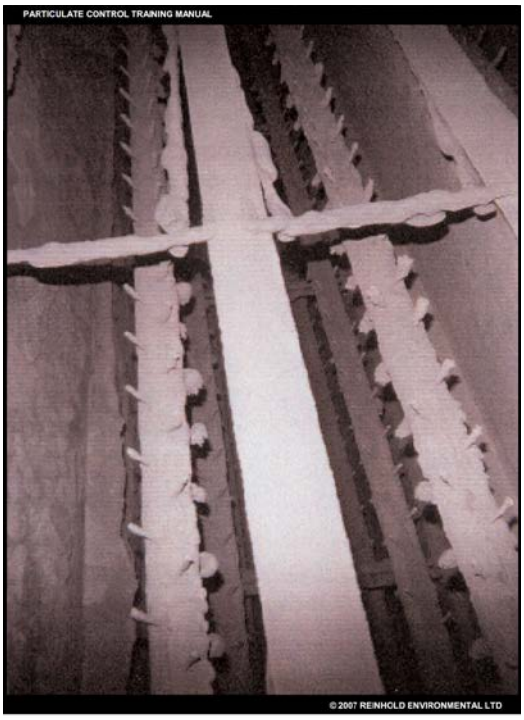
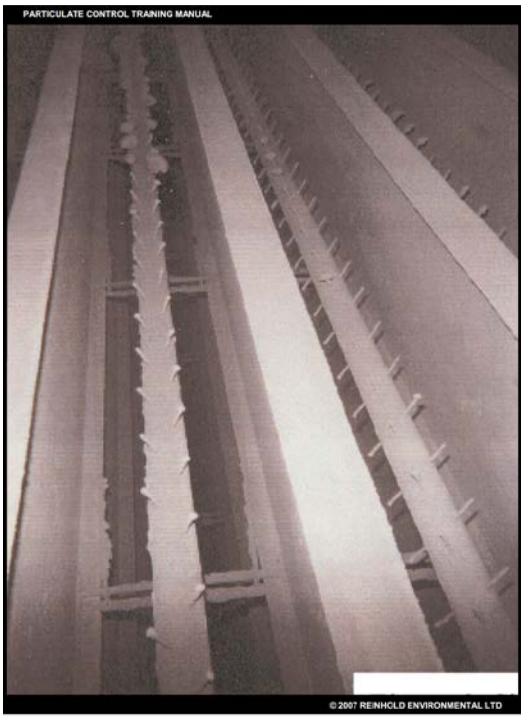


Slightly Fouled Pipe and Spike



Slightly Fouled Pipe and Spike - 1

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Partially Plugged Perforated Plate

Plugged Perforated Plate

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Perforated Plate Bent Due to Buildup Behind It

Perforated Plate Bulged Out at Bottom due to Buildup

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Interpretation of Results

To aid in interpretation, the inspector should mark results on a plan view of each precipitator section. Mark rapper locations and rapper anvils on this drawing. Indicate any stuck plates or bound spacers.

Locate non-functioning rappers, broken rapper bars etc. A clean section may indicate a disconnected or grounded power supply or a grounded insulator.

Sketching the deposits in flues or on perforated plates can show gas distribution problems.

In the final analysis, the dirty inspector should provide a road map for the clean inspector to follow.

Observation of dust deposits on electrodes can be confirmed by a review of electrical operation history. Discharge electrode deposits are usually manifested by rising voltage and falling current, while collecting electrode buildups are often manifested by falling voltage and current.

Donut type deposits on discharge electrodes are normally less destructive than a uniform smooth deposit on discharge electrodes. Heavy buildups in one sector of a field with the other sector being clean always have a bad effect since they disrupt electrical fields.

4.4 The Clean Inspection

Why Clean the Precipitator?

The answer to this question lies in two general areas:

1) In the case of hot side ESPs, periodic cleaning has been necessary in the case of sodium depletion, in order to maintain performance levels, which yield compliance. In the worst case, it may be necessary to clean the ESP every 2-4 weeks and others every 2-4 months, both of which are costly in terms of downtime and lost revenue, to say nothing of the cleaning cost. In many of these hot side cases, the strategy for avoiding these all too frequent and costly cleanings has been to convert the unit from hot side to cold side operation all of which have proven successful.

2) The other reason for the cleaning of ESPs is for inspection. This stems from the potential of internal damage. The damage could be structural or thinning of plates and wires due to long years of operation on high sulfur coal at low temperatures where corrosion has been prevalent. Damage could also stem from operation at temperatures well above design, causing binding, warpage of plates and close electrical clearances. These reasons lead to the idea that the ESP

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may be in need of major modifications internally since performance cannot be maintained. The only way to accurately determine this is to clean the ESP to bare metal for an inspection. Once cleaned the precipitators can then be inspected and accurate conclusions reached as to what modifications are needed to achieve compliance.

How Often Should the Precipitator be Cleaned?

The old adage “If it ain't broke, don't fix it” is certainly appropriate in this case. There is no definite rule of thumb or guideline for cleaning a precipitator. What applies for one does not apply for another - they are all site specific. There are cases where precipitators have not been cleaned for 20 years. In general, if performance is satisfactory, major repairs are not necessary and routine maintenance can be carried out during annual outages without cleaning - then don't do it.

Methods for Cleaning a Precipitator

There are several ways to clean a precipitator.

Air lancing and Mechanical rapping:

Both of these methods are generally used for localized cleaning where a specific area is suspect. They are not adequate for complete cleaning of a unit where heavy, tenacious dust deposits must be removed.

Water wash:

This method is very messy and imposes a heavy work load in cleaning up the muddy mixture of water and ash. It has been known to contribute to increased rates of corrosion in cases where high sulfur coal is used. It also is not totally effective in removing cementlike build up of ash deposits on wires and plates.

Grit or sand blast:

This method of cleaning is very effective in producing well cleaned surfaces. The only objection to it would be that aggressive cleaning on a regular basis might tend to produce loss of metal thickness on plates and wires.

Grain blast:

This method of cleaning is also effective in producing well cleaned surfaces and the grain is not abrasive to the point of causing concern for loss of metal.

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Equipment Required for Clean Inspection

- Flashlight: high power for good vision
- Measuring device: with 3-5 foot reach for checking wire to plate clearances and alignment
- Camera: for taking pictures of specific areas of trouble, i.e. mis-alignment, broken parts, excessive dust buildup, etc.
- Chipping hammer: to check suspect welds, corrosion loss of metal, etc.
- Battery operated grinder and/or wire brush: for cleaning spots on plates to facilitate thickness measurements.
- Micrometer or D-meter: for measuring thickness of plates, casing, etc.

Where and What to Look For

The inside of a precipitator except for those with internal cross bracing, has lines in only two directions - vertical and horizontal. If you see some sort of line running in a direction other than these, check it out closely. It could be a split in a plate or casing. It could be a temporary member welded to something during construction and never removed. Other specific items to look for during a clean inspection are as follows:

Corrosion:

If a unit has been operating on medium to high sulfur coal for a long time chances are that corrosion is prevalent. The best place to first check this out would be in the coolest area of the ESP, which would be on the bottom of plates and casing at the gas exit (last field) of the ESP. This of course is where plate and casing thickness measurements should be made to determine the extent of corrosion loss.

Air-in-leakage:

Condition of access door gaskets and tightness of any penetrations roof or side walls should be carefully checked.

Outer door panels:

Condition of insulation should be checked. Insulation may be poor or non-existent, causing heavy corrosion around the doors.

Alignment of plates and wires:

This should be carefully checked to agree with vendors recommended clearances. Areas of mis-alignment should be noted and determination made whether it is bent plates causing close clearances or the high tension frame out of position.

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Bottom plate guides or spacers:

Should be checked to allow plates free, unrestricted movement.

Midpoint spacers or rakes:

Should be checked to confirm that they are isolated for each group of plates and not firmly connected across groups of plates, which can cause binding.

Midpoint plate clips:

Some plate designs require plate clips at mid point or at one third points if plates are very high. Very often plates come out of these clips and cause close electrical clearances, which seriously reduces performance.

Lower high tension frame stand off insulators:

Sometimes these insulators become broken or out of adjustment allowing the lower part of the high tension frame to freely swing. This can cause serious arcing, broken wires and deteriorating performance. These should always be checked for sound condition.

Rapper anvil beams and impact diverter plates:

Always check the rapper rod connection to the anvil beam to see that the weld has not broken. In numerous cases this weld is broken and the rod is loose, resulting in ineffective rapping force to the anvil beam. Also check that the impact diverters (gussets) are solidly connected. They may be loose (broken welds) and even missing.

In the case of rotating hammer rappers, it is common that the hammers eventually wear and do not make positive contact with the anvil bar on the plates. These should be carefully checked and make sure they are in good alignment.

When Eriez Vibrators are used for the high tension rapping medium, they should be given regular attention. They make a lot of noise and give the impression of doing a good job of removing dust, when in fact they may be doing nothing but making noise. The pole face clearance should be maintained at about 15 thousandths of an inch for effective rapping. This type of equipment is very labor intensive to maintain effective results.

Insulators:

Always check the condition of the high tension support insulators to confirm the effectiveness of the purge air system. Check that they have no cracks and are not covered with heavy dust build up.

Water leakage:

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The precipitator should be checked carefully for any indication of water leakage which might be soaking insulation inside the lagging. This of course renders the insulation ineffective and must be corrected.

See the following "Clean Inspection" photographs for examples of these inspection points.

High Tension Rapper Connection Broken

Plate Rapper Shaft Misalignment

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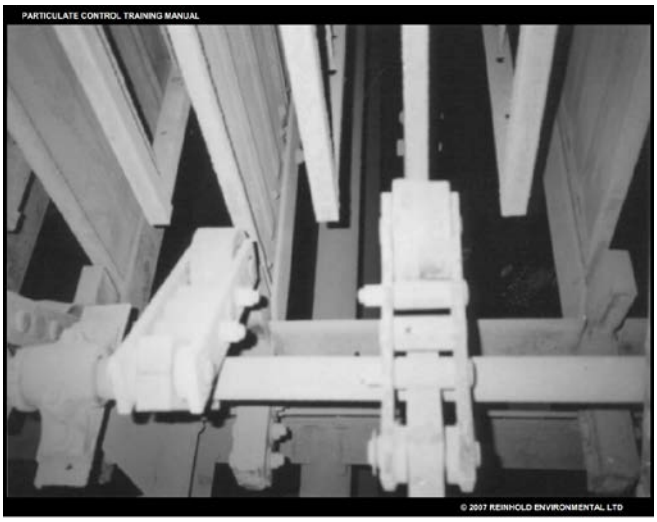
High Tension Rapper Anvil Detached



Tumbling Hammer Misalignment

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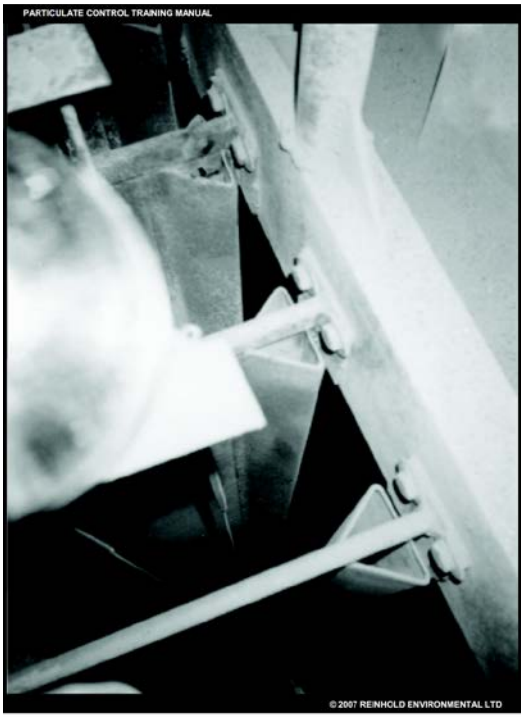
Collecting Electrode Positioner Too Loose

Collecting Electrode Positioner Not Engaged



Beginning of Plate Failure

Collecting Electrode Positioner Jammed

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Localized Fire of Combustible Material on Collecting Electrode - 1

Localized Fire of Combustible Material on Collecting Electrode

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Bent Plates - Gas Passage Explosion - 1

Bent Plates - Gas Passage Explosion

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Poor Alignment

Bent Wires

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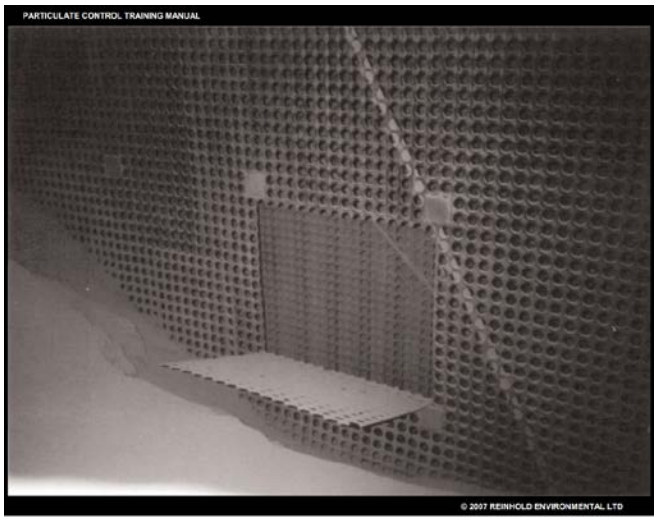

Door in Perforated Plate Left Open

Collecting Electrode Holes

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Full Hopper - Grounding Field

Corrosion - Collecting Plate Supporting Beam

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Corrosion - Insulator Support Beam

Corrosion - Sneak Baffle

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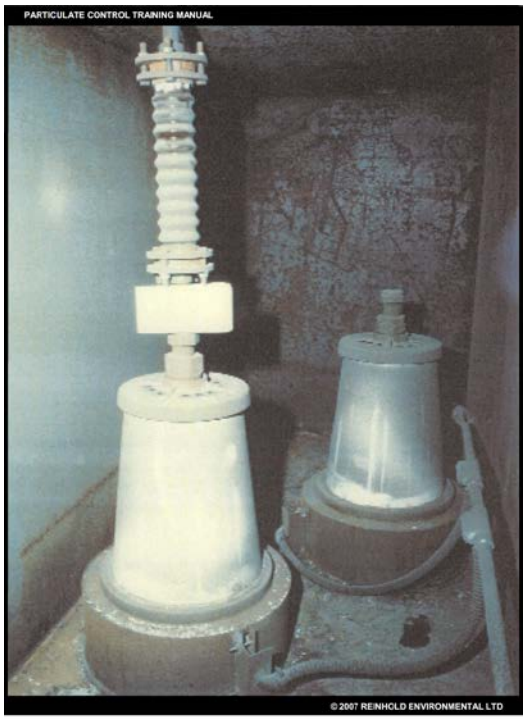
Corrosion - Insulator Protector Tube

Corrosion - Collecting Plate



Ash on Insulators

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Corrosion - Roof

Corrosion - Roof Girder

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4.5 Air Load of ESP

The air load is the electrical energization test is performed when the precipitator is filled with atmospheric air instead of flue gas. It is customarily performed just after a unit is shut down or just before it is started up.

When properly performed it provides a great deal of information concerning the physical condition of the precipitator and its subdivisions of chambers and fields individually.

In performing the test, data on air temperature, relative humidity and barometric pressure should be taken. The air should be slowly moving if possible. This should be recorded.

Starting from the exit of the precipitator each isolatable chamber field should be energized and power gradually increased and readings taken as follows: Kilovolts DC, volts AC, milliamps DC and amps AC

Purposes for Air Load Measurements

a) To assess the general quality of ESP electrode alignment and overall HV electrical energization system.

b) To correct possible misalignments and/or faults in the design, construction, handling, adjustment, etc., of critical components affecting the acceptable quality of the entire electrical energization system. The air load data provide very effective trouble-shooting assistance.

c) To provide, under new and clean electrode conditions, a basic reference record for comparison with later normal gas load or with subsequent "air load" checks - certainly after major outages and ESP cleaning, or even after some short term outages and ESP cleaning, or even after some short term outages for repairs - all before returning the system to normal load.

Corona Starting Voltage

Take readings at the point where milliamps DC just start to flow, about 10 to 20 ma. This is the corona starting voltage.

Nominal corona starting voltage in pipes or ducts can be estimated from Peek's formula:

$Vo + fr\ (30a\delta + 9\ \sqrt{a\delta})\ \ln b/a,$

where, Vo = corona start voltage in KV

δ = radius of outer cylinder, cm (or distance from corona source to place in ducts)

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a = effective radius of discharge electrode (DE) - wire or other corona source

fr = DE roughness factor - typically varies ≅ 0.7-1.0

Studies by Peek were for pipes in air using smooth round wires. Since corona starting voltages for ducts are normally somewhat higher than those for pipes, Peek's formula gives reasonably good results for typical ducts with fr closer to ≅1.0.

Voltage-Current Characteristics

Readings at 10%, 20%, 35%, 50%, 75% and 100% of rated DC current or at sparking which may occur below 100% rated current. If sparking occurs reduce voltage slightly then raise again until sparking, occurs or 100% rated current is achieved. Record sparking voltage.

Be sure meters are calibrated properly.

A typical air load data sheet is shown in **Figure:**

Air Load Current-Voltage Data Sheet

Plot measurements of average corona current density as a function of DC voltage for each TR set. The current density, J = I/A, where I = ESP current, MA, and A = collecting area of the particular section (1000 ft2). The result gives J values in μa/ft2.

A typical air load curve is shown in **Figure:**

Characteristic Air Load V-J Curve

Air load V-J curves should be essentially the same, plus or minus a few percent for the same electrode geometry. Using current density normalizes the data for different size TR sections. If different types of DE are used in some sections, different V-J curves may be associated. For example, a new barb wire DE is likely to show lower corona starting voltages, steeper V-J curves and possibly lower sparking voltages, than 0.11" diameter wires.

For 9" ducts with 0.10"-0.11" diameter DE wires with shrouds, normal acceptable electrode alignment is considered to give 42 KVav on air load, clean conditions. Many will go to 44-45 KVav

Interpret Results

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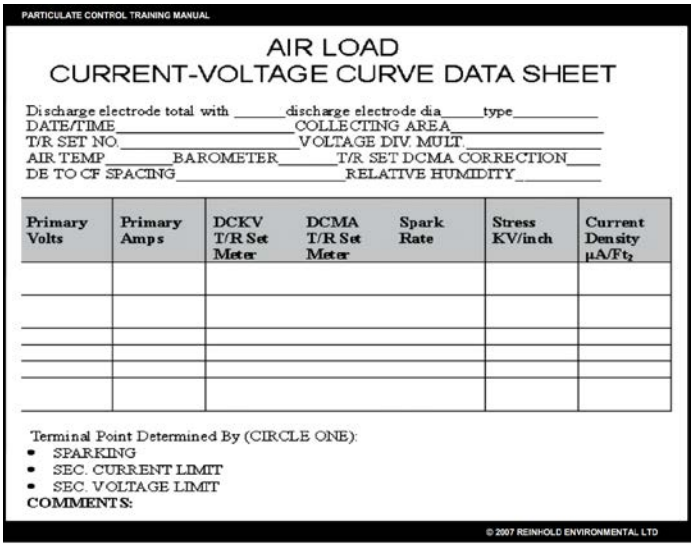
Corona starting voltage indicates the condition of the discharge electrodes and the aggressiveness of the electrodes. Compare the various chambers and fields with each other. Any obviously lower start voltages should trigger a close inspection of discharge electrodes for electrical erosion or "necking down". Any obviously high starting voltage may indicate crusty adherent deposits or erosion of points on rigid electrodes.

Sparking below a voltage of 9.5 to 10 KV per inch of clearance between collecting and discharge electrode indicates close electrical clearances and misalignment. A close inspection and physical measurement is required. A foreign body may be present.

Any discontinuity in the voltage vs. current curve indicates a gross misalignment or insulator problems.

Inability to obtain voltage indicates a growth probably due to foreign materials, or broken electrodes.

Inability to obtain DC current indicates an open circuit most probably in the DC conductor.


PARTICULATE CONTROL TRAINING MANUAL

AIR LOAD
CURRENT-VOLTAGE CURVE DATA SHEET

Discharge electrode total with _____discharge electrode dia_____type_____
DATE/TIME_____COLLECTING AREA_____
T/R SET NO._____VOLTAGE DIV. MULT._____
AIR TEMP_____BAROMETER_____T/R SET DCMA CORRECTION____
DE TO CF SPACING_____RELATIVE HUMIDITY_____

Primary Volts	Primary Amps	DCKV T/R Set Meter	DCMA T/R Set Meter	Spark Rate	Stress KV/inch	Current Density $\mu A/Ft_2$

Terminal Point Determined By (CIRCLE ONE):
- SPARKING
- SEC. CURRENT LIMIT
- SEC. VOLTAGE LIMIT

COMMENTS:

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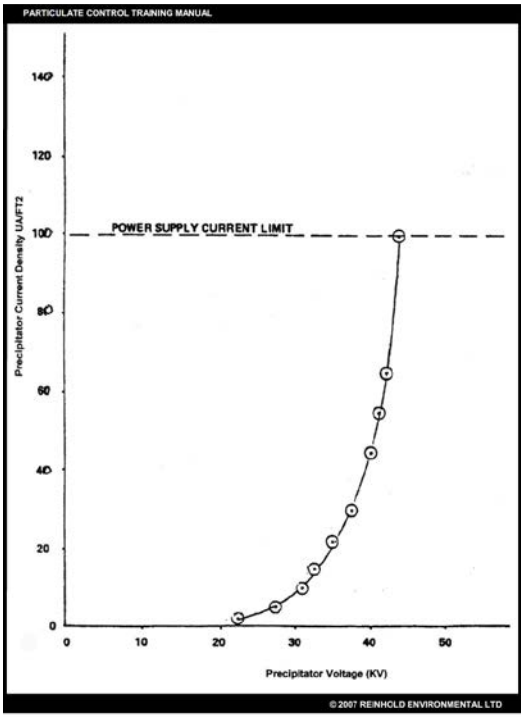
Air Load Current - Voltage Data Sheet



Characteristic Air Load V-J Curve

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4.6 Precipitator Electrode Alignment

Reasons that Proper Alignment is Necessary for Best Precipitator Performance

Voltage:

The role of voltage appears as a squared function in the fundamental equation for migration velocity. In a ten inch spacing precipitator, a misalignment of one inch impacts in the ratio of 16 to 25, not 4 to 5.

Distribution of current on the collecting electrode surface:

Most current will flow in the area of closest spacing, resulting in reduced electrical fields at the plate surface in wide spaced areas.

Precipitator voltage is always limited by the closest spacing in a bus section: One bent plate or bowed wire will cause the whole section to underperform.

Discharge electrode breakage will be concentrated in the area of closest clearance.

Causes of Misalignment

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A Disaster:

Fire or explosion in the intra-electrode space

Poor initial construction:

The casing or discharge electrodes are not square and plumb

Problems with the design and function of the collecting plate spacers:

Collecting plates may be placed in compression during startup or temperature transients.

In weighted wire precipitators:

design or function problems with anti-sway devices: Wires are not plumb.

In rigid frame precipitators:

slack wires due to over stress from differential contraction during cool down. Also, improper design and fabrication of electrode fastening in the frame.

In RDE precipitators:

a poor design which does not accommodate transient induced differential expansion placing RDE's in compression.

Dealing with Existing Alignment Problems

Always determine the root cause of the problem. Straightening deformed electrodes will not solve the problem if the underlying difficulty is not dealt with. They will just deform again, often on startup. If you do not remove the restraints causing compressive forces, you will never solve the problem.

Practical Straightening Methods

Before getting involved in a major re-alignment effort where deformed collecting and/or discharge electrodes are involved, always consider that the costs of replacing part or all of the electrode system may be less than the very costly straightening process. This is especially true if other improvements to rapping or sectionalization are contemplated.

Installation of plate straighteners in the intra-electrode space:

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There are a number of designs sold by various suppliers, which are inserted between plates to force the plates back into the original spacing. All of these devices inhibit proper collecting plate rapping.

While these devices may be useful in dealing with isolated specific difficulties in small areas of precipitators, in general, they are not useful in dealing with large areas of a bus section or a whole precipitator. Their effect on rapping effectiveness, the effect of these grounded parts on electrical clearances, and their costs mitigate against their extensive use.

Selective discharge electrode removal:

If problems are isolated to a few identifiable areas, removal of discharge electrodes plus blanking off of precipitator ducts is often quite effective from a cost standpoint.

Mechanical straightening:

Often the use of a "straightening bar" on collecting plates of the strip design, or on discharge electrode frames of RDE's is a practical and efficient way to deal with problems. More refined techniques utilize special jigs and "portapower" hydraulic jacks to precisely straighten electrodes.

Heat straightening:

Using the well developed and understood method of straightening a piece of steel by shrinking the elongated side can be used on precipitator components. Small sectors (about the size of a corn kernel) of the stiffener of a plate or the tube of a rigid frame, are heated to bright orange. They are then chilled with water or wet rags. If this is done on the convex side of a plate bow, the metal will shrink to something less than its original dimensions pulling out the bow. This method can produce good results, but it relies on experience and technique.

Gross Misalignment

Often the misalignment in a precipitator is a gross misalignment of one or more bus sections. Often this has occurred during the replacement of a high tension support insulator and is manifested by the whole set of discharge electrodes in the section being out of center in the same direction.

This problem is easily remedied by jacking up the frame and centering it.

Another problem of the same type is solved in the same way. In this case, the frame has rotated so that its axis is a few degrees off from the axis of the plates and the discharge electrodes are close to, say the west on one end and the east on the other. In this case, you correct by jacking up the frame and rotating it.

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Other Problems

Here are two other types of alignment problems.

Racking:

The plate bank or discharge electrode frame will become a parallelogram instead of a rectangle causing close clearances on plate baffles and walkways.

Full hoppers:

Occasionally full hoppers will exert upward forces on plates and electrode frames resulting in bending.

Summary

While the individual problems enumerated here have occurred and will continue to occur, determining the root cause and dealing with it before repairs are made will always be the most cost effective way of dealing with misalignment difficulties. If misalignment is extensive, a replacement of the internal parts is often the best solution.

4.7 Structural Problems in ESPs

Introduction

Objective

- To define…what is a structural problem?
- What are the causes leading to these problems?
- What is their significance?
- How do we find the problems?
- How do we correct them?
- How do we prevent a reoccurrence?

What is an Electrostatic Precipitator?

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It is an electo-mechanical piece of equipment that is protected and supported by structural elements. To have a better understanding of a "Structural Problem" we need to understand the function of the structural elements, or components, of the ESP.

What are the Major Structural Elements?

The Precipitator.

To get a better understanding of the significance of ESP problems and their impact on the operation of the system we need to review the ESP components and their function.

- The ESP casing and hoppers are like a pressure vessel; they must resist the pressure or suction, upset conditions and wind or earthquake forces. The ESP is designed to be gas tight.
- The sidewalls, walls parallel to gas flow (G/F) are structural members designed to contain the gas and provide support for the roof, columns and hoppers.
- The top and bottom end frames, (end walls above and below the duct opening) are main structural members, designed as plate girders. They not only support the internal pressure (suction) but also support the hoppers and the roof.
- The "hot" roof girders of the ESP support the internal pressure (suction) on the roof in addition to the weight of the ESP internals. Excessive deflection of the "hot" roof can cause serious operational problems because of misalignment of the ESP internals.
- The ESP corner columns, sidewalls, partition, top and bottom end frames all share in supporting cantilevered nozzles or plenums.
- Slide plates: Required for thermal expansion of steel as temperature changes. Failure to slide, as required, can cause cracking of ESP and/or duct plate or hopper corners.
- The hoppers are also structural components of the ESP, designed to support pressure (suction) in addition to a full load of compacted ash.
- Internal sway braces and column ties provide support to columns and assist in the transfer of loads.
- High Tension (HT) Support Systems (hangers and frames) support the internal electrodes and plates. They transfer the loads to the roof framing.
- Top Housing (Penthouse) encloses the H.V. support insulators. It is subjected to substantial differential temperatures in hot side units.
- Weather Enclosure on top of the ESP provides protection to the roof, electrical and mechanical equipment and provides a more comfortable work environment. It often supports a monorail and hoist to facilitate the movement of equipment to and from the top of the unit.
- The ESP casing, as a structural unit, is designed to support the internal loads, and external forces and to move, slide and grow, as the unit starts up, operates, shuts down and/or experiences an unexpected temperature excursion. The units are designed to move, with changes in temperature. They are not designed to resist forces due to differentials in temperature.

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For maximum performance of an ESP, the casing must be structurally sound i.e., it should not have leaks, it should not deflect excessively, it should not be rusting away and it should be free to move both horizontally and vertically as the internal temperature changes.

What is a Structural Problem?

A structural problem is any distortion, deflection, rotation, cracking or rupture of a structural member or plate that adversely affects the efficiency or performance the electrostatic precipitator, associated air pollution abatement system or boiler operation.

A structural problem is not necessarily a life threatening collapse of a load bearing structural member, like the failure of a support structure or precipitator column, etc. In a precipitator system the problem is usually one that causes operational problems.

Types of Problems

- Cracks or holes in roof
- Leaking roof seals for any roof equipment penetrations.
- Cracks or corrosion of the top and bottom frames.
- Cracks in hopper corners. Corrosion of hoppers, particularly in lower sections.
- Cracks or corrosion of ductwork.
- Corrosion and leaks in access doors.
- Cracked or leaking expansion joints.
- Heat sinks; steel penetrations through heat insulation.

What are the Causes of These Problems?

Structural deficiencies associated with ESPs are generally a result of the following:

- Low Temperature and moisture in combination with sulfur; cause corrosion of casing and ductwork. (Cold side)
- High temperature in combination with other factors that cause excessive differential temperatures; result in casing and ductwork cracking. (hot and cold side)
- Inadequate and/or improper installation of heat insulation.
- Failure of slide plates and/or expansion joints to function properly.
- Low velocity gas flow through system causing heavy dust build-ups; results in excessive loads and differential temperatures.
- Deterioration of chemical and/or mechanical properties of steel due to long term operation at high temperatures.

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Many of these problems are a result of poor information prior to design, improper structural engineering and/or poor construction practices.

How Do We Find the Problems (Structural Deficiencies)

Some of the deficiencies are visible from the outside. Most are only observable during a clean inspection from the inside. Others are only detected by laboratory testing.

Why Should We Inspect?

Keep in mind that the ESP casing has to function to protect what is inside (the internals). It can not perform this function properly if it is not gas tight.

We inspect to:

- Find structural deficiencies causing operation and/or compliance problems.
- Determine what is structurally adequate and what is not.
- To correct deficiencies; now and later.
- To prolong the life of the ESP.
- To possibly predict the longevity of the ESP (Life Assessment). Sample Testing

Prior to Inspection

Proper preparation can expedite actual inspection time. This is important because:

- Outages have a limited time schedule.
- Many outages are unscheduled and you need to get in and out.
- Some defects, if detected, can be corrected during the outage.

Preparation for inspection includes gathering information.

- A review of the GAs will show the overall layout, size of ESP, ductwork, relationship to air heater, economizer, fans, stack, access, etc.
- A review of the operating conditions will provide operational data, like: pressure (suction), temperature, cycling, loading, unitized, etc.
- Prior inspection reports will give clues to previous defects detected.
- History, likewise can provide clues to previous defects.

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- Safety rules, who to see for info or assistance, availability of equipment, lighting is all critical to the inspection.
- Conduct the inspection when the unit is clean.
- Obtain information about the unit when it is dirty. You can't see the structural problems when the unit is dirty. However you can get clues as to causes, i.e. dust build-ups, solidified dust, excessive dust on electrodes and plates, etc.
- If possible inspect when raining - it is easier to find leaks.

Tools and Clothing

- Seasonal clothing and coveralls
- Work gloves, shoes and glasses
- String, plumb bob and clamps
- Powerful flashlight with neck strap
- Camera (Disposable Flash)
- Tape Recorder
- Crayon Marker or Paint Stick
- D-Meter with metal gages and wire brush
- "Chipping" Hammer

On-Site Equipment Required

- Scaffolding
- Ladders
- Lift Bucket
- Safety Harness
- Hard Hat
- Respirator
- Safety Glasses
- Safety Rules

The Inspection

- Take photos
- Record data
- Mark or tag deficiencies

The structural inspection must be done when the ESP is clean in order to check for cracks, corrosion and deflection. However, knowledge of the inside of the ESP when dirty is critical.

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Ash buildups, ash conditions (dry, wet, compacted), evidence of moisture and sulfur, signs of air or water leakage; expansion joints loaded with ash; are all important in analyzing the cause and effect of structural problems.

Before you enter the ESP - look at it from outside.

Externals

Various components of the ESP are inaccessible for close inspection, however, much can be seen from a distance.

Lagging:

Check for rust stains, particularly at access doors and expansion joints. Most units have aluminum lagging, which clearly shows rust stains from the steel ESP casing or ductwork behind the lagging. Rust stains usually mean that the lagging is not watertight. If not watertight, the insulation behind is getting wet and losing its effectiveness; this can lead to corrosion. Corrosion reduces strength, causes leaks, affects the operation and reduces the life of the ESP.

Flashing, Gutters & Leaders:

Check to see if they are performing their function; to keep water from getting behind the lagging.

Expansion Joints:

Most joints are covered; look for signs of leakage or missing covers. If exposed, look for torn fabric or cracked metal.

Slide Plates:

Critical, particularly in "hot" side ESP systems. Difficult to see, particularly those under interior columns. Pay particular attention to perimeter columns. Did they slide? Do they have guides? Are they jammed, frozen?

Columns:

Have they lifted off of their supports?

Hopper corners:

If you can not inspect the slide plates from outside; pay particular attention to the hopper corners inside the ESP. Look for buckling, cracking or patching...clear indications that the ESP is not sliding as intended.

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Support Structure:

Look at the general condition of the structure particularly at the slide plates. Look for deflection (unusual), rust stains; likely if lagging is not waterproof.

Top Housing (Penthouse):

Look for buckling, cracks, and "oil canning"; particularly in "hot" side units.

Internals

After you have looked around.

Hot Roof:

Inspect from outside and underside, if possible, (some units, like Buell, are not accessible from inside the ESP).

For exposed hot roofs, like Buell, check for condition of insulation, heat sinks, and corrosion around penetrations and deflection. Exposed hot roofs, not covered by a weather enclosure, are especially vulnerable to leakage. Many roof penetrations. Where hot roofs are accessible from the underside, like RC, inspect the corners, roof framing, girders, wall, penetrations, collecting plates and wire frame supports. Look for corrosion, cracks, broken welds, deflection, water stains.

Look down the plates... look for bows, corrosion, broken or missing wires (or bowed RDEs). If you find something bent, broken, cracked, or corroded; look for the possible cause.

ESP Top of Hopper Level:

Upon entering the side access doors, look at the door itself, check for corrosion, the insulation and gasket. Look for air leakage.

Inspect the platework above and below the door and the collecting plates along the wall. Bowing or corrosion of these plates usually indicates dust build-up between the wall and the collecting plate. If corrosion is taking place in this area; staining is usually evident on the exterior lagging and holes are evident in the collecting plate along the wall.

Check the hopper corners. Cracking, is an indication that the ESP is not sliding on its supports.

Again, look at the plates and wires... look for bowing, broken wires. Shake the plates to see if they are free to move horizontally.

Check the guides to make sure that the plates are not jammed. Consider the relationship between the plates and guides and visualize if the plates will bind when the ESP is hot.

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Hoppers

Check the inside of the hoppers; if corrosion is evident take metal thickness readings. Corrosion, if present, usually takes place in the lower portion of the hoppers. Look for the cause of corrosion.

Check the heat insulation. Find out if the hopper heaters are working.

Inlet and Outlet Nozzles or Plenums

Check for corrosion, cracks, deflection of the bottom and walls. Check the access door and platework around it. Check the bottom end frame.

Look over the internal gas distribution devices.

Carefully inspect any internal trusswork, including the connections.

Most inlets and outlets are cantilevered... bowed trusswork and cracked welds could be an indication of serious problems.

If problems are evident find out history of dust that builds up... and changes in temperature.

If corrosion exists take some metal thickness readings.

Verbal Report

1) Report safety problems immediately so that they can berepaired or tagged for caution.

2) Report deficiencies that should be corrected during the outage.

3) Report deficiencies that require a long term fix and/or evaluation or analysis to determine the cause. Examples: Low velocity, dust build-ups, temperature excursions, etc.

4) Request drawings and/or other historical data that you may require to complete your evaluation.

5) Request other information that you may require but can not obtain; examples:

- Need insulation removed to see something suspicious.
- Want D-meter readings at top of duct or other hard to reach areas.

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- Want D-meter readings of an area that is of concern.
- Need information in areas that require scaffolding or lift that is not available to you.
- Want someone to observe slide plates as unit heats up.

6) Request that samples be taken, for lab testing, if material deterioration is suspected (hot side ESP's).

Lab Testing

Try to get the results of information you requested... to include it in your report.

Lab testing is usually done for material used in hot side ESPs that have been operating for 10 to 15 years, particularly if the steel used was ASTM A242 or 588. These materials change microstructure and can become brittle like cast iron.

The purpose is to identify the material, properties and present strength so as to compare them with the initial expected properties and strength. The determination of changes is critical to the overall evaluation of the material.

The more samples the greater accuracy in the overall evaluation.

Test

- Mechanical properties, like hardness, tensile strength.
- Chemical properties, to determine material.
- Metalography, to examine material microstructure (to find changes in grain structure). A competent metallurgical lab should do this testing in conjunction with a structural engineer familiar with hot side units.

The analysis of the test results by a metallurgist and an overall evaluation by the engineer will give you an idea of the present strength of material and perhaps a projection of its life (life assessment).

Written Report

The structural portion of an inspection report should follow the system description of operation and "dirty" inspection report (assuming one took place).

The structural inspection should include a record of all findings, both positive and negative.

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It should make reference all data used to support the conclusions and recommendations.

The report is to contain field data, photographs, sketches, etc. (all documents that will be a part of the history of the ESP). This information is imperative to establish whether or not solutions suggested, in fact solve the problem. The information is vital to "track" a problem, particularly corrosion or cracking.

The report must include opinions and conclusions as to both the positive and negative aspects of the areas inspected.

Based on the inspection and conclusions, recommendations must be made to correct the observed problems.

Not all recommendations are solutions to the problems. Many recommendations will call for further analysis, evaluation, lab testing or monitoring. Keep in mind that the ESP that was inspected is a steel housing; that has the purpose of protecting and preserving what is inside. If properly maintained it will keep the ESP reliable, and in compliance while operating properly and efficiently. Recommendations should be written with these objectives in mind.

How Do We Correct the Deficiencies?

Not all problems are easily or inexpensively corrected. As many of you know, the industry has learned to live with many of the deficiencies and their causes.

However many "fixes" are not costly, but left unattended are exacerbated or cause other problems.

Easy to Correct

- Re-weld cracks, patch holes (from inside or out). Patching from outside requires the removal of heat insulation. Have plate available for patching.
- Replace gaskets around doors, boot seals, fabric expansion joints. With proper planning the replacement materials can be ordered prior to the outage.
- Repair or place gutters and flashing to prevent water from penetrating heat insulation.

Expensive to Fix

- Large corroded areas will require extensive patching. Sometimes collecting plates near holes in the walls are also corroded. These plates are rendered useless.
- Sections of hoppers sometimes require replacement. Sections can be made in advance.

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- Cracks in the penthouse can be re-welded, but sometimes an expansion joint needs to be added. This is expensive but is a long-term solution.
- Minimize heats sinks, if possible.
- Repair or replace roof insulation (Buell type ESP's). Add weather enclosure.
- Replacement the internals, due to long term deterioration.
- Replace end frames due to corrosion.
- Convert from hot to cold side operation.
- Repair and/or replacement of slide plates. Could require jacking-up ESP.

The main thing to keep in mind is that the deficiency does not get better if left unattended.

How Do We Prevent a Reoccurrence?

Here again, many preventative measures are relatively inexpensive while others are costly.

Inexpensive Measures

Patching, re-welding, replacement of gaskets, seals, expansion joints take care of many problems for years.

Expensive Measures

- Problems like continuous corrosion, which is a process related problem, could require increasing or redistributing heat, providing additives in the system switching or mixing coals, etc. all of which are expensive.
- Replacement of heat insulation on the ESP or ductwork.
- Deteriorated steel might require reinforcement or a change in operation to lower the operating temperature.
- Repair or replacement of slide plate system; may be required to minimize or eliminate some persistent cracking problems.

Conclusion

Many structural problems are preventable or correctable. Some you have to live with.

It's a value judgment with one primary objective: To sell power, remain operational in an efficient manner while remaining in compliance. The structural elements of the system are

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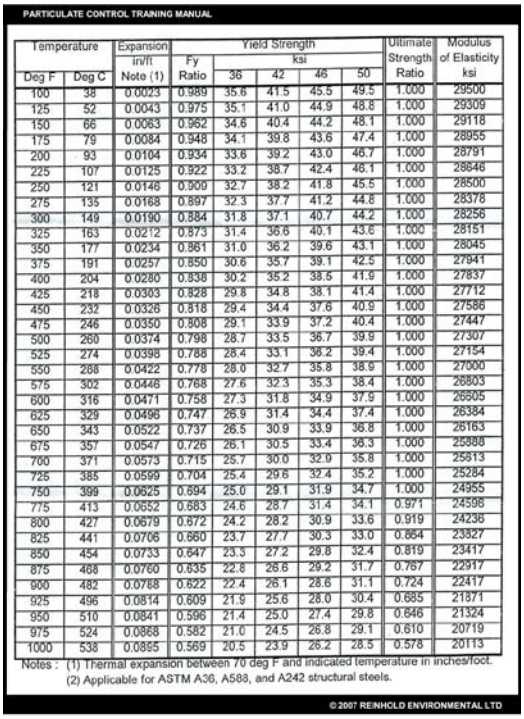
critical and must be kept in good condition to help accomplish this objective.

Refer to the illustrations and data on the following pages for clarification.



PARTICULATE CONTROL TRAINING MANUAL

Temperature		Expansion in/ft	Yield Strength ksi				Ultimate Strength	Modulus of Elasticity
Deg F	Deg C	Note (1)	Fy Ratio	36	42	46	50	Ratio	ksi
100	38	0.0023	0.989	35.6	41.5	45.5	49.5	1.000	29500
125	52	0.0043	0.975	35.1	41.0	44.9	48.8	1.000	29309
150	66	0.0063	0.962	34.6	40.4	44.2	48.1	1.000	29118
175	79	0.0084	0.948	34.1	39.8	43.6	47.4	1.000	28955
200	93	0.0104	0.934	33.6	39.2	43.0	46.7	1.000	28791
225	107	0.0125	0.922	33.2	38.7	42.4	46.1	1.000	28646
250	121	0.0146	0.909	32.7	38.2	41.8	45.5	1.000	28500
275	135	0.0168	0.897	32.3	37.7	41.2	44.8	1.000	28378
300	149	0.0190	0.884	31.8	37.1	40.7	44.2	1.000	28256
325	163	0.0212	0.873	31.4	36.6	40.1	43.6	1.000	28151
350	177	0.0234	0.861	31.0	36.2	39.6	43.1	1.000	28045
375	191	0.0257	0.850	30.6	35.7	39.1	42.5	1.000	27941
400	204	0.0280	0.838	30.2	35.2	38.5	41.9	1.000	27837
425	218	0.0303	0.828	29.8	34.8	38.1	41.4	1.000	27712
450	232	0.0326	0.818	29.4	34.4	37.6	40.9	1.000	27586
475	246	0.0350	0.808	29.1	33.9	37.2	40.4	1.000	27447
500	260	0.0374	0.798	28.7	33.5	36.7	39.9	1.000	27307
525	274	0.0398	0.788	28.4	33.1	36.2	39.4	1.000	27154
550	288	0.0422	0.778	28.0	32.7	35.8	38.9	1.000	27000
575	302	0.0446	0.768	27.6	32.3	35.3	38.4	1.000	26803
600	316	0.0471	0.758	27.3	31.8	34.9	37.9	1.000	26605
625	329	0.0496	0.747	26.9	31.4	34.4	37.4	1.000	26384
650	343	0.0522	0.737	26.5	30.9	33.9	36.8	1.000	26163
675	357	0.0547	0.726	26.1	30.5	33.4	36.3	1.000	25988
700	371	0.0573	0.715	25.7	30.0	32.9	35.8	1.000	25813
725	385	0.0599	0.704	25.4	29.6	32.4	35.2	1.000	25284
750	399	0.0625	0.894	25.0	29.1	31.9	34.7	1.000	24955
775	413	0.0652	0.883	24.6	28.7	31.4	34.1	0.971	24598
800	427	0.0679	0.672	24.2	28.2	30.9	33.6	0.919	24236
825	441	0.0706	0.860	23.7	27.7	30.3	33.0	0.864	23927
850	454	0.0733	0.847	23.3	27.2	29.8	32.4	0.819	23417
875	468	0.0760	0.835	22.8	26.6	29.2	31.7	0.767	22917
900	482	0.0788	0.622	22.4	26.1	28.6	31.1	0.724	22417
925	496	0.0814	0.609	21.9	25.6	28.0	30.4	0.685	21871
950	510	0.0841	0.596	21.4	25.0	27.4	29.8	0.646	21324
975	524	0.0868	0.582	21.0	24.5	26.8	29.1	0.610	20719
1000	538	0.0895	0.569	20.5	23.9	26.2	28.5	0.578	20113

Notes : (1) Thermal expansion between 70 deg F and indicated temperature in inches/foot.
(2) Applicable for ASTM A36, A588, and A242 structural steels.

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Structural Steel Properties vs. Temperature

WARNING; Uncontrolled and may n ot be current past 11/20/98

ESP Structural Design Considerations

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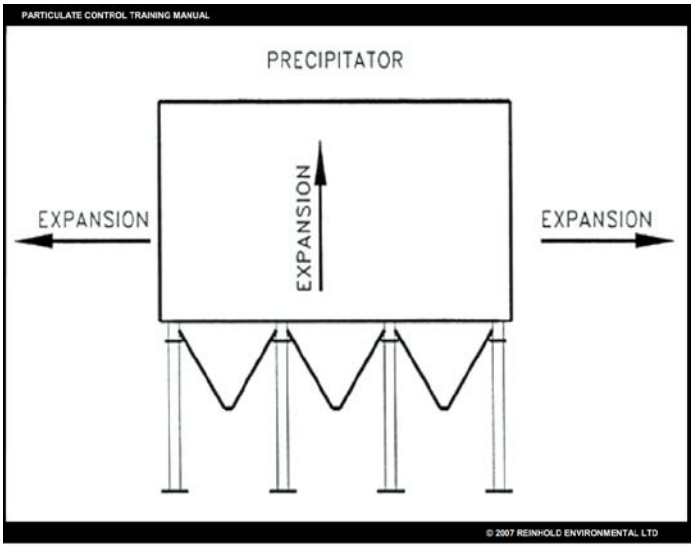
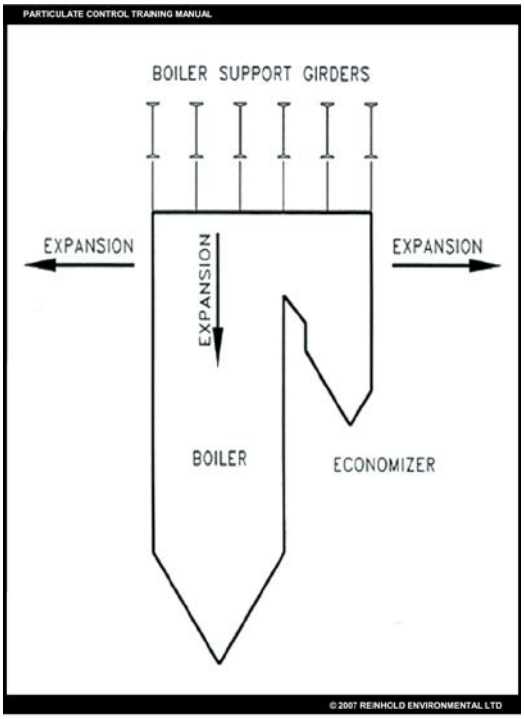


Typical Precipitator Support



Typical Boiler Support System

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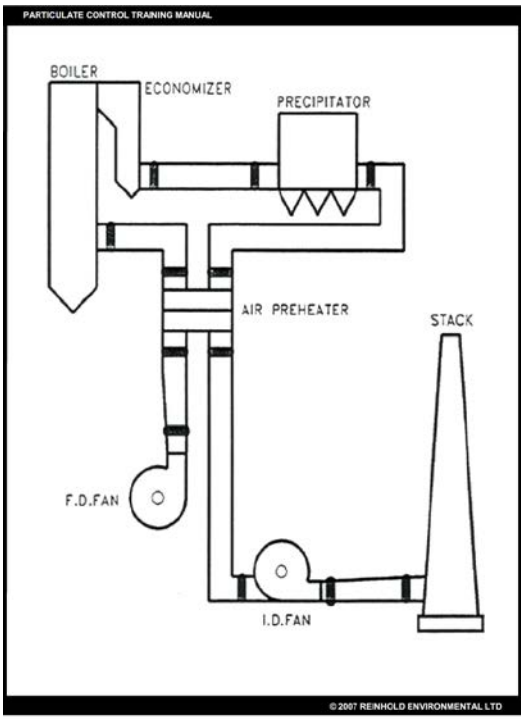
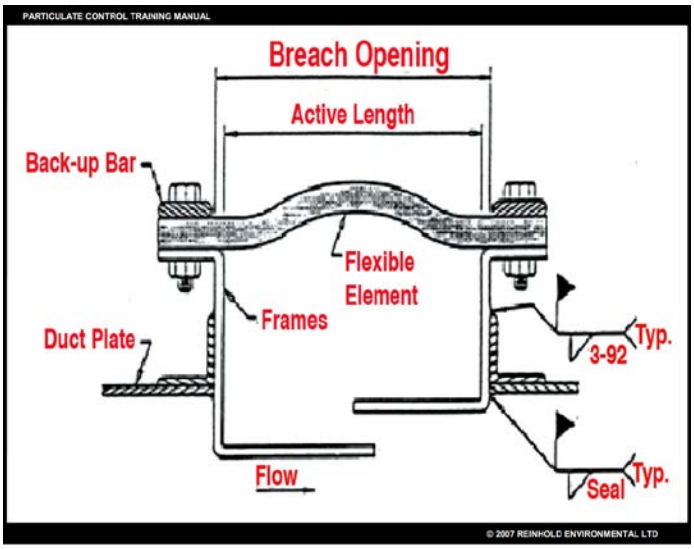


Typical Expansion Joint Locations



Nonmetallic Expansion Joint, Service Temperature 400 Degrees F to 1200 Degrees F, Bolt-through Attachment

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Active Length (in.)	Axial Compression (in.)	Axial Extension (in.)	LATERAL DISPLACEMENT (in.)
6	1	0.5	1
9	2	0.5	2
12	3	1.0	3
16	4	1.0	4

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Maximum Allowable Movement Flat-Belt Bellows Expansion Joints 400 degrees F to 1200 degrees F

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Active Length (in.)	Axial Compression (in.)	Axial Extension (in.)	LATERAL DISPLACEMENT (in.)
6	3	0.75	1.5
8	4	0.75	2.0
10	5	0.75	2.5

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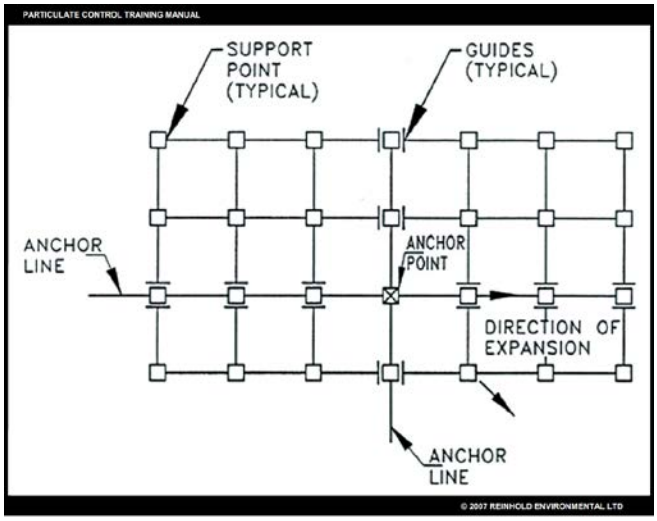
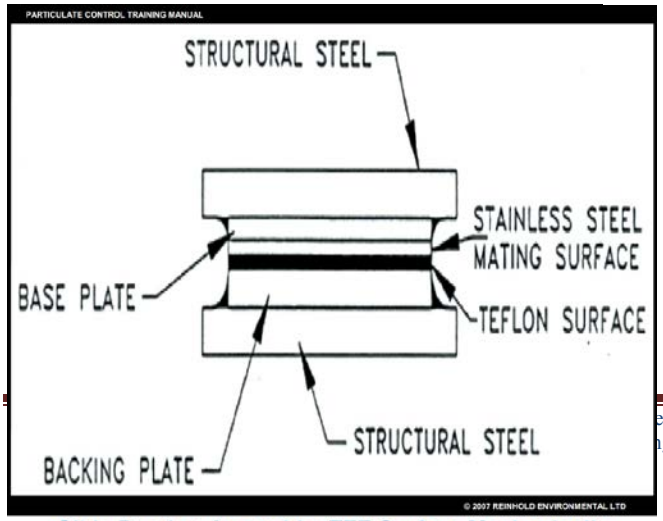
Maximum Allowable Movement Flat-Belt Bellow Expansion Joints up to 400 Degrees Farenheit



Precipitator Support Points



Slide Bearing Assembly: TFE Surface Mechanically Locked; Operating Temperature up to 450 degrees F - 500 degrees F

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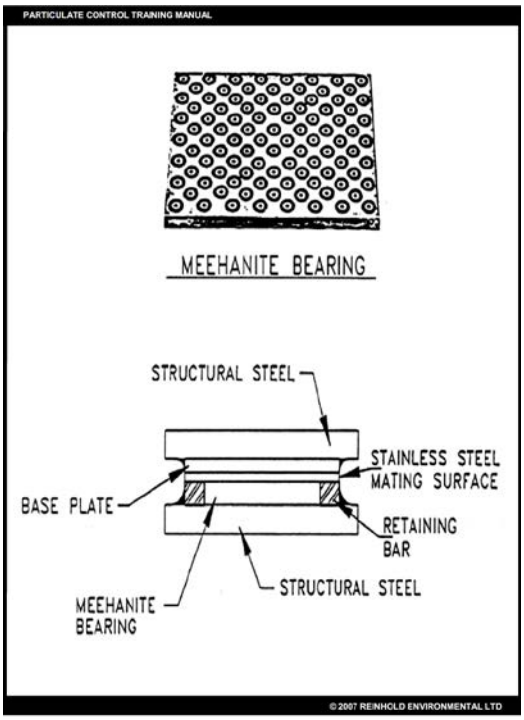
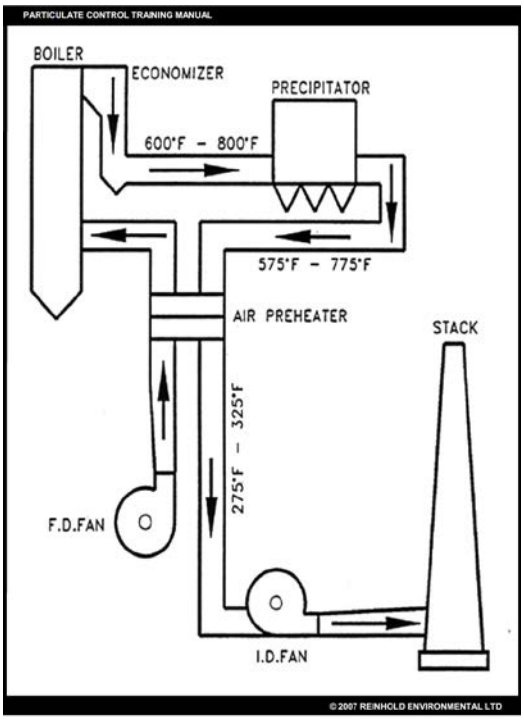
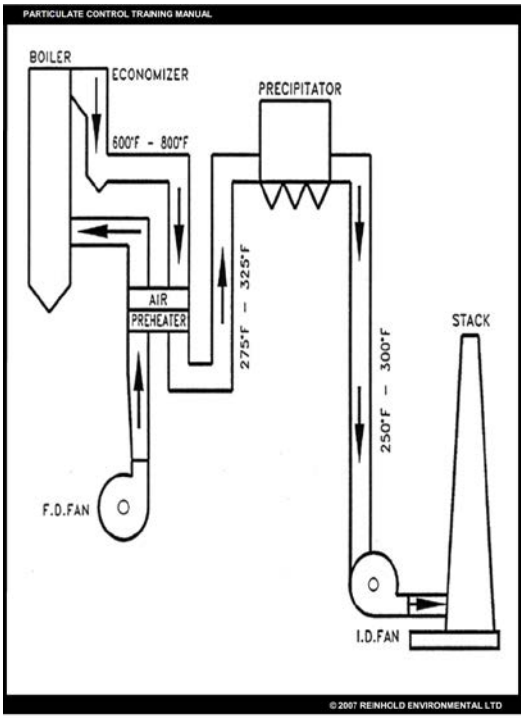


Slide Bearing Assembly - Cast Iron Meehanite Bearing - Operating Temperatures up to 750 degrees F



Hot Side Arrangement



Cold Side Arrangement

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4.8 Maintenance of Mechanical Equipment

Key Interlock Systems

Operation of Key Interlock Systems.

The key interlock system should compel the circuit breakers to be locked open before the keys required to close the grounding switches of the transformer/rectifiers can be released. Grounding the TR sets should then release transfer keys which must be inserted in a key exchange/transfer panel to release the keys required to open the access locks on the entry doors.

If nuclear level detectors are installed, then each nuclear level source must be locked closed in order to release other transfer keys that also insert in the exchange/transfer panel to release the access keys for the entry hatches.

Since certain keys are held captive at each stage in the interlock sequence, reversal of the sequence is required to re-energize the precipitator.

Maintenance of Key Interlock Systems.

A monthly inspection and lubrication of the interlock system should be done. Liquid-suspended graphite solution can be used in each lock cylinder, working it into the slot with the key.

A semi-annual purging of the interlocks should be done by injecting light mineral spirits and compressed air in the lock's interior. The locks should then be re-lubricated.

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Never lubricate a lock cylinder with oil or grease. Oil acts as a sticky base that allows particulate matter to build in the lock. When oil is left for long periods of time, a film sets up on the lock components and introduces a frictional load that makes the lock mechanism difficult to activate.

If the surrounding environment is corrosive, the bronze exteriors of the locks should be maintained with a protective paint.

Always keep lock caps in place when the key has been removed so that dust or other contaminants will not foul the lock mechanism.

Whenever a lock mechanism or key must be replaced, it should be obtained directly from the precipitator manufacturer to avoid duplicate locks and keys.

Sliding Bearings

Sliding bearings require a yearly inspection to ensure proper operation and that any signs of deterioration are noted.

Expansion Joints

Expansion joints require a yearly inspection. They need to be checked for structural integrity, corrosion, erosion, and possible dust buildup. Fabric type expansion joints should be checked for tears and punctures. Actual duct movements should be observed to insure that the expansion joints are functioning properly.

Dampers

Dampers require an annual inspection for dust buildup, structural damage, corrosion, and erosion. Isolation dampers should be checked to ensure that they seal properly. Damper bearings should be checked for proper lubrication. Dampers that remain stationary for long periods of time should be manipulated during the inspection to ensure proper operation.

Hoppers

Hopper Vibration/Fluidizing Stones.

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Hopper vibrators and fluidizing stones should be inspected monthly.

Mechanical air operated vibrators should be checked on a semi-annual schedule. The oil levels of automatic lubricators should be checked. The air pressure should be set for the most efficient operation. All air connections should be checked, the filters cleaned, and bolts tightened. If an extended plant outage is planned, the vibrators that will be shut off should be lubricated internally.

Semi-annually, fluidizing stones (diffusers) should be checked for buildup on the diffuser surface, for breaks or cracks, and for air leaks. The diffuser surface should be cleaned or replaced if necessary. Diffuser surfaces may be checked by applying low pressure air to the system and placing a handful of fry fly ash on the diffuser. Ash should flow off the diffuser immediately. All gaskets should be inspected and replaced as necessary. Air connections should be checked, and all filters cleaned or replaced. The air supply should be clean, dry, warm, and at the proper pressure.

Hoppers.

Hoppers should be checked inside and out once a year for structural integrity, corrosion, erosion, leaks and dust buildup. Exterior inspection should focus on the condition of the insulation and lagging and on any areas that may not appear to be gas tight.

The inside of the hopper should be checked for fallen debris such as weights and wires, plus corrosion due to inleakage of air or moisture.

The level of the fly ash in the hoppers should be noted. Abnormal dust buildup may be indicative of low operating temperatures, insufficient insulation, faulty hopper heaters, or inadequate hopper emptying.

4.9 Mechanical Problems and Solutions

The Electrostatic Precipitation Performance Tree

The ESP Performance Tree was developed in 1996 as a troubleshooting aid for Southern Company plant personnel. It has also been used as a reference document for other personnel in corporate environmental and engineering disciplines. See slides in Reference:

The Electrostatic Precipitator Performance Tree

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for additional figures referenced in this section.

The Tree is arranged in 6 sections: A through F. They are titled as follows:

A) Poor Reliability

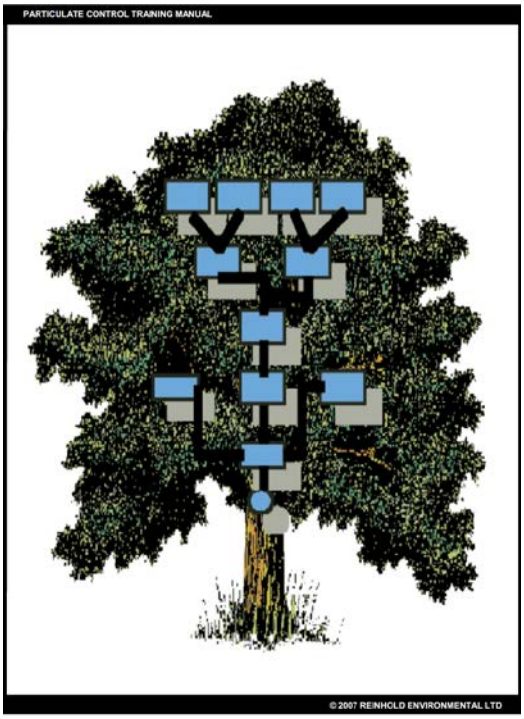
B) High Power Consumption

C) High Average Opacity - Electrical Performance

D) High Average Opacity - Mechanical Performance

E) High Opacity Spiking - Electrical Performance

F) High Opacity Spiking - Mechanical Performance.



The ESP Performance Tree

For the purpose of this section, the discussion will be mostly limited to:

- ***Poor Reliability - Mechanical***
- ***High Average Opacity - Mechanical Performance***
- ***High Opacity Spiking - Mechanical Performance.***

The principal of the Tree is based on the Root Cause Analysis method and progresses from category to symptom to cause. After the main outline page, each succeeding page is arranged with a key plan at the lower right corner showing the point at which the branch on that particular page interconnects. The flow of information progresses upward on the tree branches

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with each succeeding page.

Start.

This is the node at which one would begin if a precipitator problem exists. From the Start node on page A-1, the Tree breaks into 3 branches:

Poor Reliability, Poor Performance,

and

High Power Consumption.

Poor Reliability.

The Poor Reliability

node splits into 3 branches. The second is

Mechanical

on page A-3. The

Mechanical

node separates into 6 sub categories:

Mechanical Rappers, Expansion Joints, Slide Bearings, Hopper Vibrators, Wash Down Systems,

and

Doors.

Mechanical Rappers.

Mechanical, a class of rappers that includes side or top rap tumbling hammers and drop rod rappers. The principal symptom or problem associated with these types of rappers is, of course - wear. The root causes include excessive duty cycle (on/off time), misalignment, and the

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unavoidable exposure to fly ash. This is especially true of rotating hammers since they are immersed in the flue gas. Some variations in wear occur as a result of the location of the particular field within the precipitator. Inlet fields generally experience more wear due to a greater volume and coarseness of the ash. Also, it is likely that the duty cycle is greater in the inlet fields.

Duct Expansion Joints.

Duct expansion joints are of particular concern to those troubleshooting precipitators, especially if they are upstream to precipitator operating under negative draft. The result of an expansion joint failure is the introduction of outside air. In the case of cold side precipitators, this is detrimental for two reasons:

1) Air infiltration locally drops the acid dew point and,
2) Infiltration often brings in with it rain or snow.

Locally dropping the dew point of the flue gas can result in corrosion of the casing or expansion joint frame thus producing more area for infiltration. The introduction of precipitation can cause heavy build up in the ducts or on the electrodes themselves. If sufficient amounts of water are pulled into the hoppers, pluggage, caking or bridging can occur.

In the case of hot side precipitators, air infiltration will also cause localized cooling, however, the effect here results in more structural failures than corrosion as in cold side applications. Casing surfaces at temperatures above 600°F contract sufficiently to cause cracks or joint fractures in the presence of cold air or rain water.

The characteristics of expansion joint failure can be; Delamination (belt type), Cracking (metallic), Abrasion, and Puncture. De-lamination is associated with flouroelasatomer materials such as Viton or Hypalon. In these cases, layers of this material are sandwiched, or calendered, with a textile reinforcement such as fiberglass or Kevlar. In the case of metallic joints, stress fractures often occur as a result of flexing, torquing, or becoming brittle as a result of work hardening.

Failures can also occur as a result of abrasion or puncturing from the impingement of flow on to the joint. This usually occurs on the upstream side of the precipitator.

Slide Bearings.

Slide bearings located under the precipitator and ductwork are designed to carry the high compression loads while allowing smooth growth and lateral movement to occur of the supported structure. However, if the kinetic friction of the bearing surfaces becomes too great, the plate, will either not move or will "jump" in stages until the forces are equalized. These stored forces can result in precipitator alignment problems, casing leaks, and localized structural failure.

Hopper Vibrators.

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Poor reliability of hopper vibrators usually results from two main factors; Duty cycle and air quality. Excessive on-times will prematurely wear out the piston and cylinder. The vibrator should only be on as long as it takes to empty the hopper. If prolonged periods are necessary to clean the hoppers, internal problems may exist such as caking or bridging. Also, other malfunctions such as sticking air solenoids may result in extended on-times, thus compacting the ash.

Poor service air quality is air that is too low or high in pressure, too wet, or too dirty. Pressure regulators, filters, boilers, and water traps (in wet climates) should be used and be close-coupled to the point of use. Rust particles picked up in iron pipe between the filter and the vibrator can be enough to shorten it's life.

Washdown Systems.

Precipitator washdown systems are common in the Southern Company. The purpose of these systems is to reduce time required when washing is necessary. Further, it reduces personnel exposure to such safety hazards as eye injuries, falling on ice, and exposure to arsenic.

The principal sources of problems are; Corrosion, Fractures, and Plugging. Corrosion is a problem due to the heat sinking effect of the external piping. Fractures are mainly a result of conflicts in expansion and contraction. Nozzle pluggage is generally a result of foreign debris or contamination from corrosion occurring upstream.

Doors.

Access doors present similar problems, as do expansion joints. Corrosion and in-leakage are always a possibility with any type of penetration such as test ports, inspection ports, or access ways. Principally, the causes of door leakage are gaskets in poor condition and poor door fit up.

High Average Opacity - Electrical Performance.

There is a slight deviation in our progression of mechanical issues up through the Performance Tree. It is on page C-1 that follows

High Average Opacity and Electrical Performance.

It is the category labeled

Mid V/I Ratio w/Sparking.

On page C-3 the discipline changes from electrical to mainly mechanical following

Close Electrical Clearance.

Close Electrical Clearance.

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When this condition is present it may be characterized by three contributors;

Poor Electrode Stability, Damaged

or

Misaligned Electrodes,

or the presence of

foreign material.

Poor Electrode Stability.

Poor electrode stability is usually the result of swaying of the lower high voltage frame. Generally, these frames are restrained by stabilizers. If they should become broken or loose the frame can sway under the influence of the electrical field. There is a common misconception that this swaying is caused by the flow of gas or air through the precipitator. Generally the velocities encountered there are insufficient to produce the force required to swing the frames.

Often lower frame swaying occurs in a precipitator that was not originally designed to use stabilizers. This is usually the case in rigid frame precipitators. Prior to arbitrarily adding stabilizers, it should be conclusively shown that this is actually occurring on-line. There are methods available for testing such activity. This can be observed on the indication and behavior of analog meters. Additionally, frame swaying can be observed on the secondary current trace using an oscilloscope.

Foreign Material.

Items such as welding rods and scrap metal left after an outage are the most common sources of foreign material. However, debris such as air heater fragments have been known to find their way between the electrodes while on-line. The formation of clinkers between the electrodes can also be categorized as foreign material.

A common misconception is that some of this debris will "burn off" under power. Since the output of the transformer-rectifier is rarely greater than 1.5 amps DC, it is unlikely that any ground could clear itself under power.

Damaged or Misaligned Electrodes.

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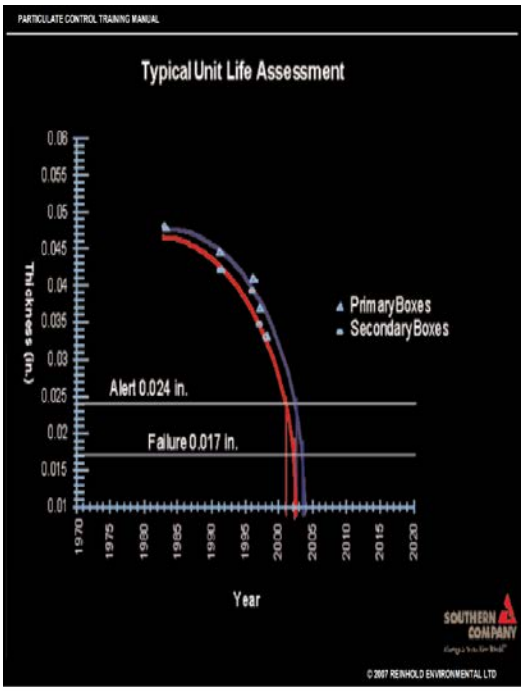
This category is the most common limitation to precipitator performance. Since precipitator internals are necessarily constructed of light gauge materials, they are prone to misalignment. This is compounded by the fact that in order to maintain sufficiently high voltages, the tolerance for misalignment is rather narrow. Probably the most common element to maintain in tolerance is the collecting electrodes, or plates. The most common complaint is bowing. Bowing is normally a result of one or more conditions; Original design, Adverse operation, or Normal wastage.

Since most collecting plates are manufactured by coldforming, there are always built-in residual stresses from which bowing originates. A good design is one that reaches the end of its useful life prior to the onset of stress equalization.



Typical Unit Life Assessment Curve
(Courtesy of Southern Company)

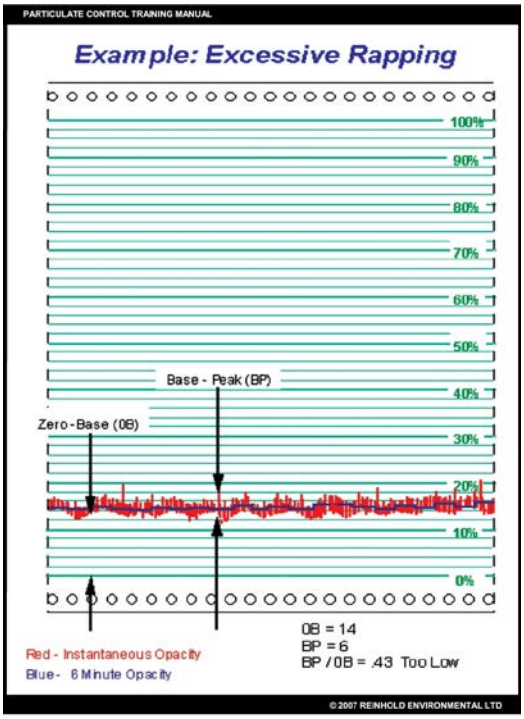
Adverse Operation.

Adverse, but not uncommon precipitator operations include, but are not limited to; Sub dew point operation, sustained operation during an air heater stall (cold side), air heater fires, precipitator volume fires, precipitator surface fires, overfilling hoppers, clinker formation, and sudden introduction of ambient air or rainwater.

Normal Wastage.

Normal wastage, defined as the reduction of crossectional thickness, primarily of the collecting plate. All plates have a life cycle function of deterioration. This function, or slope of the curve is a result of normal and abnormal operations. Normal operations, or factors that age collecting plates are mainly the elapsed time in the dew point.

Typically, we see about 0.001 to 0.002 per year of material loss, or wastage. This rate seems to be unaffected by whether the units are water washed or not. Clearly, other factors prevail, such as whether the particular unit is hot side or cold side, or whether it is



Low Aspect Ratio Opacity Trace

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base loaded or peaking.

Figure:

Typical Unit Life Assessment Curve

shows a typical Unit Life Assessment curve used to predict remaining life.

High Average Opacity.

Mechanical Performance is characterized by an opacity trace that has a low aspect ratio in **Figure:**

Low Aspect Ratio Opacity Trace

shown below:

The opacity aspect ratio (OAR) is defined as the factor of the base-to-peak value divided by the zero-to-base value (BP/0B). For example, in **Figure:**

Low Aspect Ratio Opacity Trace

, the zero-to-base value is 14. The base-to-peak value is 6. Thus, the OAR = BP/0B = 6/14 = .43

The preceding is in contrast to a normal opacity aspect ratio shown in **Figure:**

Normal Aspect Ratio Opacity Trace

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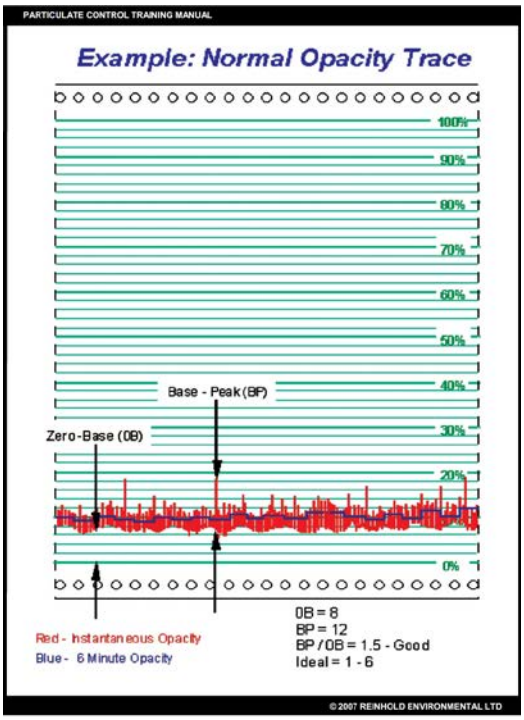
.

In the above example the OAR is 1.5. The zero-to-base value is 8 while the base-to-peak value is 12. Thus, the OAR = 12/8 = 1.5. We consider 1.5 to be within an acceptable range of 1 to 6. The range is necessarily this wide to account for different duct / monitor configurations.

For example, A large SCA hot side precipitator will produce a low OAR due to the "smoothing" effect of opacity spikes and the long residence time of the treated gas prior to passing in front of the opacity monitor. In contrast, a small SCA cold side precipitator will produce a high OAR because of the close coupling of the precipitator outlet and the opacity monitor. Additionally, the location of the opacity monitor in the flue gas stream will, of course, have an effect on the OAR. Systems with monitors in the stack will produce lower OARs than those that are installed immediately downstream of the precipitator.



Normal Aspect Ratio Opacity Trace

Re-entrainment.

Specifically, particle re-entrainment is a result of collected ash that becomes dislodged from the collecting, emitting, flow control device, casing, or structural surfaces. However the most common source of particle reentrainment is the collecting surface. Actually, a certain amount of re-entrainment is inevitable. 100% of all captured ash will not migrate from the collecting plate to the hopper in one step. Rather, the path that captured ash takes is one resembling descending stairs.

As seen on page D-2, re-entrainment can result from two sources; from the precipitator or from the ducts. Duct reentrainmentcan be quite common and significantly contributory to opacity spiking. Contributors to duct-related re-entrainment can be sweepage or sloughing. The causes of sweepage can be excessive fallout or periodic high gas velocity. These factors can be caused by cycling operation or as a result of the basic design of the ducts.

Sloughing can originate from correction device buildup such as turning or splitter vanes, "egg crate", "skid" baffles, etc. Further, fine ash consistency also contributes somewhat to sloughing. As in sweepage above, design of correction devices and unit operation contribute heavily to the tendency of ash to slough.

Of the two factors, precipitators and ducts, responsible for re-entrainment, the precipitator generally contributes the most. This is caused by three main factors: Rapping problems, chamber

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/ box maldistribution, overall maldistribution, and high gas velocity. The contributors to re-entrainment-based rapping problems are sequencing that is too fast and often too light. Also, insufficient collecting area sectionalization can be a major contributor.

Chamber / Box Maldistribution refers to the total gas volume divided equally among casings, chambers, and mechanical fields. This can be quite common when individual induced draft fans are directly coupled to individual precipitator casings. Usually, the balancing of boiler parameters prevails in lieu of balancing precipitator parameters.

Overall distribution refers to the velocity in each of the gas passages measured. Measurements may be made in the field as full scale, in the laboratory as partial scale, or on a computer as virtual scale. In all cases, the acceptability of flow measurements is determined by conformance to ICAC (formerly IGCI) standards.

Even though evenly distributed, high overall gas volume can also contribute to high re-entrainment losses. This can be a result of, but not limited to, wet coal, low BTU coal, high O2, or some process change such as the addition of low NOx burners.

Gas Flow Contamination.

On page D-3, also following

High Average Opacity - Mechanical Performance

is

Gas Flow Contamination.

This is similar to that already discussed in Poor Reliability. Factors such as Air Infiltration and Rainwater In-Leakage can result in High Average Opacity as well.

Ash Quality.

Ash quality is determined by two main factors; Chemical Properties and Physical Properties. In the case of cold side precipitators, minimum amounts of SO_3 (sulfur trioxide), MGO (Magnesium oxide), CaO (Calcium Oxide), FeO Iron oxide, and LiO, Lithium oxide are necessary to lower ash resistivity. Conversely, excessive amounts of AlO (Aluminum oxide) plus SiO (Silica) will prevent sufficient adsorption of SO_3 resulting in adversely high particle resistivities. High particle resistivities results in low applied precipitator power and high particulate emissions.

In the case of hot side precipitators, NaO (Sodium oxide) is the predominate charge carrier. Therefore, a minimum amount must be present in the ash for optimum resistivity.

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Physical Properties.

The Physical Properties associated with ash include:

Excessive moisture, Excessive volume, Low Average Particle Size, Excessive Carbon,

and

Gas/Ash Separation.

High Opacity Spiking - Mechanical Peformance.

High Opacity Spiking.

Mechanical Performance is characterized by an opacity trace that has a high opacity aspect ratio, shown earlier in **Figure:**

Low Aspect Ratio Opacity Trace

. In **Figure:**

High Aspect Ration Opacity Trace

the zero-to-base value is 2. The base-to-peak value is 60. Thus, the OAR = BP/0B = 60/2 = 30. Too high!

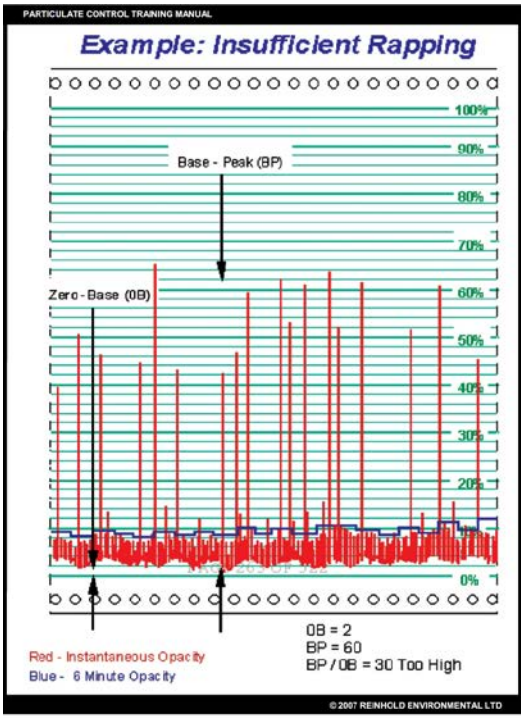
There are four main factors of this topic. They are:

High Gas Velocity, Rapping Problems, Sloughing

and

Soot Blowing.

High Gas Velocity is a result of factors discussed earlier and contribute to high re-entrainment losses from the precipitator. Indeed this behavior has been characterized as velocity-related re-entrainment. In the case of velocityrelated re-entrainment, the linear forces (particle momentum) are able to overcome the lateral, or normal forces of migration velocity. This is produced by the high voltage electrical field



High Aspect Ratio Opacity Trace

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surrounding the discharge electrodes.

Rapping Problems.

Rapping Problems are similar to those discussed in the

High Average Opacity

category, however high opacity aspect ratios are more commonly associated with rapping that is too intense and often too slow than the opposite condition that results in a low OAR.

Sloughing.

Also as in High Average Opacity, sloughing can cause frequent and high amplitude opacity spikes. This is of particular concern downstream from the precipitator. However, in the case of hot side precipitators, this effect can be more likely due to the increased length of flue duct downstream.

Soot Blowing.

Soot Blowing, especially air heater and economizer soot blowers can be responsible for opacity spiking. If the precipitator is properly sized and designed, soot blowing should not be noticeable at the outlet. However, this is most often experienced in conjunction with precipitators having short treatment times of less than 10 seconds.

4.10 Fundamentals of Troubleshooting an ESP with an Oscilloscope

See slides in Reference:

- ***Fundamentals of Troubleshooting an ESP with an Oscilloscope by Russ Ridgeway, AEP***

for a thorough discussion of fundamentals of troubleshooting and ESP with an oscilloscope.

4.11 What the Meters Tell You!

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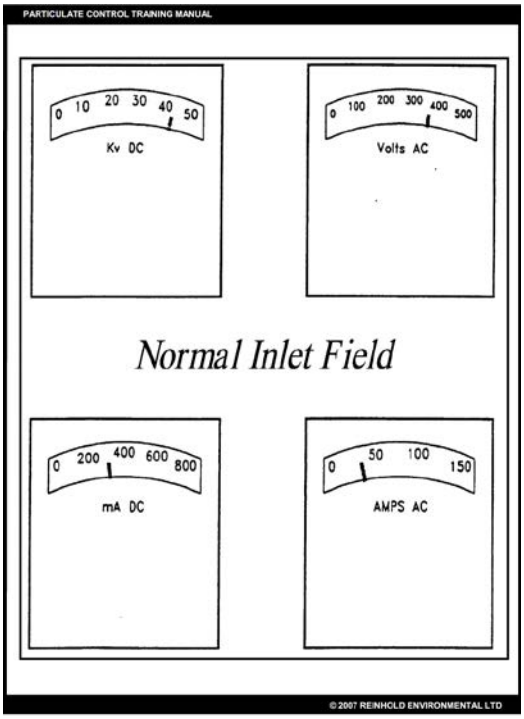
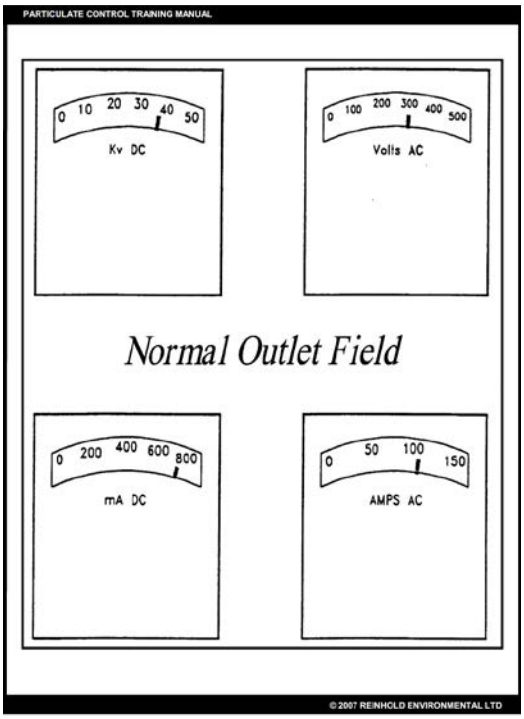
The following set of images show the readings of the control unit meters under various circumstances, which may be encountered in an operating precipitator. Observation of these readings permits us to diagnose various problems in the precipitator.



Normal Inlet Field

Although analog meters are shown, the readings from digital displays can be used in the same way. Remember that everything is relative to "normal" operational values.



Normal Outlet Field

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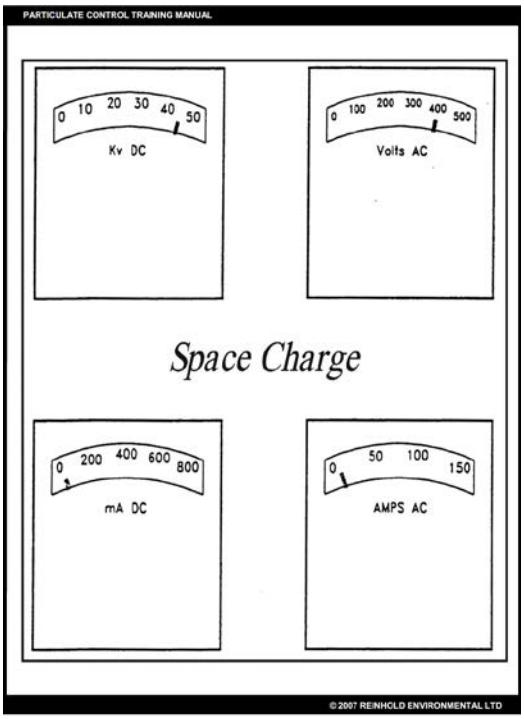
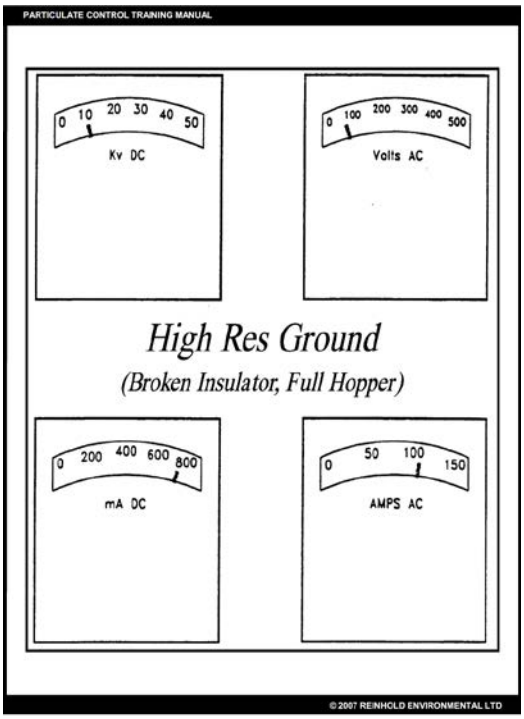
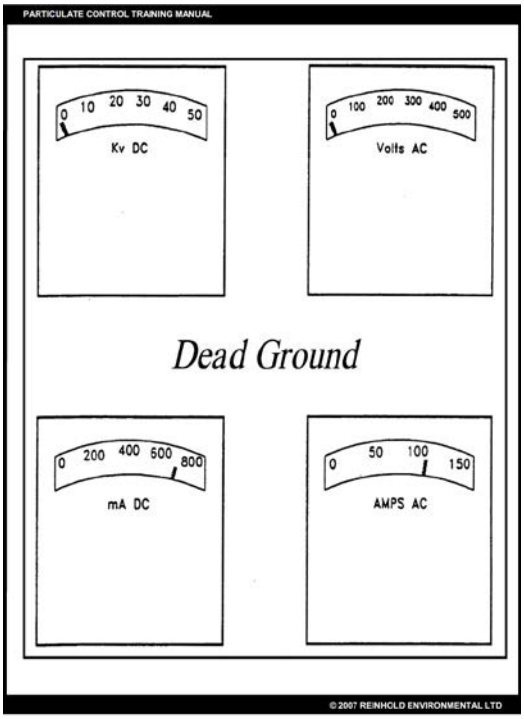


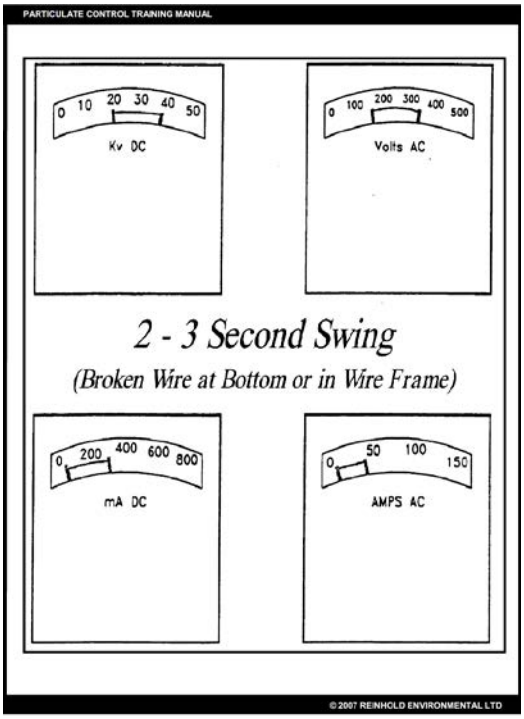
Space Charge



High Res Ground



Dead Ground



2-3 Second Swing

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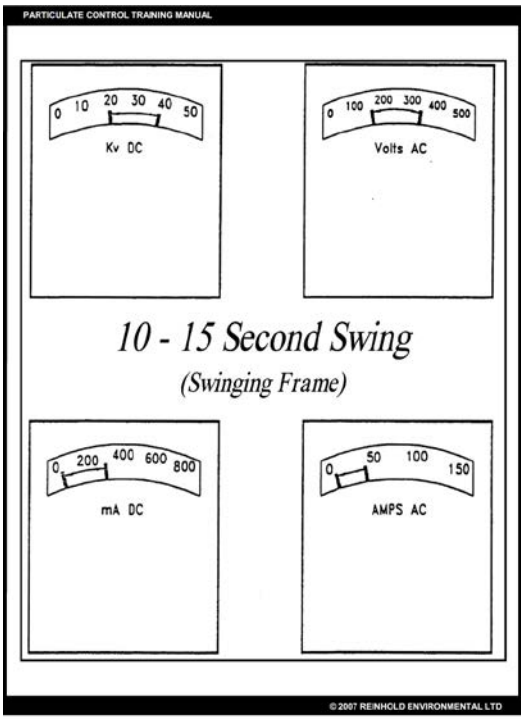
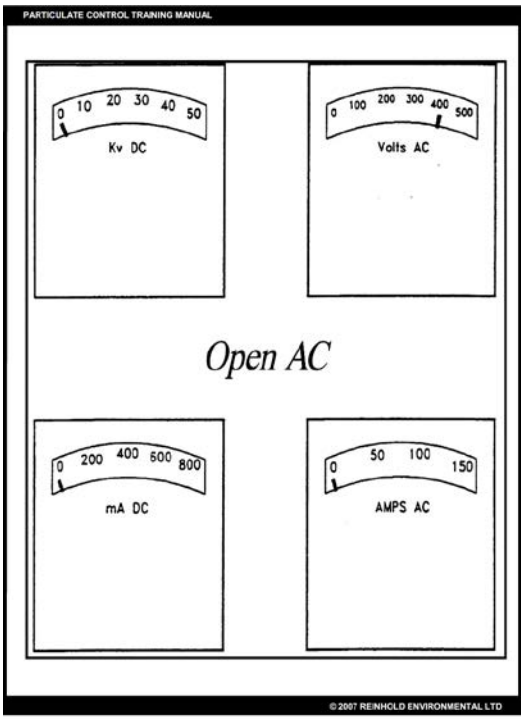
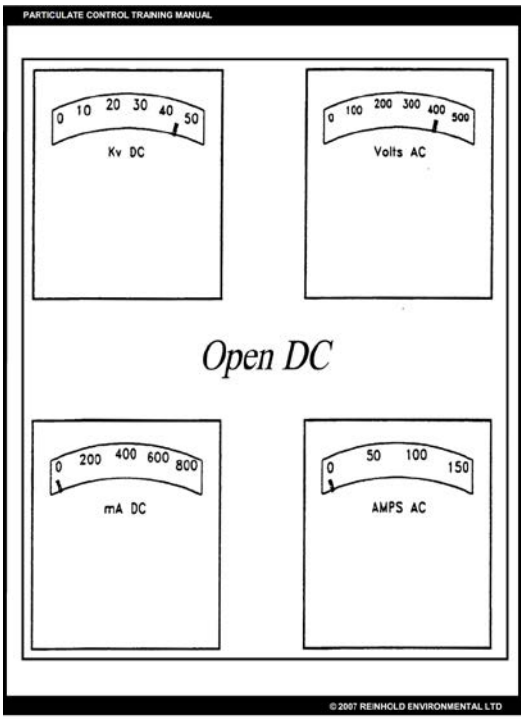


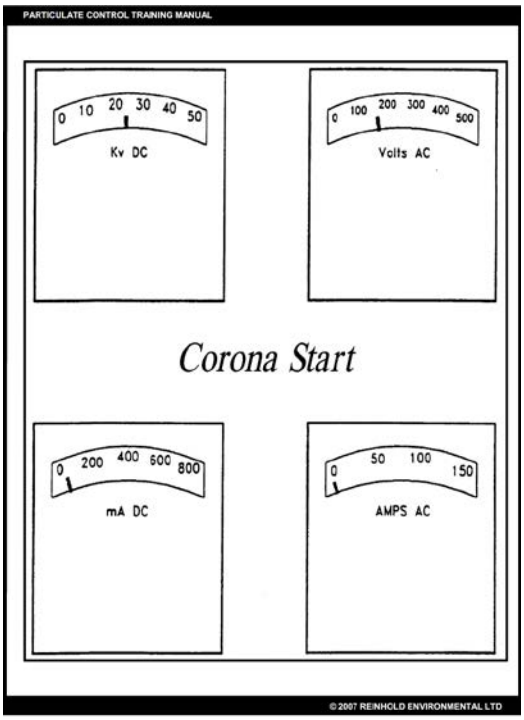
10-15 Second Swing



Open AC



Open DC



Corona Start

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4.12 Low NOx Burners Effect on ESPs

The application of low NOx combustion technology to PC and cyclone furnace boilers has had effects on the associated precipitators.

PC boilers are usually tangentially-fired or wall-fired. Wall-fired units are either front-wall or front-wall and backwall fired. There are a few old roof-fired units in service.

Cyclone boilers are all front-wall fired. Related to cyclone furnaces in some manner are Riley Turbo-fired boilers and distantly, wet-bottom PC units. These last three produce slag instead of bottom ash. The first two use crushed coal instead of pulverized coal.

The primary cause of the generation of NOx generation in furnaces is the flame temperature. The higher the flame temperature is and the longer the time at this temperature is, the higher the concentration of NOx. The nitrogen oxides of concern are NO_2 and NO_2O4. Nitrogen in the coal is also oxidized, not just in the air.

In an effort to reduce flame temperature, techniques were developed to slow down the combustion process by using deficient air in the initial stage of combustion and adding air in stages or gradually. This slows the combustion process and reduces flame temperature. It also reduces the oxygen available to oxidize the nitrogen at the high temperate. The major draw back is that it also reduces combustion of the carbon, resulting in higher ash combustible content and to some extent, carbon monoxide concentration.

This tendency to increased combustibles is most common and more pronounced in front-wall-fired units, somewhat less in front and backwall-fired units and very much less in tangential-fired units.

In slagging units such as cyclone furnaces and to a lesser extent, wet-bottom units, NOx production is much higher. This is due to the higher flame temperatures necessary to produce the slag necessary for the furnaces, especially cyclone furnaces, to function. Work has been done to

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adapt staged combustion to these slagging units and some reductions have been accomplished in NOx reduction, but it appears that selective non-catalytic reduction (SNCR), or most probably only selective catalytic reduction (SCR), will provide sufficient reduction of NOx to meet regulations.

In these cases, the use of some form of staged combustion will usually result in higher ash combustible content.

In all cases, higher ash combustible will result in increased mass emissions since large carbon particles will not hold an electrical charge and therefore be re-entrained. The generation of fine carbon particles (soot) will usually result in increased opacity since black particles absorb light and do not reflect it. With staged combustion, cyclone furnaces especially tend to produce fine carbon.

A much more extensive discussion on low NOx technology is included in other sections of this study.

4.13 Replacement Parts for ESPs

Discharge Electrode Replacement Wires for Common OEM Styles

Corona characteristics vary with wire style. Certain applications may benefit from a change in wire style or the use of several styles in one unit. Styles of discharge electrodes wires are shown in **Figure:**

Available Wire Styles

.

Replacement discharge electrodes for OEM styles are shown in **Figure:**

Available OEM Wire Styles

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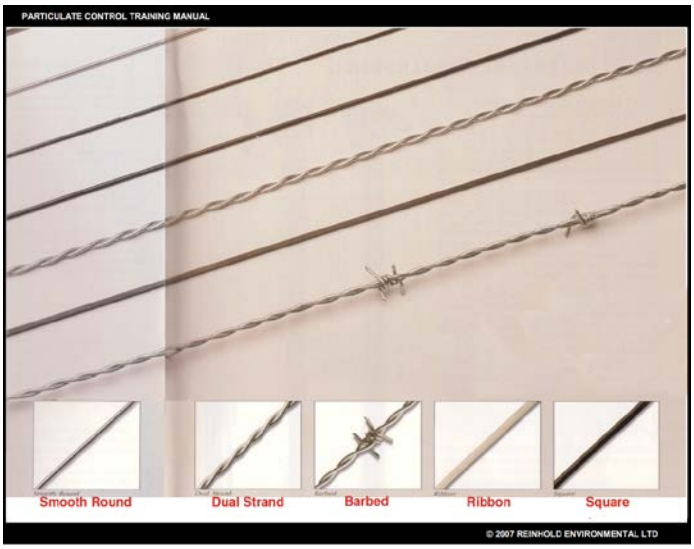
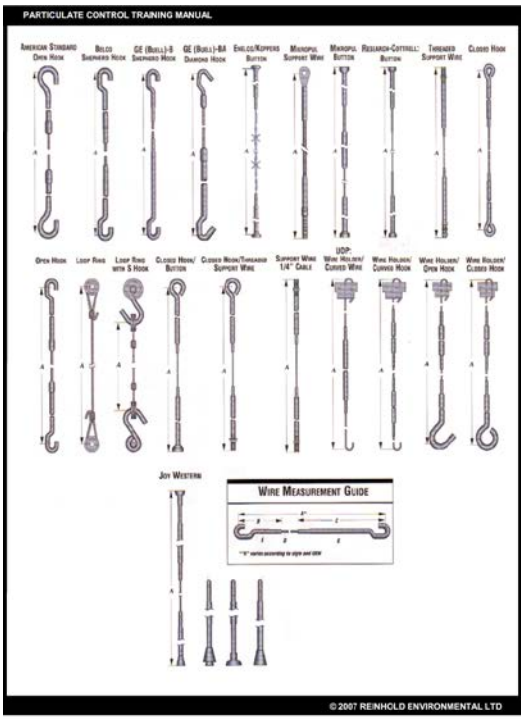


Available Wire Styles
Courtesy of BHA

.



Available OEM Wire Styles
(Courtesy of BHA)

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Weight Replacements for Common OEM Styles

Common weight replacement styles are shown in **Figure:**

OEM Weight Styles

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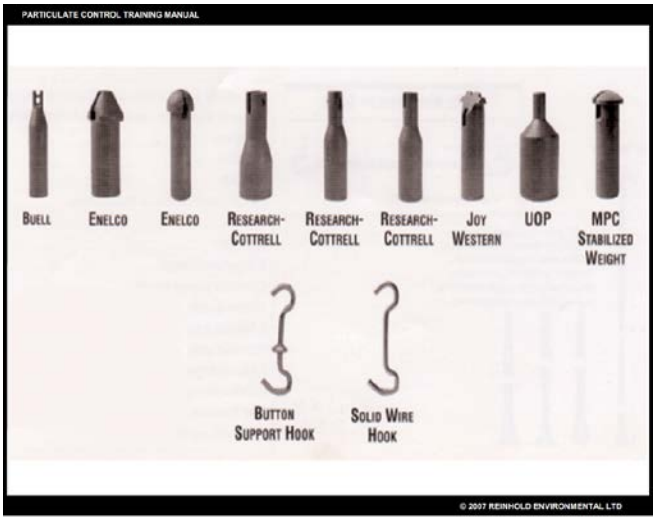

OEM Weight Styles
(Courtesy of BHA)

Boot Seals - Materials

The following table shows the properties of boot seal materials (See **Figure:**

Properties of Boot Seal Materials).

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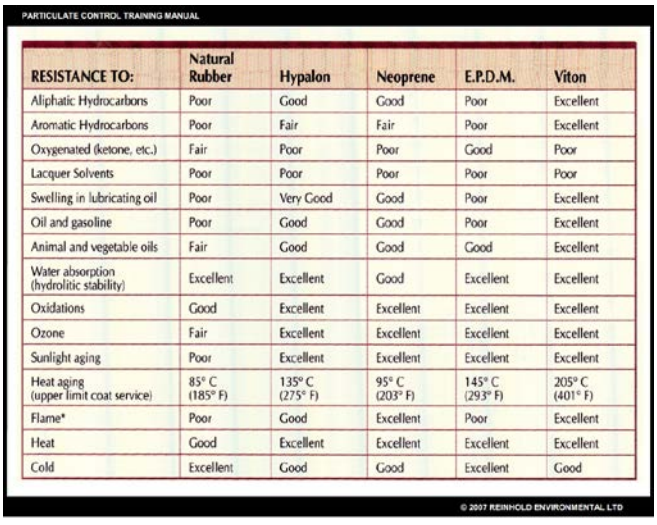

RESISTANCE TO:	Natural Rubber	Hypalon	Neoprene	E.P.D.M.	Viton
Aliphatic Hydrocarbons	Poor	Good	Good	Poor	Excellent
Aromatic Hydrocarbons	Poor	Fair	Fair	Poor	Excellent
Oxygenated (ketone, etc.)	Fair	Poor	Poor	Good	Poor
Lacquer Solvents	Poor	Poor	Poor	Poor	Poor
Swelling in lubricating oil	Poor	Very Good	Good	Poor	Excellent
Oil and gasoline	Poor	Good	Good	Poor	Excellent
Animal and vegetable oils	Fair	Good	Good	Good	Excellent
Water absorption (hydrolitic stability)	Excellent	Excellent	Good	Excellent	Excellent
Oxidations	Good	Excellent	Excellent	Excellent	Excellent
Ozone	Fair	Excellent	Excellent	Excellent	Excellent
Sunlight aging	Poor	Excellent	Excellent	Excellent	Excellent
Heat aging (upper limit coat service)	85° C (185° F)	135° C (275° F)	95° C (203° F)	145° C (293° F)	205° C (401° F)
Flame*	Poor	Good	Excellent	Poor	Excellent
Heat	Good	Excellent	Excellent	Excellent	Excellent
Cold	Excellent	Good	Good	Excellent	Good

Properties of Boot Seal Materials
(Courtesy of BHA)

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Insulator Replacements: Materials and Dimensions

The following table gives the materials and dimensions for original OEM insulators (See **Figure:**

Available OEM Insulators

).

Plate Straightening Systems

Ladder Bar System.

The following diagrams illustrate the main components of the Ladder Bar System. The system includes a device to hold the end plates straight and plumb, a side spacer for leading and trailing edges and the ladders, which are suspended from the top. (See **Figure:**

Ladder Bar System

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Type	Replacements For:	Material	Dimensions
Anti-Sway	Belco	Porcelain	Convoluted 6.5"Dia x 18"H
	Joy Western	Alumina	2"Dia x 21.125"Long
	PrecipTech/MPC	Alumina	Blade, 3" x 17.5"Long
	Research-Cottrell	Alumina	Blade, 3" x 17.5"Long
	Research-Cottrell	Teflon	Blade, 2.875" x 17.5"Long
	Universal	Alumina	2"Dia x 24"Long
	Universal	Alumina	1.875"Dia x 24"Long
Rapper/Vibrator	Belco	Porcelain	Convoluted 7"Dia x 14"H
	Belco	Porcelain	Convoluted 6.5"Dia x 18"H
	Belco	Porcelain	Convoluted 9"OD x 15"H
	Buell/GE	Alumina	3"Dia x 30"Long
	Enelco/Koppers	Fiberglass	2"Dia x 48"Long, tapered ends
	Enelco/Koppers, Research-Cottrell	Fiberglass	2"Dia x 40"Long, tapered ends
	Joy Western	Alumina	2"Dia x 21.125"Long
	Research-Cottrell	Alumina	3.94"Dia x 30"Long
	Research-Cottrell	Porcelain	3.94"Dia x 30"Long
	Research-Cottrell	Alumina	2"Dia x 30"Long, tapered ends
	Research-Cottrell	Fiberglass	2"Dia x 30"Long, tapered ends
	Universal	Alumina	2"Dia x 36"Long, tapered ends
	Universal	Fiberglass	2"Dia x 36"Long, tapered ends
Post/Stand-Off	Enelco/Koppers	Porcelain	Convoluted 6"OD x 10.5"H
	Joy Western	Porcelain	Convoluted 6"OD x 10.875"H
	Research-Cottrell	Porcelain	Convoluted 5"OD x 11"H
Support	Research-Cottrell	Porcelain	Pin-type 12"OD x 9.75"H
	Buell/GE	Alumina	12"OD x 9.75"ID x 23.5"H
	Enelco/Koppers, UOP	Alumina	14"OD x 12"ID x 24"H
	Enelco/Koppers, UOP	Porcelain	14"OD x 12"ID x 24"H
	Joy Western	Porcelain	Convoluted 6"OD x 10.875"H
	Research-Cottrell	Alumina	16.5"OD x 14"ID x 31"H
	Research-Cottrell, Belco	Alumina	16.5"OD x 14"ID x 20"H
	Research-Cottrell	Porcelain	16.5"OD x 14"ID x 31"H
	Research-Cottrell, Belco	Porcelain	16.75"OD x 14"ID x 20"H
	Wheelabrator	Alumina	Conical 10.5" x 14.75" x 20"H
Wall Bushing	Joy Western	Porcelain	Convoluted 14"OD x 20" Long
	Research-Cottrell	Porcelain	Convoluted 3.625"OD x 26"H

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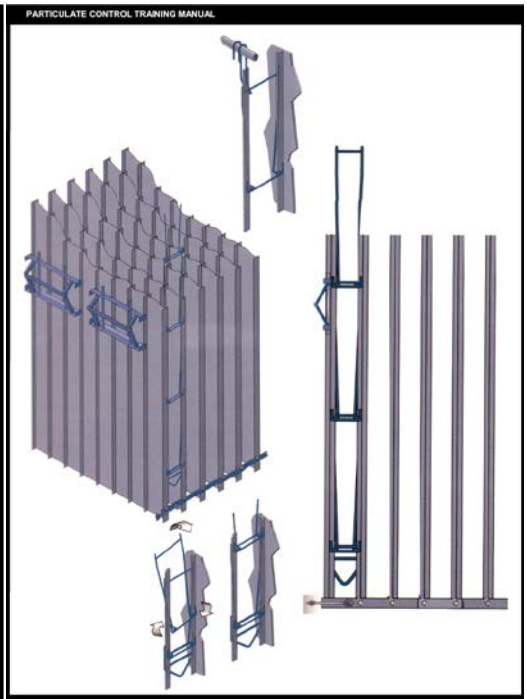
Available OEM Insulators
(Courtesy of BHA)



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Ladder Bar System
(Courtesy of BHA)

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Torque Bar.

This device is used to straighten bows in strip plates in rigid frame precipitators. See **Figure:**

Torque Bar

.

U-Bar Spacer.

This device is attached to one plate and serves as a bumper against adjoining plates to maintain spacing. See **Figure:**

U-Bar

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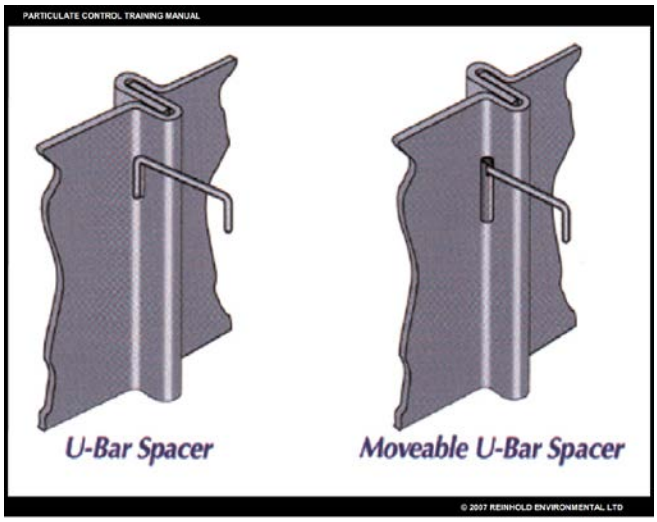
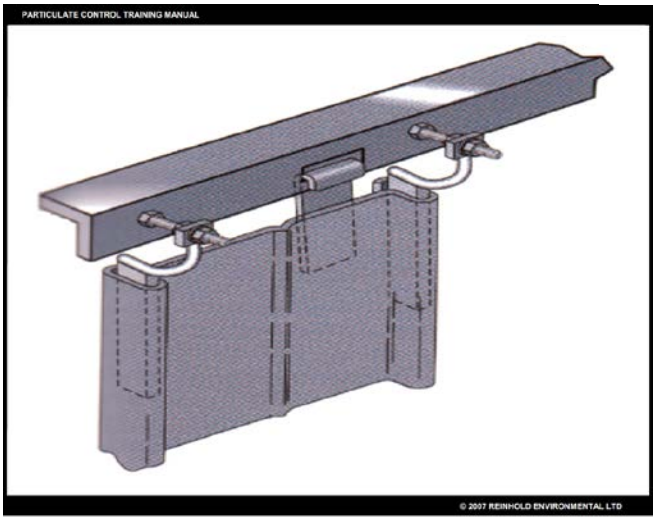


U-Bar
(Courtesy of BHA)



Torque Bar
(Courtesy of BHA)

Rake Plate Straightener.

This device was design by BHA to straighten warped Buell plate panels. It can be installed without welding. (See **Figure:**

Rake Plate Straightener

).

Collecting Plate Replacements

A wide variety of specialty suppliers along with OEMs offer replacement collecting plates for most of the ESP designs in service today. BHA Group is one major supplier of replacement plates. Their plates have some unique features as described below.

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ESP-3 Plate.

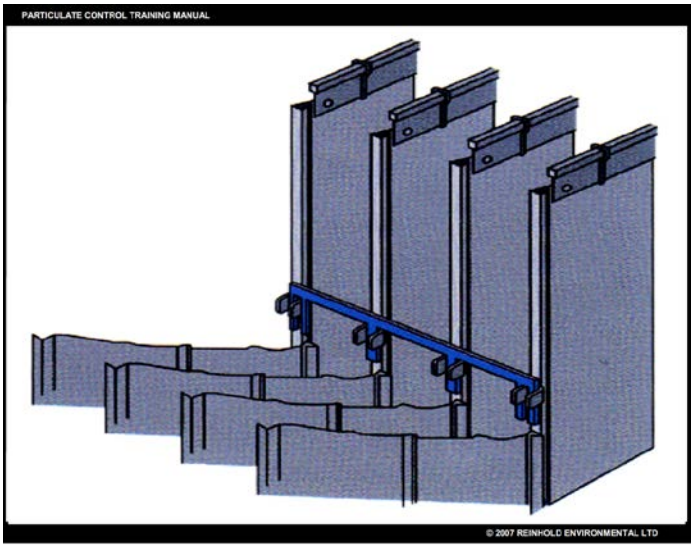
The ESP-3 plates key feature is a rollformed process that turns the stiffener section of the plate back to the base sheet, where it is spot welded down the full length of the plate. This creates a closed box shape at the leading edges of the plate, giving it strength. The roll form process has the flexibility to varying widths of the strip plate. The plate is available in 16 or 18 gauge carbon or stainless steel, in lengths up to 48 feet (14.63 m). (See **Figure:**

ESP-3 Collection Plate

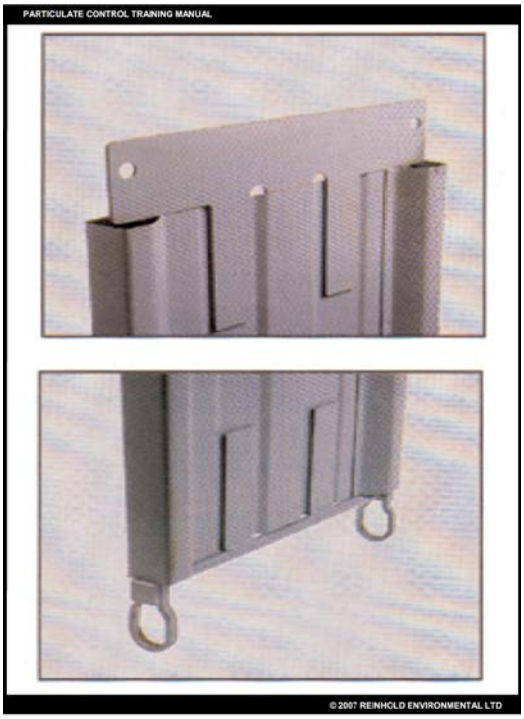
).

ESP-1 Plate.

The ESP-1 plate has a one-piece base sheet that is sandwiched between triangular stiffeners. The three thicknesses of metal are resistance welded. Since the stiffeners are not roll-formed into the base sheet, variable stiffener positions to achieve maximum electrical clearance from the discharge electrodes to the stiffeners can be offered.



Rake Plate Straightener
(Courtesy of BHA)



ESP-3 Collecting Plate
(Courtesy of BHA)

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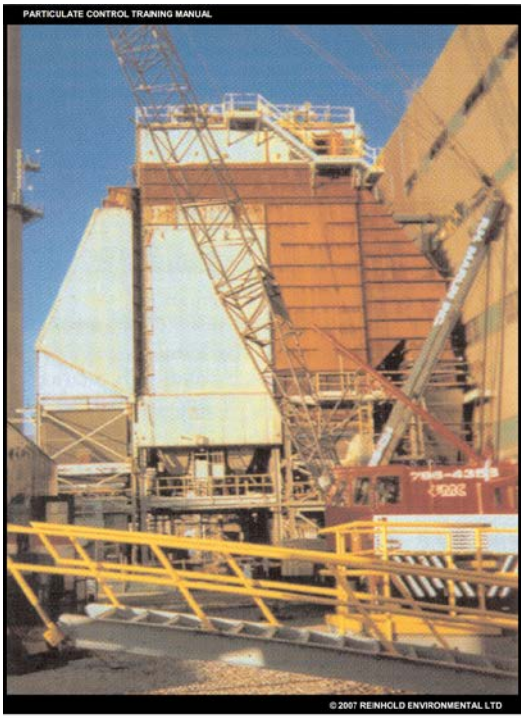
CHAPTER 5 - OPTIONS TO IMPROVE PARTICULATE COLLECTION FOR EXISTING ESPs

This chapter discusses options to improve particulate collection for existing ESPs and Fabric Filters, including:

- ***ESP Performance Enhancements Factors and Options***
- ***ESP Rebuilds with Added Length, Height or Width***
- ***Additional Stand-Alone Equipment to Increase Performance***
- ***Pulse Energization***
- ***Flow Distribution***
- ***Temperature Distribution***
- ***Particle Size Distribution***



ESP Upgrade Involving Replacement of Mechanical Collector with New ESP Fields

5.1 ESP Performance Enhancements Factors and Options

Over the past ten years on a worldwide basis, electrostatic precipitator rebuilds with performance upgrades have become a popular alternative to electrostatic precipitator replacement as a way of reducing particulate emissions. Where conditions permit, rebuilding and upgrading an electrostatic precipitator can result in significant cost savings over complete replacement with totally new systems. This section describes some of the cost-effective rebuild and upgrade options available to the electrostatic precipitator user to enhance precipitator performance and maintain compliance with all pollution control regulations.

Rebuild and Upgrade Options

There are many options available to rebuild and upgrade an electrostatic precipitator to improve its efficiency and reduce emissions. Some combination of the following set of options will likely be used to upgrade an electrostatic precipitator on any application.

1) Modify boiler/process operation
2) Gas/particulate conditioning (SO_3, ammonia, proprietary chemical)
3) Humidification (moisture conditioning)
4) Add collecting area within existing casing

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5) Increase field height to increase collecting area without increasing footprint
6) Increase electrical sectionalization
7) Modify collecting plate spacing
8) Modify discharge electrode geometry
9) Reduce system air infiltration
10) Minimize heat loss
11) Modify gas distribution
12) Modify rappers and rapping control
13) Upgrade automatic voltage controls
14) Match power supplies to loads
15) Upgrade auxiliary equipment

Many of the above items are discussed in this section. However, flue gas conditioning and gas temperature issues are discussed in detail in other sections in this manual.

Increased Specific Collecting Area

Although increasing the existing casing by increasing its width, length, or height is always an alternative, it is usually not the most cost effective. Rigid discharge electrode (RDE) technology provides a design of components that can be tightly packed into an existing casing to produce a larger specific collecting area. Rigid frame type electrostatic precipitators typically have large spaces between fields due to their design and requirements for maintaining electrical clearances between high voltage and grounded components. The RDE design technology uses the open spaces in a rigid frame electrostatic precipitator to add collecting area to an existing electrostatic precipitator casing. Rigid frame ESP designs with top rapping can also provide more SCA in a rebuild.

Increased Electrical Sectionalization

Sectionalization can be increased in the direction of gas flow and across gas flow. Intuitively, the smaller the electrical section, the less affect any disturbance, such as sparking or heavy dust load, has on the remainder of the electrostatic precipitator. Many studies have shown significant enhancement of electrostatic precipitator performance with increased sectionalization in the direction of gas flow. Sectionalization across flow may be possible. The use of RDE technology in the rebuild and upgrade of electrostatic precipitators can facilitate increased sectionalization by the very nature of its design and use of short field lengths. Because of the capacitance of large electrical sections, they store large electrical charges. Increasing sectionalization reduces the violence of arcing and sparking.

Modify Plate Spacing

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Traditional Deutsch-Anderson electrostatic precipitator theory says that electrostatic precipitator efficiency is maximized with collecting area. This theoretically means that for a given casing volume, the efficiency can be maximized with close plate spacing. However, for many years now, the theory of wide plate spacing has been accepted, typically increasing plate spacing to 16 inches (400 mm) from 10 - 12 inches (250 - 300 mm). It has been shown that effective migration velocity increases at least proportionally with plate spacing, keeping the efficiency nearly the same for any plate spacing between these values. With wider spacing, less internal components are required, making it an attractive rebuild option. Additionally, with wider plate spacing, alignment and electrode straightness is relatively less critical.

One wide plate spacing theory is based upon the belief that the collecting area for a given volume of precipitator casing will be reduced, but the specific power (secondary DC volts x secondary DC current divided by gas flow) will remain the same or increase. According to Dr. H.J. White, if the specific power is the same the efficiency is the same.

For best performance ESPs are normally run near the spark limit. Sparks are initiated at the collecting electrode when the electric field strength at the plate surface has reached a certain critical value, i.e. when the current density at the electrode has reached a critical value (field = current density times dust resistivity). This critical current density is the same regardless of the electrode spacing. Therefore the total current decreases in proportion, when the collecting area is decreased, by increasing the spacing. The voltage is increased and the current decreased leaving the wattage approximately constant.

There are applications where wide plate spacing is not recommended. Wide spacing is not recommended for high particle concentrations or for fine particle size. A phenomenon known as "space charge effect" inhibits the charging and collection of particulate under these conditions. Plate spacing may be varied in the ESP with narrower spacing in the inlet and wider spacing in the outlet. Electrode geometry may be varied with plate spacing.

Modify Discharge Electrode Geometry

As mentioned in the section above on plate spacing, electrode geometry can be varied from inlet to outlet. More aggressive electrodes that have the ability to produce large amounts of corona maybe necessary in the inlet fields to adequately charge the particulate. An aggressive electrode is characterized by having spikes, a larger quantity of spikes, more pronounced spikes, and /or spikes oriented toward the collecting plate. This is particularly important in applications with very fine particles or large quantities of particles. These conditions tend to make it difficult for normal electrodes to generated adequate corona. In the case of large particle concentrations that are removed in the first few fields, a less aggressive corona-producing electrode is preferred to enhance operating voltages and electric field strengths.

Reduce System Air Infiltration

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Air infiltration is an obvious, but often overlooked source of electrostatic precipitator performance problems. If not addressed effectively as a part of routine maintenance, it must be considered as a part of an electrostatic precipitator rebuild. Door seals, expansion joints, rapper penetrations, hopper seals, and dampers are potential sources of air infiltration. Extensive casing corrosion can be a major source of air infiltration. Identifying and eliminating sources of air infiltration on negative draft systems can have a profound effect on electrostatic precipitator performance. Air infiltration not only promotes corrosion of the electrostatic precipitator casing and internal components, it can adversely affect electrostatic precipitator performance by increasing gas volume, distorting gas distribution, reducing treatment time, and causing particle re-entrainment. Worn or improperly adjusted regenerative air heater seals are also a large source of air infiltration.

Modify Boiler/Process Operation

Before considering a major capital expense of improving the electrostatic precipitator, a close look at the process operation is important. Sometimes a minor change in process operation can result in a change of particulate chemistry, size, and/or resistivity to significantly improve electrostatic precipitator efficiency. As an example, keeping the boiler tubes clean can improve heat transfer and result in reduced flue gas temperatures. The reduced temperatures will reduce dust resistivity and allow efficiency to increase. Modifying the soot blowing equipment and/or schedule may be a cost-effective technique to achieve this. Modifying the air heater to reduce gas temperatures is another example. Reduction of dust resistivity may increase the electrostatic precipitator operating voltage, and therefore, increase the migration velocity.

Minimize Heat Loss

Like air infiltration, heat loss can lead to corrosion and poor electrostatic precipitator efficiency. Poor gas distribution and poor thermal insulation around the electrostatic precipitator casing can lead to poor heat distribution in the electrostatic precipitator. If local temperatures drop below the acid dew point, condensation will occur. The acid condensation will not only lead to corrosion, it will make removal of the particulate from the electrodes and from the hoppers more difficult. Dust build up on the electrodes will reduce operating voltages, and thus reduce electrostatic precipitator efficiency. Dust accumulation in the hopper can build up into the discharge and collecting electrode area, shorting out an electrical section that effectively reduces the collecting area. Such hopper storage can exert compressive forces on electrodes and distort them permanently.

Modify Gas Distribution

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Traditionally, electrostatic precipitator efficiency is considered maximized if gas distribution is uniform; that is, the same velocity across the face of the electrostatic precipitator from inlet to outlet. Perfectly uniform gas distribution is not possible in industrial electrostatic precipitators. In the United States, gas distribution is generally required to meet the specification of the Institute of Clean Air Companies (ICAC). This specification requires 85% of all readings be not more than 1.15 times the average, and that 99% of all readings be not more than 1.40 times the average. Electrostatic precipitator suppliers providing equipment outside of the US have generally not had gas distribution requirements specified. These suppliers have established gas distribution criteria that are sometimes different than that required in the US (see the following section on skewed flow). Usually the gas distribution can be improved. Reduction of gas sneakage around the active collection zones is a vital part of improving electrostatic precipitator efficiency.

Recently, the traditional theory of maximizing the uniformity of gas distribution has been questioned. The concept of skewing gas distribution from top to bottom on the electrostatic precipitator and changing the skew from inlet to outlet is being suggested as a way of reducing particulate re-entrainment. There have been several cases of documented electrostatic precipitator performance enhancement with skewed distribution. ESKOM, the South African utility, is doing an extensive investigation of this concept and has met with some good results. However, the uniform distribution philosophy still dominates worldwide.

Modify Rapping and Rapping Controls

Rigid frame electrostatic precipitators traditionally have tumbling hammer rapping. Tumbling hammer rapping of the collecting electrodes can result in "over rapping" and produce excessive rapping re-entrainment. Tumbling hammer rapping cannot be adjusted, except by changing the hammers during an outage. Drop hammer rapping systems are usually adjustable, but each mechanism must be individually adjusted mechanically.

With the retrofit of RDE technology described above, modified rapping systems can allow for more flexibility and easy adjustability. The gravity impact rappers of RDE technology use a cylindrical slug of metal to impart the rapping forces to the electrodes. The 10-20 pound (4.5-9 kg) slug is lifted by magnetic force from an electrically energized coil surrounding it. When the coil is de-energized, the slug falls by gravity to impact the rapping rods. The length of energization time of the coil determines the lift height of the slug, and thus, the rapping intensity. Since a control panel independently energizes each rapper coil, each rapper can be individually adjusted simply and easily. Intensity, frequency and number of impacts per rap can be adjusted, making this a flexible system that minimizes rapping re-entrainment.

Abnormal material accumulation on discharge and collecting electrodes will reduce operating voltages and currents. Thus, the migration velocity and the efficiency will degrade. Although the

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Deutsch-Anderson equation does not directly address rapping re-entrainment, it is obvious that reduced re-entrainment will result in reduced losses.

Upgrading of Automatic Voltage Controls

Modern microprocessor based controls should replace old analog controls. Modern silicon controlled rectifiers should replaced old saturable reactor power control elements. Microprocessor based controls have faster response to sparking and can operate effectively over broader operating conditions than analog controls. They have new energization features, such as intermittent energization, that can improve electrostatic precipitator performance. Their self-diagnostic features make them easier to maintain. Future upgrades of new technology can be made with simple microprocessor chip changes.

Microprocessor controls can also be linked to a central computer control for remote data acquisition and control, and the data can be fed directly to the plant process control computers. Comparing process data to electrostatic precipitator electrical data is a useful tool to identify process conditions that affect electrostatic precipitator efficiency. Identifying these process parameters is important in maximizing the migration velocity.

Matching Loads

Electrostatic precipitator performance can be enhanced with matching of power supplies to loads. Mis-matches may be a result of improper application initially, or from changes in operation since initial operation. Power supply mis-match occurs when operating and rated levels are significantly different. A 55 kV rated power supply operating at 30 kV is an example of a mis-match. The automatic voltage control must keep the firing angle of the silicon-controlled rectifiers at a low level, artificially keeping the corona current even lower than normal. The mis-match can be corrected by selecting different electrode geometries, changing transformer input taps, or adding impedance matching linear reactors. Sometimes power supplies should be replaced because of age or because they contain PCBs (polychlorinated biphenyls) that are known carcinogens. This is a good time to investigate matching the power supplies with the loads. Pulse energization power supplies may also be considered on high resistivity applications.

Upgrade of Auxiliary Equipment

Although auxiliaries do not have a major effect on electrostatic precipitator performance, some consideration should be given to the auxiliary equipment when rebuilding and upgrading an electrostatic precipitator. Upgrade of hopper heaters, hopper level indicators, hopper vibrators, and hopper evacuation systems can minimize ash build up problems that could lead to lost operation of electrical sections. Door seals, expansion joints, and dampers should also be

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upgraded, as discussed above in the air infiltration section. If an air purge system is used for the high voltage support insulators, it should be sized appropriately for the rebuilt electrostatic precipitator to deliver sufficient air volume. This will avoid excessive insulator contamination that can lead to failure and loss of proper electrical energization.

Rebuild and Upgrade Example

The best rebuild and upgrade options are site specific. Any combination of the above modifications can be made, based on technical and economic considerations. The following is an example of a hypothetical, but somewhat typical case. Consider a three-field electrostatic precipitator of rigid frame design operating on a coal-fired boiler. Efficiency is about 97%. The flue gas temperature is 338°F (170°C) and the fly ash has high resistivity. The electrostatic precipitator casing is in good condition and corrosion is not a problem. Electrostatic precipitator efficiency must be increased due to a change in the coal supply. The following actions may be recommended.

- Air heater modifications to produce an electrostatic precipitator inlet temperature of 266°F (130°C).
- Gas distribution is improved and maintained by rapping inlet distribution screens and eliminating build up in the bottom of the inlet nozzle.
- Increase of 20% in collecting plate area with retrofit of RDE technology, using large areas between fields.
- Increase collecting plate area by an additional 20% by raising the roof and increasing the plate height.
- New RDE internals form six electrical fields in the direction of gas flow compared to the original three.
- Rebuild the first two fields with 300-mm plate spacing and very aggressive RDEs.
- Rebuild the last four fields with 400-mm plate spacing with less aggressive RDEs to promote higher voltages and electrical field strengths.
- Use gravity impact rappers to reduce re-entrainment.
- Install modern electrical energization equipment, especially microprocessor-based controls.
- Eliminate air infiltration and heat loss as required.

It is not hard to visualize that the above modifications could improve electrostatic precipitator efficiency to 99.5% from its original 97%. The increase could be even greater if the electrostatic precipitator to be rebuilt is in poor condition.

Summary

Rebuilding and upgrading an existing electrostatic precipitator can be a cost effective alternative to increasing the casing of an existing electrostatic precipitator, building a completely new

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electrostatic precipitator, or installing a fabric filter. This is particularly true of rebuilding and upgrading rigid frame electrostatic precipitators with rigid discharge electrode technology. Savings can arise from the reuse of foundations, support steel, nozzles, ductwork, casing, hoppers, ash handling equipment, access, and insulation and lagging. The above rebuild and upgrade techniques are proven technologies that have already been successfully used worldwide.

A key to rebuild and upgrade technology is the ability to predict the performance of the modified equipment with a high degree of confidence. This is not a task for the inexperienced. With extensive theoretical understanding of electrostatic precipitators, a good database of experience, and specialized modeling capabilities, the performance improvement can be predicted with the high degree of confidence necessary to make this a viable option to more costly alternatives.

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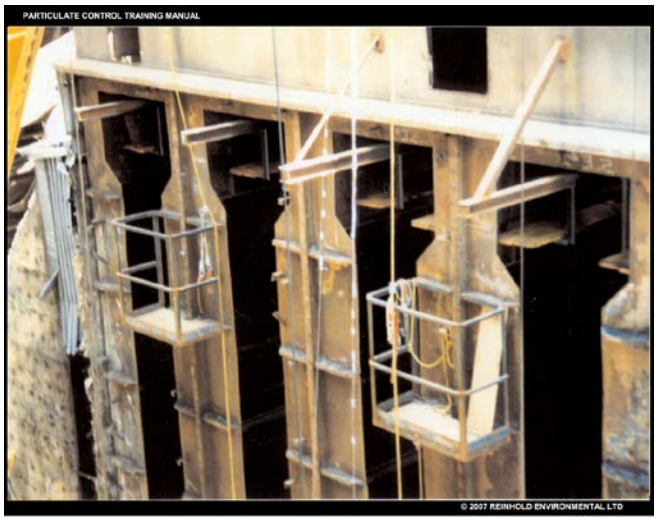
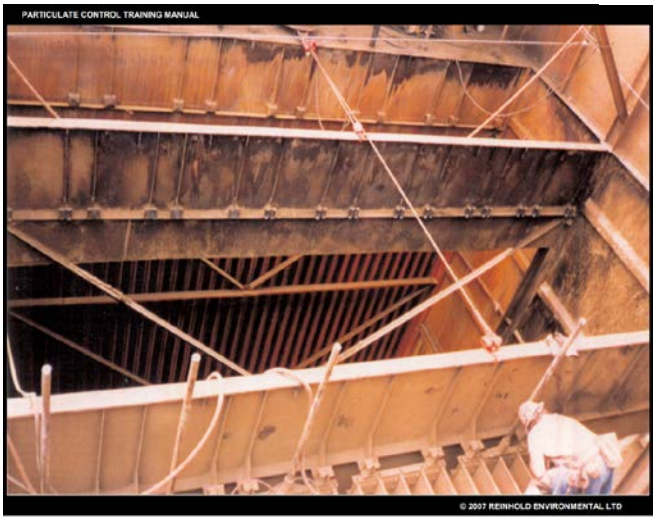
Photographs following this section show various rebuild techniques.



Rebuild through the Side



New Internals with Roof Off

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Material Removed During a Rebuild

Removal of Plates with Roof Off

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Installing Plates through Hopper Crotch

Installing Rigid Discharge Electrodes

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Installing Rigid Discharge Electrodes-1

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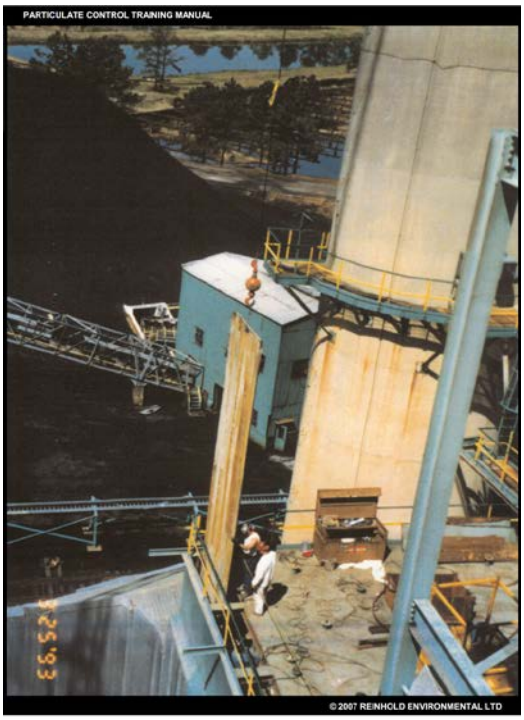
Preparing to Install Plates through Roof



Installing Plates through Roof Slot

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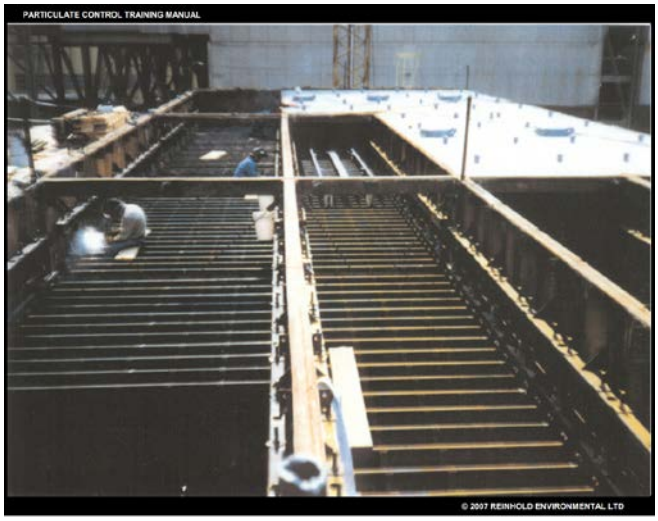
Installing Plates with Roof Open



Final Welding

5.2 ESP Rebuilds with Added Length, Height or Width

Installing Plates with a Crane

Rebuilding a precipitator with added collecting electrodes surface (A) is often economically done by increasing collecting electrode height and/or adding sections to collecting electrodes in series.

If it is found that the existing internals of the ESP cannot be improved, the ESP casing must be extended to increase the gas treatment time. Local conditions determine which dimension to increase, width, length or height. Structural problems from the weight of electrodes can be avoided by increased electrode spacing as described in the following paragraphs.

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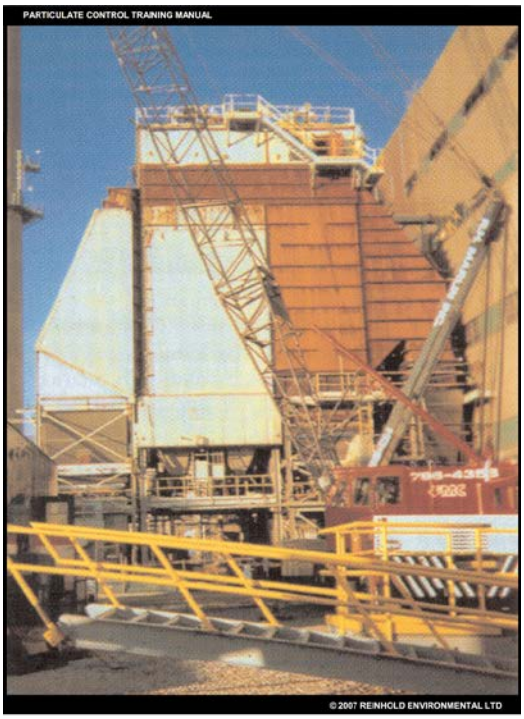
A good example of this is a case where the collecting electrode height was increased from 24 feet (7.32m) to 28 feet (8.57m) and the mechanical cyclone collector in front of the existing precipitator was replaced with two (2) electrostatic fields, each six (6) feet (1.83m) x 28 feet (8.56m) high. The side-walls, hoppers, ash handling support and access systems of the mechanical collector were reused. The two 9 feet (2.74m) fields of the existing precipitator were split into four 4.5 feet (1.37m) fields in series. This permitted increasing the unit load from 80 MW to 105 MW and brought the unit into compliance with a more difficult fuel. The total cost for doing this work, including strengthening the support structure was less than 40% of the cost for replacing the precipitator with a new unit of equivalent size.

ESP upgrade project involving replacement of mechanical collector with new ESP fields, increased sectionalization of existing ESP and increased plate height.



ESP Upgrade Involving Replacement of Mechanical Collector with New ESP Fields

Usually the least expensive addition of surface is achieved by increasing collecting plate height since all parts, including high-tension frame and insulators, can be re-used. The only precaution necessary in increasing plate height is avoiding destroying the aspect ratio (length/height) of the precipitator. You cannot, for example, double the plate height and keep the same treatment

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length.

Adding treatment length (adding fields) is more expensive since structures, supports, foundations and access to the new fields as well as ash handling systems must be provided. In some designs, usually European rigid frame designs, there is space within the casing, usually in the access aisles, and rapping aisles to add plate surface, if rappers are changed to top mounted and rigid frames are replaced with rigid discharge electrodes (RDE). This type of rebuild is usually a very economical way to increase collecting surface by up to 20%, while improving series sectionalization. This approach can be used along with increased plate height to produce an addition of 40-50% in collecting area.

These approaches often require substantial downtime on the generating unit. This type of addition is usually scheduled concurrently with major work on the furnace, boiler and/or prime mover.

Another approach is the addition of parallel capacity. Often there is some space available between units permitting the construction of one or two "wing" precipitators in parallel with the existing precipitator. While the capital cost is much higher, the "wing" precipitators may be constructed with the unit in operation and only a very short outage is required for tie in to the existing flue system.

Caution must be used in the design of such systems to avoid gas distribution problems. Models, either physical or mathematical must be used to insure proper distribution.

Additions to plate height or "wing" precipitators both reduce gas velocity and re-entrainment. Adding series capacity of course does not help solve excessive gas velocity problems.

In summary then, there are a number of ways to increase precipitator collecting area. Before action is taken, all reasonable alternatives should be examined from the standpoint of capital cost and outage requirements.

Plant with COHPAC

5.3 Additional Stand-Alone Equipment to Increase Performance (COHPAC I and II)

Introduction

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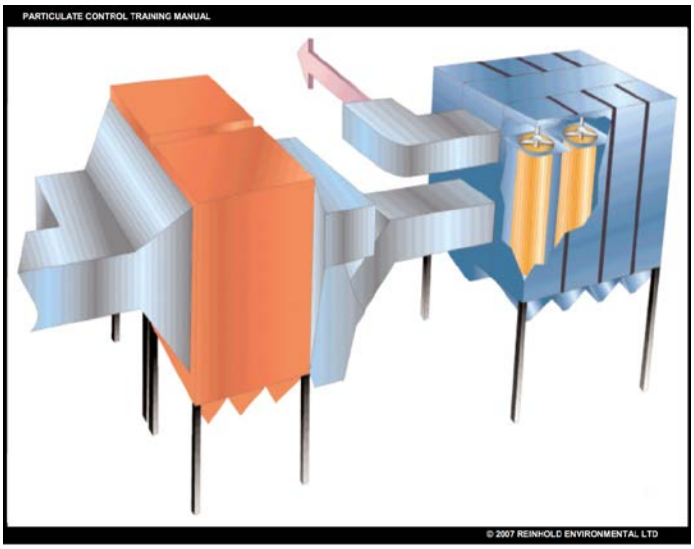
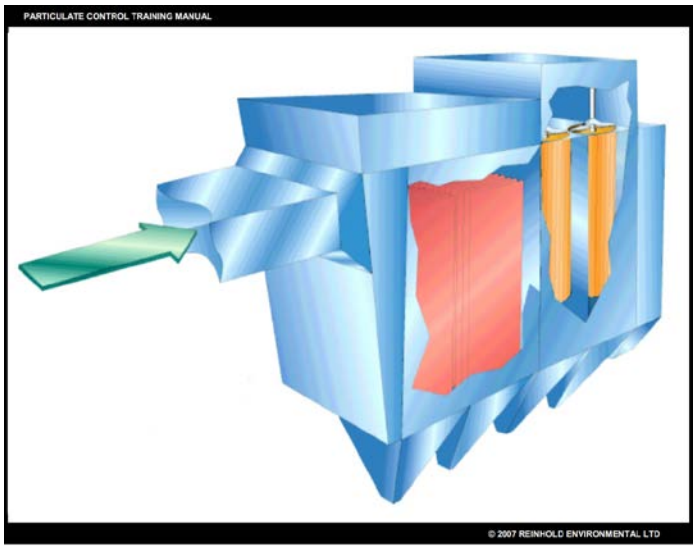
After many years of service, there are an increasingly large amount of existing electrostatic precipitators installed on numerous applications, including coal-fired boilers, municipal waste combustors, and other non-combustion applications such as cement kilns, steel applications, etc. that can no longer meet their original, current and/or future emission control requirements. These requirements can be: total particulates, fine particulates, metals and even toxins such as mercury, dioxins, etc. One method that has been successfully applied to meet these more stringent requirements has been the installation of COHPAC fabric filter technology in series with the existing ESP collectors.



COHPAC I Arrangement
(Courtesy of HR-C)

Technology Overview

COHPAC stands for "COmpact Hybrid PArticulate Technology". This patented and licensed technology was originally developed by Dr. Ramsay Chang of the Electric Power Research Institute (EPRI) about 10 years ago as a means to effectively improve the particulate removal capability of aging or undersized electrostatic precipitators at a reasonable cost. While this technology was originally developed for use on electric utility coal-fired boiler installations, its use on other precipitator applications has recently developed. The concept of COHPAC is fairly simple. A high ratio pulse jet fabric filter collector (baghouse) is installed in series with an existing, energized electrostatic precipitator, serving as the polishing or final collection device. Due to the fact that the ESP removes the majority of the ash or dust prior to entering the fabric filter, the filtration rate (air-to-cloth-ratio) can be increased substantially while still maintaining the same



COHPAC II Arrangement
(Courtesy of HR-C)

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pressure drops as conventional filtration rates. It is also believed that the ESP serves as a pre-charger and helps to agglomerate the dust particles into a larger, and thus more porous structure, which also aids in the filtration process. While the true cost benefit of COHPAC is achieved at the higher filtration rates, there are several installations around the world that while operating at conventional filtration rates, still provides the benefits of having a pulse jet collector serving as the final filtration device. Some of these will be discussed later.

COHPAC can be either installed in a separate casing (COHPAC I) located after the ESP, or within the last 1-2 fields of the ESP casing (COHPAC II).

COHPAC Experience

To date, the COHPAC technology has been utilized on over 1,700 MW of combustion type applications. This experience base includes a total of four (4) coal-fired boilers and two (2) refuse fired combustors. All of these installations were designed to operate at filtration rates of 2 - 3 times higher than normal air-to-cloth ratios. These higher filtration rates provide many advantages over normal ratios, including lower capital cost and reduced real estate requirements.

While the type of pulse jet cleaning technology is not the most critical factor to success, a pulse cleaning system must have the inherent ability to be able to effectively clean long filter bags while utilizing on-line filter cleaning and still be able to maintain reasonable pressure drops and deliver acceptable bag life. Typically, this can only be accomplished with either low pressure (0.62 to 1.03 bars/9 to 15 psi) or medium pressure (2.1 to 4.1 bars/30 to 60 psi) type pulse jet designs.

While a normal gross (all cells in service) air-to-cloth ratio for pulse jet collectors ranges from 0.015 to 0.02 m/s (3 to 4 fpm), with the use of COHPAC, the filtration rates can be increased anywhere from 0.03 to 0.06 m/s (6 to 12 fpm) and higher with minimal increase in pressure drops depending upon the application and the existing ESP outlet dust loadings. This higher filtration rate as discussed earlier can offer the end-user significant savings in capital cost over other ESP enhancements or replacement. Some excellent examples of the use of this unique technology are as follows:

Big Brown Station COHPAC Installation
(Courtesy of HR-C)

TU Electric, Big Brown Station, Units #1 and #2

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Big Brown Station consists of two (2), 600 MW pc fired, super critical type, lignite coal-fired boilers located about 90 miles south of Dallas, Texas. These units originally had small (156 SCA) weighted wire ESP's installed primarily to protect the ID fans from excessive erosion by maintaining the stack opacity levels below 40%. As the emission regulations in Texas were tightened and the opacity levels were reduced to 30%, SO_3 and ammonia gas conditioning systems were added to the system to help in the reduction of resistivity levels in the ash being collected. With the anticipation of further opacity reductions to 20%, the decision was made to install COHPAC collectors in series with the existing ESPs. Full system start-up occurred on Unit #1 in May, 1996 and Unit #2 in November, 1995.

Each 600 MW boiler is equipped with a total of four (4) COHPAC pulse jet casings, each having eight individual compartments. The current filter bags are a nominal 6.1 grams/m2 (18 oz./yd2) PPS (Ryton) felt fabric, 312 bags/compartment, 6.1 meters (20 feet) in length. This equates to 2,496 bags/fabric filter casing or 9,984 bags per boiler with nearly 20,000 total bags installed.

Being the first commercial COHPAC installation installed on a coal-fired boiler, the air-to-cloth ratios utilized were fairly high in comparison to today's, more modern designs. Even though this installation utilizes off-line cleaning, filtration rates were as high as 0.07 m/s (13.5 fpm) on a net basis with one compartment isolated for cleaning. This coupled with the high inlet ash loadings generated by the poor quality lignite fuel, and the small primary ESP collectors, proved to be a more difficult installation than first anticipated.

While emission levels remained low with stack opacity levels maintained at less than 5%, reduced bag life was soon identified as an issue, primarily due to high flue gas operating temperatures and higher pulse frequencies than originally anticipated. Additionally, the SO_3/ammonia flue gas conditioning system may also have contributed to weakening of the fabric, especially during frequent low load operation and sub-dew point operation. Bags typically lasted from 12 to 18 months before being replaced.

Regardless of these initial operating difficulties, COHPAC now provides TU Electric with low stack emission levels, over two years bag life and flange-to-flange pressure drops in the range of 1.75 to 2.0 kPA (7 to 8 in. w.c.). This successful installation has proven itself to be the lowest cost of all technologies evaluated and has provided TU with consistent environmental performance. In an attempt to further improve the long-term bag life, new fabrics and fabric construction are constantly being evaluated. The most promising to date being a high permeability PPS fabric, constructed out of larger 6 denier fibers vs. the more typical 2.7 denier size. Preliminary indications are that a stronger fabric can be produced that potentially offers longer life and lower tube sheet pressure drop. Full scale testing is currently under way and holds much promise for future COHPAC installations

Alabama Power, E.C. Gaston Station, Units #2 and #3.

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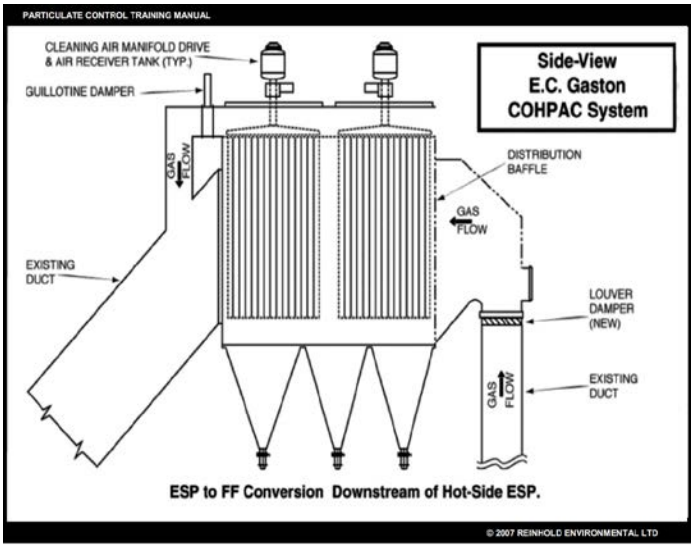
Alabama Power Company's (APCO), E.C Gaston Power Station consists of hot side electrostatic precipitators installed on all five PC fired boilers. With the fuels being fired and the nature of hot side ESP's, consistent environmental compliance under full-load operating conditions has proven to be difficult. During peak summer load operation, there were many days when load reductions were required to remain in compliance and to avoid opacity excursions above 20% permitted levels. To remain in compliance, the use of sodium additives in the boilers, were required to maintain ash resistivity in acceptable ranges for the ESP's. Additionally, the ESP's required frequent water washing of the plates and the boilers were limited in the type and number of coals able to be fired.

These system limitations prompted Alabama Power to evaluate the use of COHPAC technology at the Gaston facility. To ensure success at their facility, Wallis Harrison of Southern Company Services with support from Alabama Power and EPRI initiated a 1-MW size pilot test program at their Miller Steam Plant to examine the applicability of COHPAC on the type of Eastern Bituminous coals being fired at their Gaston facility.



E.C. Gaston COHPAC I Installation
(Courtesy of HR-C)

The success of this test program prompted APCO to install COHPAC on Unit #3 at Gaston, with the first system started up in December 1996. Due to a very congested site with little, if any open space for this installation, it was decided to convert an abandoned, cold side ESP casing which was located under the existing hot side ESP and being utilized as a section of ductwork. Approximately 12 feet (3.7 meters) was added to the existing casing and the hoppers (which had been removed earlier) were re-installed with as much of the existing casing and ductwork re-used as possible. The existing fans were also upgraded with new wheels and motors to compensate for the additional static pressure.

A total of four (4) compartments were installed per boiler with two (2) independent compartments per air-heater. A total of 1,088 PPS (Ryton) felt bags are installed in each compartment, 7.3 meters (23 feet) in length x 4 compartments = 4,352 total bags. The COHPAC

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system operates at a gross air-to-cloth ratio of 0.043 m/s (8.5 fpm) utilizing online cleaning.

This installation proved to be so successful that an additional unit was installed on Unit #2 and started up in June, 1999. Since startup, emission levels have consistently been maintained below the guarantee levels of 5% with typical levels of 1-2% at the COHPAC outlets. Pressure drops are typically maintained at levels less than 1.87 kPA (7.5" W.C.) across the system and bag life has reached 4 years.

In late fall 2000, the front bag bundles (50% of the bags) in both Unit #3 pulse jet casings were removed due to failures caused by erosion at the bottom of the bags. This appears to have been caused by localized high velocity zones at the bottom of the bags at the top of the first hopper in the section of the old ESP, which was converted to the COHPAC casing. While not all the bags appeared damaged, it was decided to remove all the bags in the front bundles and keep the remaining bags in service as they still show high fabric strengths and acceptable permeability.

Unit #3 COHPAC Installation, Front View
(Courtesy of HR-C)

Complete operation of both units, are monitored via a remote monitoring system that allows users to look at both real time and long-term trend operation. Unit #2 has a blended stack discharge with Unit #1 and Unit #3 has a shared stack discharge with Unit #4. With this arrangement, a 20% average opacity must be maintained out of the stack discharge at all times.

For E.C. Gaston, the installation of the COHPAC units has provided enhanced operation of the power plant. Since the initial operation of the COHPAC, more coals are available to be burned at the plant. Over 13 coals can now be fired with little if any impact to the system operation while still maintaining stack opacity levels below the required 20%. Additionally, the use of sodium additives to the coal has been discontinued for all four boilers since the COHPAC units have been placed into operation. Overall O&M costs have been low and the ability to required performance levels have remained high.

American Re-Fuel, SEMASS Station, Units #1 and #2

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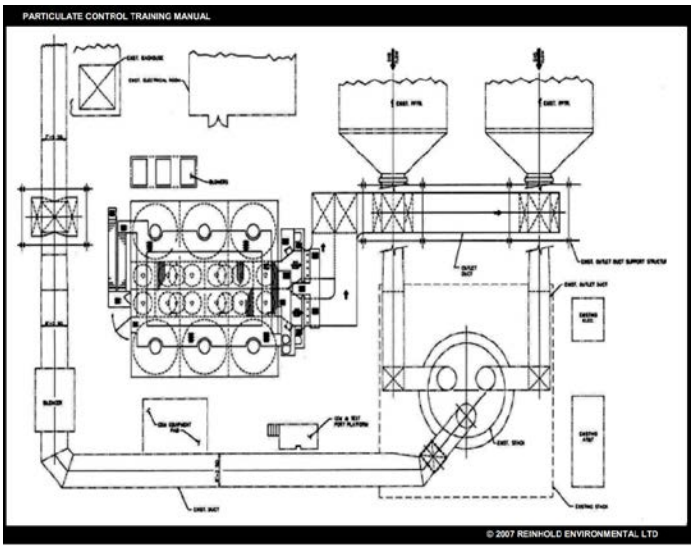
In an attempt to meet the expected reduced emission levels (MACT Standards) for refuse fired combustors in the State of Massachusetts, after evaluating several alternatives, including enlarging the existing electrostatic precipitators or installing new, full-size pulse jet fabric filters, SEMASS decided to install COHPAC fabric filter technology after conducting a successful, 1-MW pilot plant demonstration on Unit #1 at their facility.

SEMASS Pilot Plant Facility
(Courtesy of HR-C)

COHPAC has provided SEMASS with a low cost approach to meet the new MACT standards at their existing facility for particulate and also for mercury, lead, cadmium, dioxins and furans. The existing facility incorporates the use of a rotary atomizer type DFGD system followed by an electrostatic precipitator. The COHPAC fabric filter is located after the ESP before going into the existing stack. In addition to total particulates, one of the primary reasons for the installation of COHPAC at this facility was to remove air toxics. With this in mind, a more conservative approach was chosen in comparison to normal coal-fired COHPAC facilities.



SEMASS System Arrangement
(Courtesy of HR-C)

The installation consists of a three (3), compartment COHPAC fabric filter system/boiler, with 608 x 7.62 meters (25 foot) long, P-84/PPS composite bags per compartment. With the new MACT standards in mind, conservative filtration rates of only 0.03 m/s (6 fpm) were selected as the gross air-to-cloth ratios. On-Line cleaning was once again utilized for this installation. With one compartment isolated for maintenance, the A/C ratios increase to as high as 0.048 m/s (9.5 fpm) at full load operation due to the small number of available compartments per boiler.

With the installation of the COHPAC technology at SEMASS since June 2000, the Plant has

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been able to meet all revised MACT standards required by the State. With the addition of an activated carbon injection system, mercury reduction levels exceeding 96% have been demonstrated. Stack opacity levels are maintained below 3% and no opacity excursions have been observed. In the past, especially during the summer months, due to the uncertainty of the fuels burned in a mass combustor, opacity excursions have forced load reductions and loss of income. This past summer has been the first summer where this has not occurred, even though several ESP upsets had occurred due to poor fuels.

Additional COHPAC Applications

The COHPAC approach to particulate emission control has been utilized in the past on other, combustion and non-combustion applications. While these installations have been designed utilizing more conventional filtration rates, nevertheless, pulse jet fabric filters have been installed downstream of electrostatic precipitators serving as the final polishing device on a wide range of industrial applications in many parts of the world.

Some of these installations have include:

- Refuse Fired Boilers
- Sinter Plant
- Cement Kilns

Basically, any application that has an existing electrostatic precipitator and the operating temperatures are within the range of conventional fabrics are candidates for the use of the COHPAC technology to enhance its operation.

Sinter Plant

. The installation shown in **Figure:**

DFGD ESP PJ System in Sinter Plant in Germany

was installed in 1998 on a sinter plant in Germany. This facility utilizes a medium pressure, pulsejet cleaning design with on-line cleaning and 6.7 meters (22 feet) bag lengths. While originally equipped with an electrostatic precipitator, a tightening of the emission standards forced the facility to install a semi-dry flue gas scrubber system in addition to a

DFGD/ESP/PJ System on Sinter Plant in Germany
(Courtesy of HR-C)

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final polishing type fabric filter system located downstream of the existing ESP. This scrubber and polishing fabric filter allowed the facility to meet all required emission standards with a minimal required outage time. The conventional filtration rates are maintained below 0.02 m/s (4 fpm).

Cement Applications

The concept of COHPAC II, while at this time not commercially demonstrated on a coal-fired boiler system, has also been successfully incorporated on two cement kilns located in Canada. These dry process kilns originally had ESP's installed and in the early 90's were partially retrofitted into pulse jet collectors in the back-end of the ESP casing. Conventional air-to-cloth ratios were also utilized on this installation, which utilized woven fiberglass fabric with a PTFE membrane finish.

Recently, the installation of a COHPAC pulse jet system on a wet process cement kiln located in the North Eastern part of the United States has been proposed. This installation if approved will be the first true application of COHPAC on a cement kiln operating at elevated filtration rates. The existing ESP is in good operating condition and the COHPAC system will help prevent opacity excursions during kiln upsets and when first starting up the ESP's. This installation will consist of a four compartment, pulse-jet, utilizing a medium pressure pulse cleaning technology with 6 meter bags and conservative gross air-to-cloth ratios of approximately 0.03m/s (6.5 fpm) due to the potential high ESP outlet loading. On-line cleaning will also be utilized for this installation.

Mercury Reduction Technology

As demonstrated at the SEMASS waste-to-energy facility, the use of COHPAC in the control of air toxics, such as mercury emissions, has been successfully demonstrated. This same technique has also been demonstrated on a pilot scale at several coal-fired boiler installations. Mercury reductions of greater than 90% can be achieved with the use of Powdered Activated Carbons (PAC) additives.

To further demonstrate its effectiveness as a cost effective means to control mercury emissions on large coal-fired boilers, under a DOE sponsored test program, Alabama Power will host a full-scale demonstration program for mercury reduction at their E.C. Gaston Steam Plant in early 2001. In addition to Alabama Power, Hamon Research-Cottrell and EPRI are also co-sponsors of this full-scale demonstration. This program will be conducted on Unit #3 utilizing the COHPAC fabric filter system in addition to a dry sorbent (Toxicon) injection system. The evaluation will be conducted on 50% of the gas stream, which equates to a nominal, 125 MW facility. Gaston Station is one of four other sites in the U.S. that will be evaluating mercury reduction techniques under a $6.7 million grant, awarded to ADA-ES out of Littleton, Colorado. The three other sites all will utilize existing electrostatic precipitators along with some type of sorbent additives.

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Gaston Unit #3 was chosen for this evaluation because COHPAC represents a cost-effective retrofit option for utilities with existing electrostatic precipitators (ESP's). The benefits over ESP's for mercury reduction are believed to be as follows:

- The total sorbents are mixed with a very small amount of ash, which greatly reduces the impact on ash reuse and disposal. If existing ESP ash is being sold, this would not be impacted, nor contaminated by the introduction of agents such as activated carbon.
- Pilot plant testing has determined that a much smaller amount of carbon is required with fabric filters and COHPAC systems in comparison to ESP's by as much as 1/10 the total sorbent to achieve similar mercury reductions.
- The capital cost for COHPAC is less than many other options such as the total replacement of the ESP with a full-size fabric filter or electrostatic precipitator, and in many cases even a larger ESP.

Conclusion

The use of COHPAC technology has been successfully utilized on both coal-fired boilers and waste-to-energy combustors. The addition of COHPAC has allowed many facilities to meet current and future emission control requirements. Emission levels have remained low and bag life has exceeded 4 years to date. Additionally, the use of COHPAC type technology on other, non-combustion type applications, has been demonstrated, although while utilizing more conventional filtration rates.

The use of dry additives such as Powdered Activated Carbon (PAC) in combination with COHPAC, also known as "Toxicon", has been demonstrated to achieve high mercury reduction levels on both coal-fired and waste-toenergy combustors. A full-scale demonstration of mercury reduction utilizing COHPAC technology on a coal-fired boiler will soon be demonstrated at Alabama Power, E.C. Gaston Station COHPAC installation.

COHPAC has proven itself to be an effective pollution control device for both particulates and gaseous pollutants. It is truly a multi-pollutant control technology.

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5.4 Pulse Energization

Brief History of Pulse Energization in the United States

Full pulse energization, a pulse superimposed upon DC voltage, is totally different from intermittent energization (IE), usually a DC voltage pulsed. Although pulsing has been investigated for the last 66 years, it has never been accepted by the U.S. utilities. In most cases, pulsing systems have been installed on poorly operating ESPs or poorly operating pulsers have been installed or both. In the past, pulse energization has been mainly designed for enhancement or to reduce size requirements for new ESPs. It has been successfully installed throughout the world industrially and on limited fly ash applications. In general, it has been the cost of the power supplies that has limited the technology.

Pulse energization was explored as far back as 1931, at which time R. Heinrich applied for a U.S. patent. Much of the present techniques are based on radar modular work with which, Harry White and Herb Hall were associated at Radiation Lab., MIT, as early as 1941.

In 1952, White and Hall applied the pulse voltage with about 100 to 150 microseconds duration and 60 Hz frequency to a conventional wire-plate type ESP. This was the first full-scale test done on pulsing. The pulses were applied by the action of a rotary spark gap, or hydrogen thyristor switch, a pulse transformer, and blocking diode, which prevented the current from flowing back to the pulse generator. The voltage had a relatively fast rise time in the order of 50 microseconds and a somewhat slower decay. White achieved higher voltages and currents at the same degree of sparking as well as improved precipitator efficiency.

Dr. Senichi Masuda of Japan furthered pulsing technology in 1976. He added a DC bias-voltage in series to the pulse voltage. The bias voltage enabled the use of half-wave AC voltage for

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corona creation. Masuda went on to develop a unique pulse energization system named "Boxer Charger". The system operates as a precharger to an ESP.

In the U.S. several pulse energization systems have been installed with limited success. The following are some details of a few of those installations.

1) EPRI - Arapahoe: SRI was contracted by EPRI to investigate narrow pulses with a fast risetime (such as Ion Physics or Masuda's pulsers) to long pulses (such as GEESI and FLS pulsers).

2) GEESI conducted tests at Rochester Gas & Electric. In 1982 they contracted Brown Boveri (now the BB in ABB) to develop an optimized pulser system. A demonstration of GEESI's new mobile pulser system was conducted at two ESKOM sites in South Africa: Rooiwal Power Station and Hendrina Station. The results of the three-year tests were not conclusive. ESKOM installed SO_3 flue gas conditioning instead of pulse energization.

GEESI then brought their mobile unit back to the U.S. For those at the EPRI Hot side Workshop in Birmingham in 1986, you might remember the GEESI trailer in the parking lot. This unit was tested on Wisconsin Power & Light's Columbia Station Unit 2 hot side ESP, Wisconsin Public Services's Pulliam Station Unit #8 and #8A cold side ESP and finally installed on NSP's Black Dog Station, Unit #2, a 130 MW converted atmospheric fluidized bed application.

A total of five GEESI pulsers were installed at Black Dog. Their performance was good until the fluidize bed was changed from inert to active limestone. The increased loading and marginal ESPs were too much for the pulsing system.

3) Early in the 1970's Ion Physics (IPC) and R-C made a joint agreement. Ion Physics would develop a pulsing system and R-C would market it. The first full scale installation for IPC/R-C was on a pulp & paper ESP. Following this installation, CPL's Sutton Station was equipped with pulse energization as part of a two phase upgrade.

The installation was completed in March 1980. R-C had agreed to improve Sutton Station to 99.3% efficiency. They felt that the ESP rebuild would achieve 97% efficiency and then pulsing could do the rest. When the system came online using Marrow Bone coal, 89% efficiency was the best that could be achieved without pulsing. The pulsers were unable to improve the efficiency from 89% to 99.3%. Following this period, cables began to fail in the system. The system was overridden to find the problem for about 10 minutes. The problem was unable to be found. The system was overridden again. A cable fire resulted. Thus ended pulsing at Sutton Station.

4) EPRI - Lansing Smith Plant, Gulf Power (1980): EPRI designed a series of tests to compare narrow and broad pulse energization. They used the GEESI pulser (broad pulsing) and the Ion Physics pulsers (narrow pulsing). The Lansing Smith ESP was a hot side. Because of many disruptions in the testing and uncontrollable conditions, the test results were questionable. But the test was note worthy for one reason, it perhaps did the most damage to the reputation of

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pulsing in the U.S. of any other test.

5) In the early 1980's, Lucidyne installed one of the few pulsers to operate continuously on a power plant in the U.S. The pulsers were placed on NIPSCO's Schahfer Station, Unit #14. Soon after installation, Lucidyne discontinued operations (1986) leaving the maintenance of the pulsers to NIPSCO. These lumbering giants were used until NIPSCO's hot-to-cold side conversion in the mid-90's.

6) In the 90's, Ion Physics systems have been installed in two other utilities. Rochester Gas & Electric and Madison Gas & Electric. Eventually the former removed the units, while the later, a cycling unit still operates its systems.

Theory

The electric current from the ESP discharge electrodes traverses the space between the electrodes in the form of electrons, ions and electrically charged dust particles. When reaching the collecting electrode the current must penetrate the precipitated dust layer. The current then builds up an electric field in the layer:

$E = \rho * j$

where E = field strength, volts/meter

ρ= dust resistivity, ohm*meter

j = current density, amps/m2

When E reaches a certain maximum value, say Ec, the dielectric strength of the dust layer is exceeded, an electric breakdown called back-corona occurs. The back-corona causes reverse charging of the dust and/or initiates sparking. It is very detrimental to the ESP performance. If the dust resistivity ρis high then the current density j must be kept correspondingly low.

Let's look at a discharge electrode, e.g. an RDE with many sharp protrusions for corona generation. If you slowly increase the applied DC voltage, suddenly the sharpest point lights up with a corona glow. As you increase the voltage more points are lit up. Finally all points are lit up more or less. Now, in those cases where we must decrease the current density because of high dust resistivity you may run into a situation where only the sharpest points are lit, the rest are dead. Parts of the collecting area in front of the sharpest points have a current density where back-corona is about to occur. Parts of the area in front of the dead points receive no current at all. The current distribution on the collecting electrode has been destroyed. This is obviously a detrimental situation for the ESP.

The electric charges accumulating on the dust layer before leaking through constitute a

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capacitance. For common high resistivity ashes the dust layer time constant, resistivity times capacitance, is longer than a second. Therefore the layer does not react to current variations shorter than a second. You are allowed to apply a small average amount of "DC" in the form of short larger bursts as long as the burst frequency is not too small. The large bursts of current allow for all points to light up even when the average current (the current you read on the meter) is very small.

Intermittent Energization

Long ago it was found that half-wave rectifiers sometimes gave better result than normal full-wave. Understand that the fewer (and larger) half-waves improved the current distribution. Now the modern microprocessor controlled T/Rs allow us to apply even fewer half-waves. To avoid DC magnetization of the transformer it is practical to let the thyristor remove an even number of half-waves. You can set the controller to fire only each 3rd, 5th, 7th, 9th....half-wave. This intermittent energization has given dramatic improvements in many high-resistivity applications where you are forced to reduce the operating current level. In other applications you do not expect great improvements, but intermittent energization can be used as a method of energy conservation.

Full Pulsing

By feeding very large but very short electric pulses (in the micrisecond range) to the discharge electrodes it is possible to improve the charging of dust particles witout giving time for a spark to develop. The technique is similar to that used for the ignition system in automobiles. To avoid magnetic losses in the transformer core the pulse transformer must be of a very special design. This leads to an extremely high price for a microsecond-pulse unit. Intermittant energization is obtained at the very moderate cost of some additional software. Since experience has shown that the result is nearly the same as that of full pulsing very few such units are sold today.

5.5 Flow Distribution

Uniform Flow

For many years, precipitator vendors, users and consultants, targeted uniform gas flow in the precipitator as an objective. The trade association of vendors published criteria regarding uniform gas flow in scale model studies and in actual field installations. A look at the fundamental equations governing precipitation would lead to that conclusion.

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In many cases, a relatively uniform gas flow is a worthwhile objective. It is definitely worthwhile to eliminate local high velocity zones (jets). As the techniques of mathematical modeling improved, some questions regarding the desirability of absolutely uniform flow began to emerge. In any case, uniform flow with all velocities approaching the average, and the elimination of high velocity areas is certainly a desirable objective and is a target pursued by a majority of precipitator technologists.

Skewed Flow

Often at precipitator velocities and with certain inlet flue arrangements, the concentration of particulate matter is substantially higher in the lower portions of the inlet flue. This is caused by a number of factors:

The coarser dust is more or less in the Stokes Law region, and gravity settling will occur, especially on coarser material.

Some flue configurations, especially those with top inlets, cause internal separation of the coarser material, which tends to concentrate at the bottom of the inlet flue and precipitator.

All the fly ash collected must pass through the bottom portion of the precipitator to get to the hopper. This raises the fly ash concentration in the gas at the bottom of the precipitator. Designs with large fields and limited bottom baffling are prone to this.

The finer material collected tends to agglomerate to larger particles and become subject to Stokes Law.

Fly ash re-entrainment from rapping and from hopper sweepage will tend to appear in the bottom of the precipitator, especially in bottom-rapped units with limited electrical sectionalization.

All of these factors suggest that lower gas velocities at the bottom of the precipitator should produce higher precipitator efficiency and a lower mass emission. This tendency would be more pronounced with coarser fly ash, high hopper sweepage, strong agglomeration affinity for the ash and certain flue configurations. The tendency should be less for fine, non-agglomerating fly ash and straight-in or bottom-inlet flues.

Finally, opacity is principally a function of the 0.6 to 1.7 micron fraction of the fly ash. Since this material is not subject to Stokes Law or inertial separation, skewing the flow to the top should have little or even a slight negative impact on the stack opacity, unless there is a substantial agglomerating tendency.

In summary, adoption of skewed flow may be of substantial use in improving precipitators in certain circumstances

- where there is a substantial portion of coarse material,

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- where bottom rapping with no possibility of adjusting the rapping intensity is available, and
- where long electrical fields with no possibility of extensive anti-gas sneakage baffling exists.

These conditions will probably improve high efficiency precipitators. On the other hand, with adjustable rapping intensity on with many short sections in series with extensive anti-sneak baffling and little hopper sweepage skewed flow will be of little or no benefit in improving performance. In this latter case, the uniform flow should be the objective.

Distribution Among Separate ESPs

Where a multiplicity of individual precipitators or precipitator chambers are arranged in parallel, equalizing the gas flow between these separate gas paths is of substantial importance. Examination of the Deutsch Equation applied to multiple gas paths will quickly demonstrate this fact.

Obtaining equal flow in these multiple gas paths without imposing substantial pressure drop on the system is a challenge to design engineers. Scale models are extremely useful in dealing with this problem, but we must caution that solutions developed with these models should always be field verified.

The use of vanes, preferably adjustable, is always preferred to the introduction of additional pressure drop through perforated plates, egg crates and channel strips, which not only cause pressure loss but are subject to plugging with fly ash. When the final adjustment to moveable vanes is made, they can be welded in place.

5.6 Temperature Distribution

Because of the shape of a typical fly ash resistivity curve, good equal temperature distribution of the gases entering a precipitator is of prime importance in obtaining optimum performance.

With the use of regenerative air heaters such as the Ljungstrom and Rothemuller, it is extremely difficult to obtain good temperature distribution. This is magnified by the large sizes of units and larger diameter air heaters and further complicated by the use of high moisture coals and the introduction of the trisector air heater to provide hotter primary air.

In extreme case of units above 700 MW with two trisector air heaters, there can be side-to-side temperature differentials in excess of 100°F (56°C). This places one side of the precipitator in a high resistivity area where power input is severely limited and the other side in a very low resistivity, high corrosion potential area. In one case like this, the specific current (current density) on one side of the precipitator was in the area of 7 microamps/ft2 (10.9 nA/cm2) and the other side at 60 microamps/ft2 (93 nA/cm2). Obviously the precipitator performed poorly.

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In dealing with these problems, radical and expensive solutions are often necessary. In a number of cases, cross ducting was employed to mix hot and cold gases. The use of economizer bypasses has been employed to raise the temperature of a portion of the gas entering and leaving the air heater. Air heater rotation speed has been altered. In a few cases, additional heating surface has been added to portions of the boiler.

This is a difficult and continuing problem, and the solution must be arrived at on a case by case method. Separate air heaters from primary and secondary air tend to reduce the problem. Use of different baskets such as dense pack or the use of different packing depths in the separate air heaters can then be employed to further mitigate the problem.

Substantial flue runs between the air heater and precipitator can be used to mitigate the problem.

Horizontal and vertical shaft air heaters also provide problems of both horizontal and vertical temperature differentials.

These difficult problems can best be solved by joint meetings of the air heater & precipitator vendors, the owner and his consultant.

5.7 Particle Size Distribution

The fundamental equation for migration velocity derived by H. J. White has a term "a" - the particle radius in the numerator. This means that the particle migration velocity or the particle collecting rate is directly proportional to the particle size.

The Matts Modification to the Deutsch Equation by using the additional exponent tries to take this particle size into effect.

In any case, it is well established that large particles are easier to collect than small particles (different mechanisms are involved with particles under a micron).

A further complication may present itself in the case of substantial concentrations of small particles. This is space charge, which limits current flow and distorts fields. Space charge problems are dealt with by adjusting electrode spacing and discharge electrode design.

Because the wavelength of visible light is in the range of 0.7 to 1.7 microns, particle sizes in this range have a profound effect on opacity. Particles above 5 microns and below 0.7 micron have almost no effect on opacity.

Mass emissions are of course an entirely different problem, since large particles have a profound effect on mass emissions. This explains why often there is no problem in meeting one standard (say mass emissions) and failing another (opacity) and visa versa.

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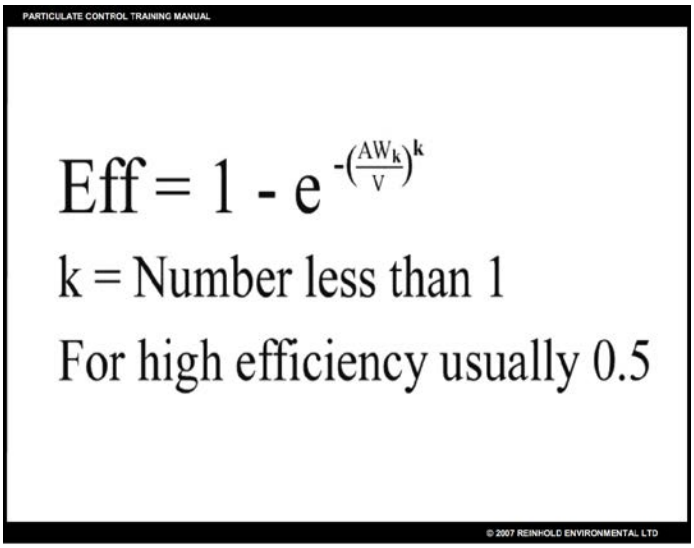
Careful attention to coal mills, adjustment of classifiers and distribution of coal in burner pipes can have effects on particle size and therefore on precipitator performance. This, plus the use of low NOx burners especially in single wall or roof-fired units can greatly effect mass emissions.

Aside from the effects noted above, there is little that can be done about particle size in the gases arriving at the precipitator.

As always with a precipitator, uniformity of particle distribution is desirable and everything that can be done to provide uniform conditions without wide variations is usually helpful.



Matts Modification to the Deutsch Equation

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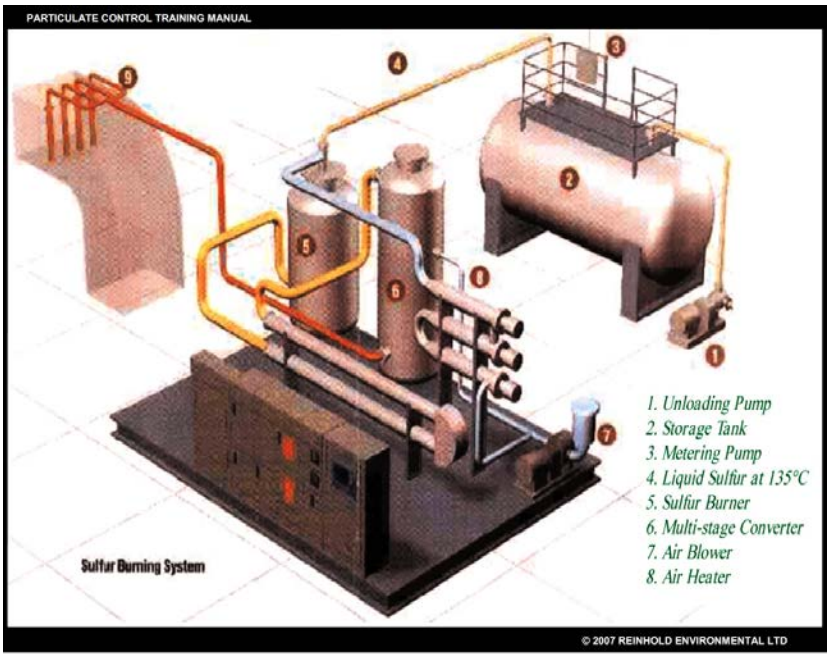
CHAPTER 6 - FLUE GAS CONDITIONING

This chapter discusses the principles of flue gas conditioning, including:

- *SO_3 Conditioning*
- *NH_3 Conditioning*
- *Dual Conditioning (SO_3 and NH_3)*
- *Humidification*
- *Chemical Additives*

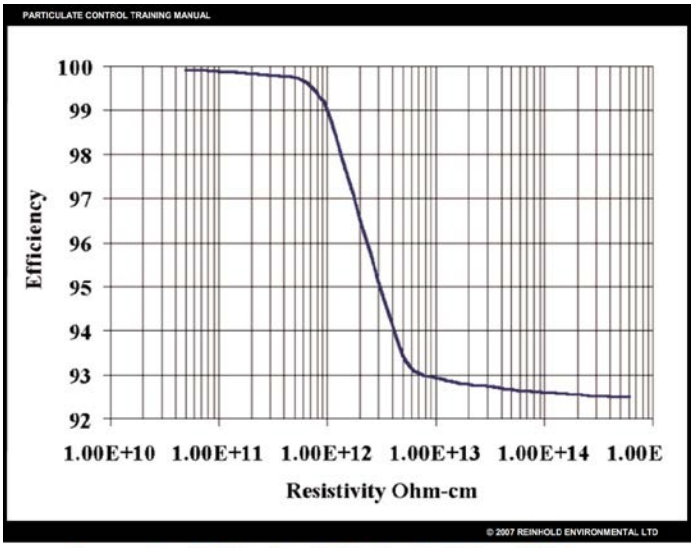


Typical Sulfur Burning FGC System
Courtesy of Chemithon Corp.

6.1 SO3 Conditioning

Theory and Application

The term "Flue Gas Conditioning" (FGC) is somewhat misleading as most of the applications involve modification of the flue gas particulate properties. These are ash resistivity, ash cohesivity and to some degree ash particle size.



Approximate Electrostatic Precipitator Efficiency vs. Ash Resitivity (SCA~325)
Courtesy of Chemithon Corp.

The history of flue gas conditioning dates back almost as far as the first electrostatic precipitator does. As early as 1912, experimental work at the Garfield, Utah smelter indicated that increasing levels of SO_3 in smelter converter gases increased the collection efficiency of the ESP. The work demonstrated that many non-conductive dusts and fumes could be made collectable by adding SO_3 and/or moisture to the gas stream ahead of the ESP.

Since that time, many other substances

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have been used to condition flue gases. These include: ammonia, triethylamine, and various proprietary chemicals. SO_3 is still the predominate conditioning agent for high resistivity ash.

Electrostatic Precipitator particulate removal efficiency is in large part dependent upon the ability of the collected particulate matter to accept and release an electric charge. This characteristic of the particulate is generally referred to as the "ash resistivity". Optimum particulate resistivity is generally in the range of 5.0E+9 to 5.0E+10 ohm-cm. (See **Figure:**

Approximate ESP Efficiency vs. Ash Resistivity

). Ash resistivity below the optimum range results in good charging of the ash and high field current densities but since the charged particles easily release the charge on the precipitator collecting plates the ash has a low holding force. This causes excessive re-entrainment of the collected ash and makes it difficult to get the collected ash into the hoppers. This can be a major problem if the precipitator is small with high gas velocities.

High resistivity ash is difficult to charge and when charged may not release the charge at the collecting plate. This inability to release the charge can cause difficulty in removing the ash from the collecting plate resulting in an insulating layer of material on the collecting plate and leading to a situation referred to as "back corona". In back corona the material on the collecting plate releases the charge into the gas passage instead of the collecting plate which dramatically lowers the field voltage and reduces further charging of the inter electrode particles. Precipitators designed to collect very high resistivity ash often are several times as large as units, which collect ash of optimum resistivity. There are many other factors that can affect the precipitator collection efficiency some of which are: the ash particle size, the effectiveness of the rapping, the degree of precipitator sectionalization, the ash cohesivity, and the gas and particle distribution.

Frequently when utility boilers switch from high sulfur coal to medium or low sulfur coal, high resistivity ash will result and precipitator performance degrades to an unacceptable level. It has been known since the early days of electrostatic precipitation that some of the sulfur in the coal is converted to sulfur trioxide, which reacts with the moisture in the flue gas to form a sulfuric acid mist. This sulfuric acid mist is absorbed or condensed on the surface of the ash and lowers its resistivity by improving the surface conduction of the ash. Generally only a small portion of the coal sulfur is converted to sulfur trioxide and as the sulfur in the coal decreases the amount of sulfur trioxide decreases.

In many cases flue gas conditioning with sulfur trioxide is a cost effective means to adjust the ash resistivity to an optimum value. Small quantities of sulfur trioxide usually in the range of 2 ppm to 18 ppm are injected into the flue gas ahead of the precipitator. This process has been installed on hundreds of units worldwide.

Fly Ash Resistivity

Fly ash resistivity is a function of the composition of the ash, the gas temperature, and the flue

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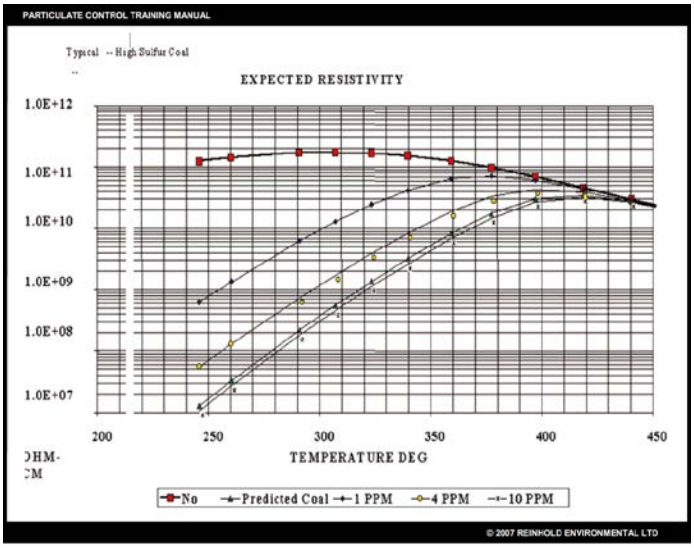
gas composition. The bulk ash resistivity is composed of two components: The surface conductivity of the ash and the volume conductivity. At low gas temperatures the surface conductivity has the greatest impact on the bulk resistivity and at higher temperatures the volume conductivity has the most effect.

Gas moisture and small amounts of sulfuric acid condense on the fly ash at temperatures below about 400°F (204°C) to improve surface conductivity. However, SO_3 conditioning is most effective when the flue gas is in the 270°F to 320°F (165°C) range. Sulfur in the coal burns in the boiler to form sulfur dioxide, of which, a small part converts to sulfur trioxide. How much of the sulfur dioxide that converts to sulfur trioxide is variable and not well understood, but generally coal with more than 1.5% sulfur produces enough sulfur trioxide in the boiler to adequately condition the fly ash. Average conversion to sulfur trioxide is 0.4% but this can range from 0.15% to over 1%.

The volume component of the ash resistivity is determined by the mineral composition of the fly ash. High concentrations of compounds such as silica and alumina contribute to high resistivity and metallic elements such as sodium and potassium improve the conductivity.

Bickelhaupt and Sparks developed a mathematical model to approximate fly ash resistivity based on the coal "ultimate" analysis and fly ash elemental analysis. Subsequently the model has been converted into various computer programs, which can generate plots of ash resistivity versus temperature for various sulfur trioxide "equilibrium" concentrations. The model was designed to replicate the results of laboratory resistivity testing for U.S. coals in which the resistivity of ash samples were measured in a test cell contained in an oven with an "equilibrium" concentration of sulfur trioxide. **Figure:**



Typical High Sulfur Coal Ash Resistivity
Courtesy of Chemithon Corp.

Typical High Sulfur Coal Ash Resistivity

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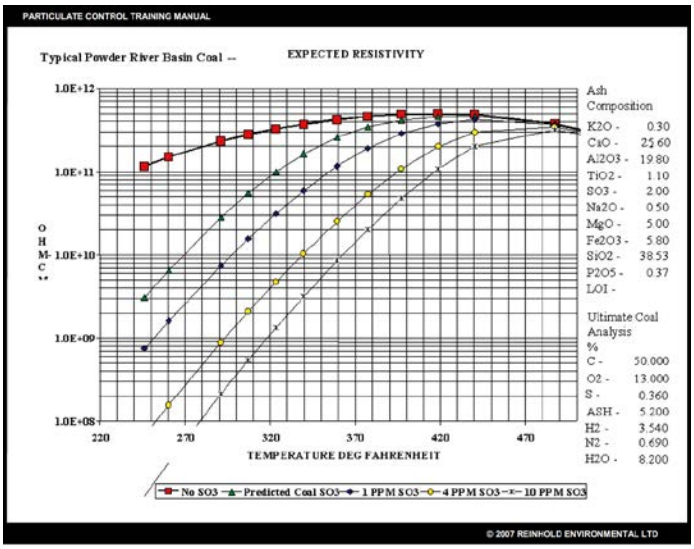
illustrates the ash resistivity of a typical high sulfur coal.

The curves indicate that at a typical precipitator inlet temperature of 320°F (160°C) the sulfur trioxide adjusted ash resistivity should be near an optimum value of about 2.0E+9 ohm-cm. However, it should be noted that if less of the coal sulfur is converted in the boiler to sulfur trioxide than the model predicted, than the ash resistivity could be considerably higher.

The resistivity curves in **Figure:**

Powder River Basin Coal Ash Resistivity

are for a typical "Powder River Basin" (PRB) coal. The expected ash resistivity for the "PRB" ash at 320°F (160°C) is about 1E+11 ohm-cm. To achieve an optimum resistivity of less than 5E+10 ohmcm a sulfur trioxide equilibrium concentration of about 1 ppm is required. As stated previously this is the required gas concentration in equilibrium with the ash. In a sense values above this concentration could be considered the sulfur trioxide slip. To achieve this concentration a quantity of sulfur trioxide can be injected into the flue gas. As a general rule fly ash is well conditioned when the sulfuric acid concentration in the ash is about 0.5%. For most ash typical injection rates are usually less than 15 ppm of sulfur trioxide. Since most electrostatic precipitators have multiple fields, and the optimum resistivity is usually not required at all fields, the sulfur trioxide slip up the stack from sulfur trioxide injection is usually less than 2 ppm.



Powder River Basin Coal Ash Resistivity
Courtesy of Chemithon Corp.

Sulfur Trioxide FGC

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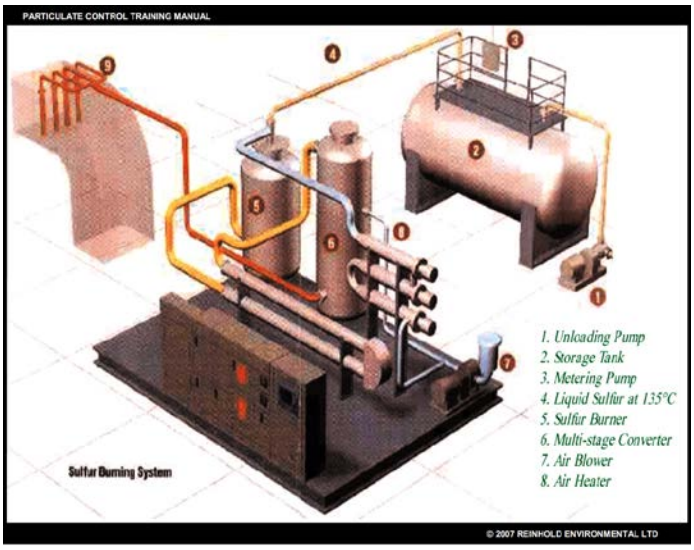
Sulfur trioxide is the most common type of flue gas conditioning with over 600 installations worldwide. The earliest systems, which were installed in the early 70's were liquid sulfur trioxide or sulfuric acid vaporizing systems. Subsequent systems employed sulfur dioxide feedstocks with catalytic conversion to sulfur trioxide. Nearly all of the modern systems burn elemental sulfur and convert the sulfur dioxide catalytically to sulfur trioxide. These systems are safer, use inexpensive feedstocks, and have low energy consumption.

Figure:

Typical Sulfur Burning FGC System



Typical Sulfur Burning FGC System
Courtesy of Chemithon Corp.

illustrates a typical sulfur burning FGC system. The basic process is as follows: Molten sulfur is stored in an insulated steam heated tank or pit maintained at about 285°F to 295°F. From the tank it is pumped to a sulfur burner where it is mixed with heated air and combusts to sulfur dioxide. The hot gas then enters a catalytic converter where it is oxidized with the aid of a vanadium pentoxide catalyst to sulfur trioxide. The hot sulfur trioxide/air mixture exits the converter and is conveyed through insulated piping to the injectors in the flue gas ducting. Typically, SO_3 is injected at rates to achieve 5 to 25 ppm in the flue gas. For an 880 MW boiler, an injection rate of 25 ppm is equivalent to an SO_3 production rate of 710 lb/hr or about 300 lb/hr of sulfur.

To achieve a high conversion of the SO_2 to SO_3 within the catalytic converter,the temperatures entering and exiting the converter must be within a specific range. Typical catalysts convert SO_2 to SO_3 in the range of 750°F to 1100°F (400°C to 600°C). The conversion of SO_2 to SO_3 within the converter is exothermic. As the temperature of the reaction approaches 1100°F, the chemical equilibrium tends to favor a reverse reaction back to SO_2. Therefore, it is important to initiate the reaction at the lowest practical temperature for good conversion. **Figure:**

Sulfur Trioxide Catalyst Equilibrium Curves

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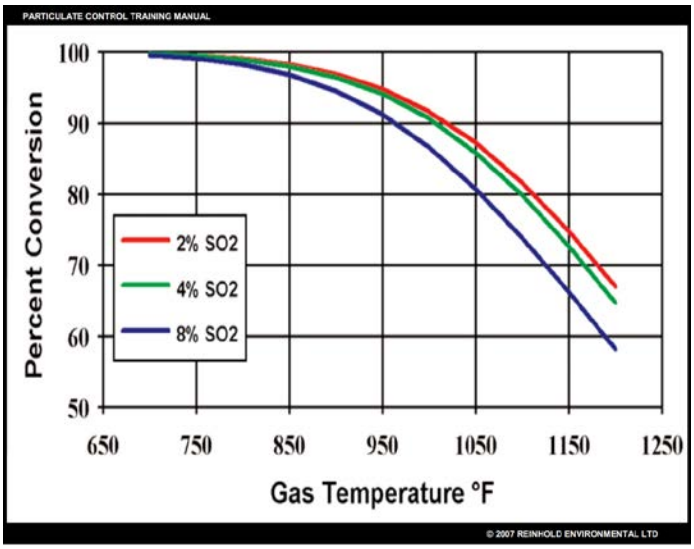
illustrates the temperature dependent conversion equilibrium for various gas concentrations. The closeness to which the curve can be approached is influenced by a variety of parameters, such as: gas velocity through the bed, gas distribution in the catalyst bed, and catalytic activity.



Sulfur Trioxide Catalyst Equilibrium Curves
Courtesy of Chemithon Corp.

This figure shows that the effect of temperature on conversion efficiency attenuates as the temperature is reduced. Below about 800°F, the effect on efficiency due to varying the SO_3 concentration becomes minimal because of slow reaction rates.

Experience has shown that the optimum temperature for the SO_2 mixture to enter the converter is about 820°F (438°C) for conventional vanadium pentoxide catalyst. To ensure that the SO_2 mixture enters the converter at this temperature, most systems rely on a process air heater to raise the temperature of the air entering the burner. This supplements the heat provided by the sulfur combustion. The process air heater is also used to heat the air entering the burner to at least 650°F (343°C) to light the sulfur for system startup.

Many of the systems supplied utilize a fixed speed centrifugal blower to provide the process airflow for combustion. The blower is sized such that the burner exit temperature at the maximum sulfur burning rate is a little less than 820°F (438°C), without adding much heat from the process air heater. Then at all lesser sulfur burning rates, the process air heater supplies additional heat to maintain the converter inlet temperature. This technique is simple but energy intensive. A typical system for a 500 MW boiler will use as much as 150 kW of energy for the process air heater at low sulfur burning rates.

Many of the newer systems use much less energy by varying the process airflow with the sulfur rate so that the process air heater is off at most operating rates. Some of the other improvements are:

- Distributive probe design.
- Positive displacement process air blowers.
- In tank sulfur pumps.
- Sulfur mass flow elements for accurate feedrate control within 1%.
- SO_2 Cooler between the burner and converter.
- Two stage converters to achieve over 96% conversion.
- Fully automated PLC control and remote supervisory systems.

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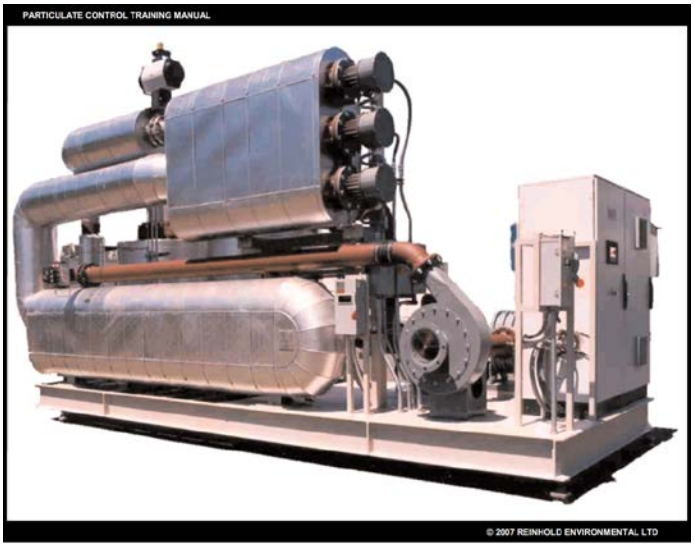
• Probe biasing to attempt to accommodate temperature stratisfication in the flue gas duct (more SO_3 in hot end of duct than in cold end of duct).

Figure:

150 lb/hr Sulfur Feed SO_3 Gas Generator Skid

is a photograph of a 150 lb/hr (68 kg/hr) sulfur burning gas generator skid.



150 lb./hr Sulfur Feed SO3 Gas Generator Skid
Courtesy of Chemithon Corp.

Positive Displacement Process Air Blower

Typically positive displacement blowers designed to operate up to 10 psig (0.68 atm) are furnished. These generally operate at only 1 to 2 psig (0.068 to 0.136 atm) at most operating rates. The use of a positive displacement process air blower enables the system to maintain proper process airflow regardless of converter pressure drop increases. Frequently systems utilizing centrifugal process air blowers require replacement of converter catalyst due to increased pressure drop. Another advantage of the "PD" blower is that a smaller diameter hot gas pipe from the converter to the injectors can be utilized. This saves installation costs and minimizes the system heat loss.

In-Tank Sulfur Pumps

In lieu of external sulfur pumping and metering systems often the sulfur pumps are installed within the sulfur storage tank. The in-tank pumping system consists of a small gear pump, strainer, relief valve, and drive shaft connected to an external motor.The sulfur rate is measured by a mass flow meter and regulated to achieve the desired rate by varying the speed of the pump motor. This pumping arrangement eliminates the requirement for an external pumping skid, which, generally requires a weather enclosure. It is also safer since the gear pumps do not operate at the pressures of the piston type pumps and the relief valve is contained in the molten sulfur with the pump and thus is not subject plugging with solid sulfur from a failure in the steam jacketing. The other main advantage of the in-tank pumps is that they are much cleaner as there is no leakage of sulfur outside of the tank. However, care must be taken to not operate an in-tank sulfur pump until the sulfur in the tank has melted. **Figure:**

In-tank Sulfur Pump Assemblies

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is a photograph of a typical in tank sulfur gear pump.

In-tank Sulfur Pump Assemblies
Courtesy of Chemithon Corp.

Generally two sulfur pumps are furnished per boiler unit. Each unit will have an operating and standby pump. Automatic block valves are installed to enable remote switching of the pumps.

Sulfur Mass Flow Meters

The early sulfur trioxide FGC systems did not measure the sulfur flow to the sulfur burner and depended upon the stroke or speed of a metering pump to estimate the production rate. There was always a question of accuracy with the stoke method of measuring injection rate. These systems generally rationed the production rate to a boiler load parameter. If more sulfur trioxide was required the ratio was increased and the actual injection rate was not reported. Most of the new systems use a mass flow meter, such as a corolio's type flow element, to directly measure the sulfur flow to the burner. This information coupled with a boiler load signal enables a fairly accurate calculation of the actual sulfur trioxide injection rate. This makes it much easier to determine proper injection rates for various coals.

Sulfur Dioxide Cooler

Some designs utilize a "cooler" between the sulfur burner and converter to precisely control the temperature of the gas into the converter. This enables the system to maintain high converter efficiency during periods of changing treatment rate. The SO_2 cooler also protects the catalyst from temperature extremes that could damage the catalyst caused by a rapid increase in the sulfur burner temperature during load increase. This can occur because during system startup the process air heaters energize at full capacity to heat the sulfur burner and converter to operating temperature. Once the system is hot enough to initiate sulfur burning, about 700°F (371°C), then the process air heater temperature is reduced. Unfortunately the air heaters have considerable mass and thermal lag and if the sulfur rate is increased too quickly the burner outlet temperature can exceed 1200°F (650°C) and damage the catalyst.

Two-Stage Catalytic Converters

Many systems sold in the last five years have two-stage sulfur dioxide to sulfur trioxide

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converters. At full process rates the first stage of the converter oxidizes about 75% of the sulfur dioxide to sulfur trioxide. The gas is then cooled with dilution air or with a heat exchanger and enters the second stage at about 820°F (438°C). The exothermic reaction on the second stage is less since the gas mass flow is larger and there is much less sulfur dioxide to oxidize. At design rate the gas exits the second stage at about 950°F (510°C) for an overall conversion of over 95%.

Partially Automated Control Systems

All of the modern systems have automatic sequential startup and shut down capabilities. Generally PLC controllers are installed on the gas generator skid with a local operation station. These are often interfaced to a control room PC based supervisory system or to the plant DCS to provide a graphical interface, monitoring of all the system parameters, data logging, and operator control of all system functions. On some systems, plant monitoring us still required to ensure proper injection rates and proper feeding of sulfur.

Granular Sulfur

Some of the sulfur trioxide FGC systems utilize dry granular sulfur feed stock instead of liquid molten sulfur. The granular sulfur feed is usually supplied as “prills” or “pastille” forms to minimize dusting. The prills are round about the size of a "BB" and the “pastille” are similar in size and shape to split peas.

There are two main types of granular sulfur systems: those that move the granular sulfur pneumatically to the burner without melting, and systems that melt the sulfur prior to the burner.

The pneumatic systems usually consist of a hopper into which granular sulfur is loaded by gravity from one-ton supersacks. From the hopper the granular sulfur is metered with a screw feeder or auger into a pneumatic line where it is conveyed directly into the sulfur burner.

The pneumatic system eliminates steam that would be required to melt sulfur and heat the sulfur line to the sulfur burner. The capital cost of this type of system is less than the cost of the conventional molten sulfur FGC system primarily due to the fact that equipment is usually not provided for bulk sulfur storage as the sulfur is received in super sacks and stored in a warehouse. However these systems use a significant amount of dry (minimum -40° F dew point) compressed air to convey the sulfur.

The other type of granular sulfur system is similar to a molten sulfur system with the exception that granular sulfur is loaded into a fairly large vessel where it is melted, filtered, metered and then pumped through heated sulfur lines to the sulfur burner.

Cost: Capital and Operational Costs of Molten & Granular Systems

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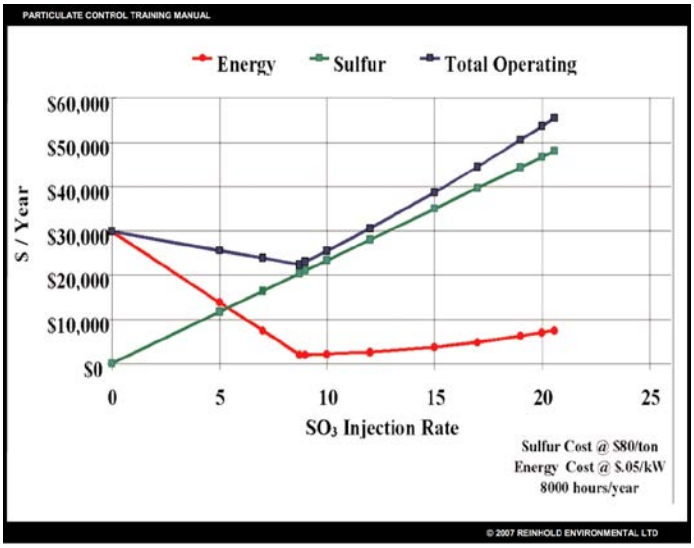
Capital Costs

The cost of Sulfur Trioxide FGC equipment is relatively inexpensive when compared to other options such as adding additional collecting plate area or retrofits to fabric filters. However, SO_3 systems must still have the proper application. On an average, the equipment cost in today's dollars is about 25% of the price in 1990. Presently the equipment price for two molten sulfur systems serving two 500 mW boilers with common sulfur storage is about $1,000,000. Installation costs for the two systems are about $500,000 to $750,000.

Operating Costs

In addition to reductions in equipment capital costs over the last ten years the new systems have much lower energy consumption. Most sulfur trioxide FGC systems use the most power when they are in the 'standby' mode of operation since the heat required to keep the system hot is then provided by the process air heaters. Some of the systems vary the process airflow with the sulfur rate and are able to reduce the energy consumption to less than 100 kW in the standby mode. Ten years ago a similar system might have used up to one MW. When running at normal treat rates a modern FGC system will use very little electricity since the process air heater is usually turned off. **Figure:**



Expected Gas Generator Operating Cost per Year
Courtesy of Chemithon Corp.

Expected Gas Generator Operating Cost per Year

shows the expected operating cost for a system serving a 500 MW boiler. Sulfur costs were assumed at $80/ton and energy consumption at $.05/kW. The figure shows that the most economical operation is near the expected treat rates of 5 to 10 ppm. Within this range the cost is about $2.75 per hour (all cost values are in 2000 dollars).

The steam requirement to keep the sulfur molten in the storage tank and piping is a function of the ambient temperature and the heat loss from the piping and storage tank. On average most systems use about 150 lb/hr (68 kg/hr) of steam. If saturated plant steam at about 80 psig (5.4 atm) is not available other plant steam sources can be desuperheated or small process steam boilers can be furnished.

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In the United States molten sulfur is widely available and delivered costs ranges from a low of about $35/ton to about $120/ton. The range in cost is principally due to the distance the supply is from the point of use. Granular sulfur costs range in delivered cost from about $120/ton to $220/ton (costs are in 2000 $).

There are advantages and disadvantages for each system. Overall operating costs of the molten feed systems are considerably lower for large base loaded boilers. Conversely the granular systems may be more competitive for smaller units and those that only need FGC for part of the year. In this case the higher feed cost may be offset by steam savings. Molten feed systems also have advantages for the larger plants as sulfur handling labor cost is greatly reduced since a single truck load of 20 to 40 tons (18 to 36 mt) is quickly unloaded in about a half an hour and no further handling is required.

Problems Associated with Molten and Granular Systems

Problems Associated with Molten and Granular Systems.

1) In some cases, it may take days (up to a week) to see changes in collection due to changes in SO_3 injection rates. In other cases it may be noticeable in an hour.

2) In order to properly inject SO_3, there must be a fundamental understanding of how a precipitator operates.

3) Duct and precipitator corrosion can occur over a number of years.

4) Multi-orifice probes often plug in areas of the duct that are below the acid dew point.

Problems Associated with Molten SO3 Systems.

1) Steam jacketed molten sulfur lines can become plugged.

2) Steam to the tank & pipe must be properly tapped.

3) Delivery of molten sulfur is often by railcar. The railcar must have steam to melt the sulfur so it can be transferred to the site sulfur tank. This requires plant personnel.

4) Calibration of the sulfur mass flow meter can be a reliability issue.

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5) Steam supply can have significant impact on cost/kw depending on availability of auxiliary steam.

Problems Associated with Granular SO3 Systems.

1) Proper feedstock is critical.

Sulfur feed quality is very critical for granular systems in which the sulfur is not melted prior to burning since all the sulfur impurities enter the sulfur burner. The impurities do not fully combust in the burner and over time will cause fouling of the converter catalyst. In some cases this can plug the converter in as little as a few months. Conversely the systems utilizing a melter, which is designed to provide settling of the impurities with a minimum residence time of three days and further filtering of the molten sulfur before pumping to the burner. The physical properties of the formed sulfur are also critical for the pneumatic granular feed systems. The granular sulfur must have uniform particle size to meter accurately. It must have adequate hardness to resist breakdown in the pneumatic conveying system or it may buildup and cause plugging. In addition the material must not contain fines and must be robust enough that it does not dust since sulfur dust is explosive. To date there are only a few supplies in the United States that provide granular sulfur that reliably meet the requirements of the pneumatic granular systems.

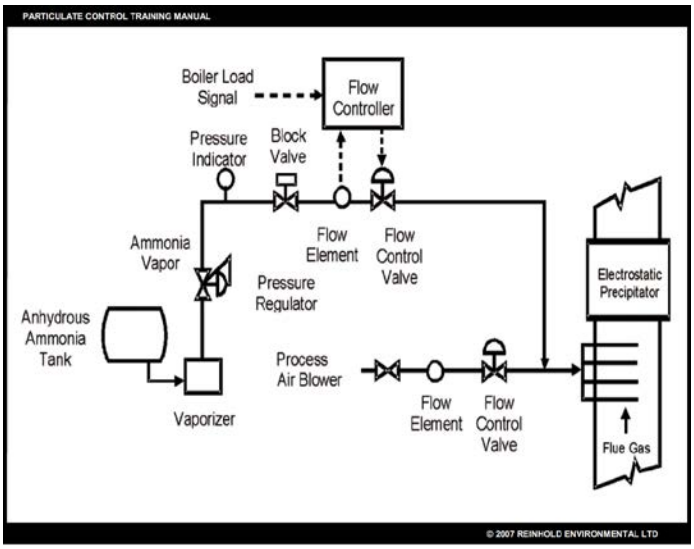
2) Instrument quality air is required, if necessary, for conveying the granular sulfur. moisture in the augurs cause the augurs to break.

3) Unless there is a conveying system to move granular sulfur, plant personnel are required to load the bins.

4) It is difficult to convey granular sulfur over long distances from the augur to the sulfur burner.

5) The actual injection rate tends to cycle somewhat due to the natural frequency of turns of the augur.

6) Explosion sulfur dust problems are present with granular sulfur.



Anhydrous Ammonia Flue Gas Conditioning System
Courtesy of Chemithon Corp.

6.2 NH3 Conditioning

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Ammonia gas conditioning has been used by the petroleum industry to treat catalyst dust since about 1940. In addition, ammonia alone has been used on boilers firing high sulfur coal for many years to improve precipitator performance, reduce the acid dew point and corrosion, and in some cases eliminate the "blue plume" from high sulfur trioxide emissions. Although it is not understood why in some cases ammonia has been successful in improving performance in high resistivity applications. Possibly the ammonia has improved the absorption of the "native" sulfur trioxide.

An anhydrous ammonia injection system is fairly simple. The equipment consists of anhydrous ammonia storage and vaporization equipment, ammonia metering, an ammonia/air mixer, and ammonia injectors. Generally to provide distribution the ammonia vapor is mixed with air to a concentration of less than 10 percent. **Figure:**

Anhydrous Ammonia Flue Gas Conditioning System

is a simplified P&ID of the process.

The **Figure:**

Typical Anhydrous Ammonia Metering

is a photograph of an anhydrous ammonia metering and air dilution skid.

Typical Anhydrous Ammonia Metering
Courtesy of Chemithon Corp.

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6.3 Dual Conditioning (SO3 and NH3)

Dual FGC System

In some cases of high ash resistivity, sulfur trioxide flue gas conditioning alone is not effective. Some of these are:

1) The fly ash does not absorb the sulfur trioxide. This is generally true of fly ash that has a combined silica-alumina content of more than 87% and a low concentration of alkali metals. These ashes are frequently referred to as acidic ashes.

2) Flue gas temperatures are too high for the sulfur trioxide to attach to the ash. This can be as low as 320°F (160°C) and depends on ash composition and gas moisture.

3) High precipitator gas velocities above 4-5 ft/sec (1.2-1.5 m/sec). The performance improvement from lowering ash resistivity is offset by increased re-entrainment due to lower holding forces."

4) High unburnt carbon carryover in the ash. The carbon particles do not hold a charge. In addition they are extremely fine and will increase the stack opacity without a proportional increase in mass loading. When the carbon carryover exceeds about 10%, re-entrainment becomes a severe problem.

5) Iron content in the coal which is less than 57% and/or low calcium content will benefit from dual conditioning.

The simultaneous and independent injection of both ammonia and sulfur trioxide referred to as dual gas conditioning can be an effective solution to these problems. In situations when the flue gas temperature is less than 240°F 116°C), dual conditioning is not effective.

Ammonia injected into flue gas in the presence of sulfur trioxide and flue gas moisture reacts to form many ammonia compounds, principally ammonium sulfate and bisulfate compounds. These particles nucleate on sub micron particulate in the gas stream and help to agglomerate and increase ash particle size. The ammonia also reacts with "acidic" ash to facilitate absorption of sulfur trioxide. The resulting ammonium bisulfate is a sticky compound above its melting point of about 290°F (143°C). It is believed to help agglomerate the ash and improve the ash cohesivity. Another observed effect is an increase in the flow of ions, electrons and charged particulate in the interelectrode space, or space charge.

Precipitators with high gas velocities sometimes do not benefit from reductions in ash resistivity. The lower ash resistivity enables the ash to more readily release its charge to the collecting plate, reducing the electrostatic holding force. The reduced holding force allows more ash to reentrain into the gas stream when the collecting plates are rapped. The improvement in ash cohesivity from dual conditioning reduces rapper re-entrainment by agglomerating ash on the collecting

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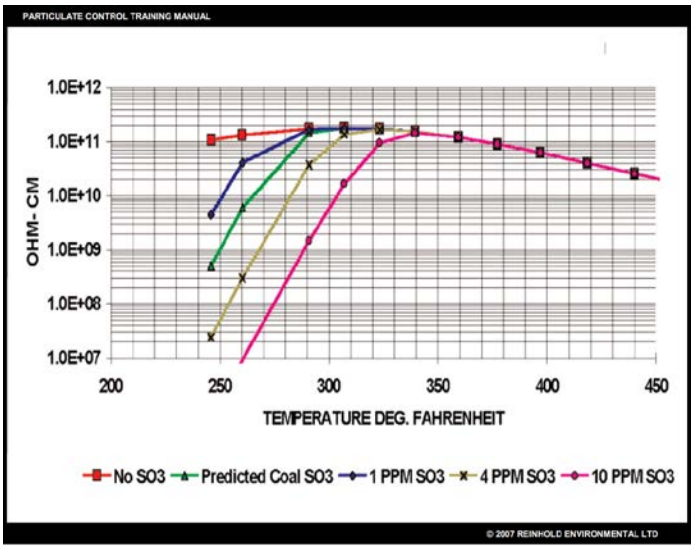
plates.

Recently many utilities have switched to low sulfur fuel and converted to low NOx burners. The low NOx burners frequently cause an increase in the unburned carbon particles. The unburned carbon-coupled with the lower sulfur trioxide concentrations from the lower sulfur coal -presents a difficult collection problem. The resultant ash is a mixture of high resistivity particles and low resistivity carbon particles. The lower resistivity particulate readily re-entrains into the gas stream. In addition, the low resistivity particulate tends to reduce the maximum field strength and prevents charging of the high resistivity ash. Injecting sulfur trioxide alone improves the capability to charge the high resistivity ash but the benefit is often offset by increased reentrainment of the carbon particles.

Dual injection overcomes this problem by reacting the carbon particles to form various ammonia-sulfate based compounds, which agglomerate the carbon particles and increase ash cohesivity. This reduces re-entrainment, and allows an increase in the sulfur trioxide which in turn reduces ash resistivity.

Figure:

Low Alkali Ash Resistivity Curves



Low Alkali Ash Resistivity Curves
Courtesy of Chemithon Corp.

is an example of a coal ash that does not condition well with sulfur trioxide alone and would be expected to have excessive un-reacted sulfur trioxide emissions, or "slip." This ash has a silica and alumina content of about 85% with low iron and very low calcium, of about 1%. Experience has shown that high silica and alumina ash with a low concentration of alkali elements such as calcium do not absorb sulfur trioxide well. This problem becomes more pronounced at higher precipitator gas temperatures. Note that the sulfur trioxide equilibrium curves are steep and that above about 340°F (171°C) adding sulfur trioxide does not decrease the resistivity. When iron concentrations are less than about 5% with low calcium the 'Bickelhaupt' resistivity model tends to generate steep sulfur trioxide equilibrium curves. Experience has shown that coal ash with very low calcium and other alkali metals may not condition well with sulfur trioxide alone regardless of the iron concentration.

Control of Dual FGC System

The ratio of ammonia to sulfur trioxide is important. Too much ammonia may cause the

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following problems.

1) Higher ash resistivity and increased particulate emissions.

2) Un-reacted ammonia can escape up the stack (NH_3 slip).

3) Excessive precipitator ash buildup.

Excessive sulfur trioxide concentrations could cause excessive sulfur trioxide slip, possible acid dew point problems, and excessive rapper re-entrainment. As a general rule the ammonia treat rate is one half to two thirds of the sulfur trioxide treat rate. The ammonia flow is measured with a mass flow element using a boiler load signal indicative of the precipitator gas volume to control to a desired injection rate in ppm.

Problems with Dual Conditioning Systems.

1) Probe design must be properly done to ensure mixing of the SO_3 and NH_3 in the gas stream prior to the precipitator.

2) Determining the proper injection rates is a very time consuming practice.

3) Units that cycle off everyday may find it difficult to use dual conditioning due to the time required to determine injection rates.

4) Frequent coal changes: may have difficulty in changing injection rates quickly enough to keep up with the coal changes.

5) The rapper program must be modified often when dual conditioning is being used.

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6.4 Humidification

Humidification of flue gas to reduce resistivity has been common in the cement industry for many years. It has recently been used effectively for coal fired boiler and other applications. Humidification is accomplished by water injection that results in a drop in gas temperature caused by the evaporation of the injected water. This can improve electrostatic precipitator efficiency in four ways. First, the lower temperature results in a direct reduction in the resistivity of the particulate. Second, the additional moisture in the gas stream also lowers particulate resistivity. Third, the drop in temperature reduces the actual gas volume being treated. This increases the specific collecting area (area per unit of gas volume) of the electrostatic precipitator and the treatment time of the particles. Fourth, the reduced face velocity helps reduce particle re-entrainment.

Problems with Humidification

1) Care should be taken to ensure that atomized water is not over injected in the duct, otherwise the ash will coagulate and harden in the duct. Also duct corrosion can occur.

2) Lowing exit gas temperature by using humidification can trigger the need to install taller stacks.

3) It should be understood that excessively high temperatures in the output of the combustion process might be due to other problems in the boiler. Care should be taken to treat the cause not the symptom.

Overview

"Humidification", or evaporative gas conditioning, has been applied extensively in cement, non-ferrous metals, hazardous waste incineration and steel industries to condition process off-gases before treatment in an ESP or baghouse dust collectors. Traditionally its application has been limited to large conditioning chambers following various processes. Recent advances in atomization technology and control have allowed its successful application directly in ductwork, when conditioning chambers are not feasible or when desired ESP inlet temperatures are lower than achievable with conventional technologies. Since some power station exhausts must be conditioned in order to lower resistivity, flue gas conditioning techniques, such as SO_3 and NH_3 are implemented. Evaporative gas conditioning is another option. Each of these technologies has its own set of advantages and disadvantages, and must be evaluated for a specific application.

Because conservation is viewed as an important element in the preservation of the environment, evaporative gas conditioning's characteristic of optimum resistivity levels plus energy savings

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through lower gas volume (due to cooling) has made it the choice of many industries. In evaporative conditioning, water is injected into a hot gas stream to cool the gas from a higher temperature to a lower temperature (typically 350 degrees F to 300 degrees F (177 degrees C to 149 degrees C) in power plant applications). With an ESP, the objective is the humidification of the suspended particulate in order to lower its resistivity. A beneficial result is that the gas volume is decreased, resulting in reduced fan horsepower, improved specific collection area (SCA) and lower yearly power consumption.

The purpose of this section is to help evaluate the performance of a humidification system and show what to look for in maintaining and evaluating the installed equipment.

The evaluation will cover:

- ESP operation
- Fan capacity increase
- Operational issues
- Maintenance
- System design

Introduction

A typical application is a pulverized coal fired boiler. We will focus on a Tangentially fired, 600 MW rated boiler, with two air heaters for our example. The air heaters lead into a multiple gas path ESP followed by multiple fans, where the ESPs receive gas from the air heaters in a separate ducting arrangement.

Low sulfur, sub-bituminous coal from Powder River Basin is fired in the unit. At full load, elevated gas temperatures (>340°F (171°C)) exist in some portions of the two ESPs. At these gas temperatures, the SO_3 injection system loses its efficiency to lower the resistivity of the flyash introduced in the ESPs, resulting in low ESP collection efficiencies.

At full load operation and with high gas temperatures (>340°F (171°C)), the unit's efficiency is affected, limiting the MW output of the unit. This occurs when the high resistivity of the collected flyash and the increase in the flow volume of gases in the ESPs (through high temperatures) reduces treatment time, limiting the optimum T/R set power that can be maintained in the ESP fields, reducing particle collection efficiency. The result is high opacity readings (up to the 20% limit) in the combined outlets of the ESPs, especially during periods of elevated ambient temperatures, necessitating, at times, limiting the unit's power output in order to remain in compliance.

Another factor affecting the overall efficiency of the unit is that, at these elevated ambient temperatures, the fan does not have the capacity to maintain draft, thereby lowering the overall output in MW of the unit.

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A solution to the above enumerated problems is to humidify the hot gases ahead of the ESPs via evaporative cooling, thus reducing flyash resistivity by raising moisture levels and lowering the temperature of the gases. The effect is to operate low on the "cold side" of the resistivity curve, usually between 1.0E+9 and 1.0E+10 ohm-cm. Reducing the flyash resistivity maintains high operating secondary voltage (kV) and maximum optimum secondary current (mA) in the ESPs preventing excessive sparking and "back corona" degradation with elevated temperatures.

Cooling the hot gases before the ESPs also maintains a lower flow volume in the ESPs, resulting in higher operating SCA and particle collection efficiency, reducing reentrainment losses and lowering the volume of gas moved by the ID fans.

The overall effects of lowering the temperature and humidifying the gases are hard to quantify due to the number of factors affected by the various phenomena and the conditions found at each particular site.

Although one cannot quantify each factor, the various benefits can be enumerated as follows:

- Reduces flyash resistivity
- Reduces sparking
- Reduces occurrence of back corona
- Reduces re-entrainment losses
- Reduces particle adhesion
- Reduces rapping re-entrainment losses
- Reduces fan horsepower
- Reduces flow volume
- !Increases operating secondary voltage (kV)
- Increases secondary current (mA)
- Increases operating SCA
- Increases particle collection efficiency
- Increases fine particle migration velocity
- Increases particle cohesion
- Increases the fan's capacity to maintain load

The specific goals of the test should be to attempt to quantify some of the advantages as are applicable to the particular site-specific conditions. This report will address these points in evaluating the system's performance.

Background

The example unit was recently fitted with an evaporative gas cooling system. The in-duct cooling system is composed of eight spray lances, spraying in direction of gas flow. It was installed prior to the last outage, and was installed at a very high and competent level in order to

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execute the project successfully.

The system is designed to cool the gases at the inlet of the precipitator in order to lower the resistivity of the dust so that it can be collected. The spray system poses other valuable advantages. Among them is that, as the gases are cooled, the lower volume of the gases going into the fan results in considerable horsepower savings throughout the year. Another is that, as the gases are humidified, there is a tendency in the dust to want to remain attracted to other dust particles, through agglomeration, thereby reducing rapper re-entrainment. Other, more technical advantages are also imparted to the gases and the dust, resulting in additive, aggregate theoretical advantages.

The ducting, for the record, is of ample dimensions to fully evaporate the water required for improved ESP operation. The target ESP inlet temperature is 300°F (149°C), with an average air heater outlet temperature of 350°F (177°C). It is understood that the air heater outlet temperature variations will be affected to some degree from season to season, but the 50°F (28°C) temperature drop in the ducting will remain the same, as long as the spray system inlet temperature is not below the design value of 350°F (177°C).

Following will be a detailed list of items found to be wrong with the system, which will be followed by recommendations for its improved operation and performance.

In the first part of this report will deal with the equipment installed. The second will deal with the implementation of the equipment within the existing ductwork and the tests that could be performed. Lastly, there will be recommendations for improving system performance, keeping cost in mind.

System Equipment Description

A dual-fluid humidification system is most basically composed of spray nozzles mounted on spray lances, an atomization and temperature control system based on gas temperature, liquid pressure and flow measurements, and of a water and air sources, typically made up of water pumps and air compressors.

The system is composed of:

a) 4-zone control valve rack (water and air pressure control)

b) Screw type air compressor

c) Spray lances

d) Rapid response thermocouples

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The system is being used in conjunction with an existing flue gas conditioning system is composed of:

a) SO_3 furnace

b) SO_3 injection probes

c) Existing thermocouples

Site-Specific Issues - Introduction

In any retrofit technology, there are site-specific issues and existing equipment that must be taken into consideration in order to ensure a quality installation and a successful implementation. Not only must the humidifying equipment not impinge on the walls of the ductwork, but the injected water droplets must not cause considerable buildup on the internal bracing.

Gas Flow and Temperature Distribution

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Gas flow and temperature distribution across the air heater outlet is an issue of major concern when implementing a humidification system. The water to be evaporated has to be injected in a location where it can be evaporated and so that it cools the gases down to set point. The injected atomized water can overcool or undercool the gases if the correct conditions are not present, and, under extreme conditions, the water may not fully evaporate, causing impingement and build-up within the ductwork.

As the air heater rotates from the primary and secondary air ducting (the F.D. side, where it is imparting heat the outside air), the heat transfer surfaces are cooled. As the heat transfer surfaces (baskets) rotate from the F.D. side to the I.D. side (hot gases exiting the economizer), the heat transfer surfaces are at their coolest, and are most able to cool the hot gases. As the air heater baskets make their way through the air heater he gas temperature distribution in the ductwork varied from 290°F (143°C) on the side of the ductwork corresponding to the beginning of the air heater rotation on the hot gas side, all the way to 390°F (199°C) on the side of the ductwork corresponding to the end of the air heater rotation on the hot gas side.

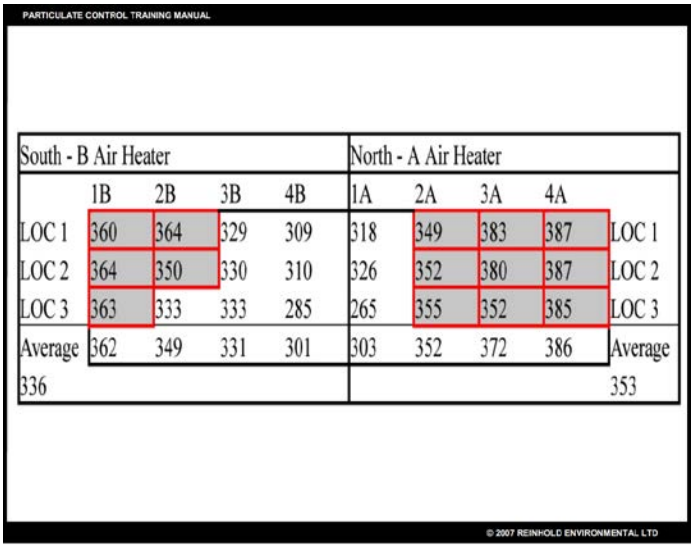
What the temperature sensors did not tell us, however, is that the gases at the extreme sides of the ductwork are infiltrated by air from the air heater seal leaks. This very cold air introduced into the I.D. gases from the F.D. side must not be humidified at all for it is considerably below the moisture dewpoint of the gases.

It is therefore important to note that the distribution of injected water is of paramount importance. The water injection system provided has been engineered to inject the water only in those locations where it is needed most and where the hot gases are most able to evaporate it.

Figure:

Temperature Distribution

shows a temperature distribution from a springtime test. This distribution was used to size the spray system and to locate the spray lances.



Temperature Distribution
Courtesy of EnviroCare

NOTE: One can see that the temperature profile in duct B (hot portions are shaded), that which exits the south air heater, is much more even than that in duct A, or the north air heater outlet. Even more telling is the fact that the temperatures in duct A are well above the 340°F (171°C) limit recognized by most to be the limit of the efficacy of SO_3 on low sulfur,

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Powder River Basin coal flyash. The gases in duct B will most likely be able to mix to some degree at the inlet of the ESP, thereby lowering the maximum local temperature going to the various sections of the precipitator. Still, even these temperatures are high for consistent ESP operation. Another thing that is clear from this chart is that many of the temperatures are much lower that the average in the B duct and are a bit higher than the average in the A duct.

Ductwork Geometry, Obstructions and Supports

Installing evaporation equipment in an existing duct takes some finesse. Care must be taken to avoid impinging the spray on the internal ductwork support bracing, which is downstream of the spray lances, and in some cases, in the direct path of the sprays.

Longitudinal bracing and trusses are troublesome in the sense that any spray that is introduced in the gas stream may impinge on it due to gas flow translation across the supports. This may be caused by gas flow directional impetus resulting from the inability of the gas straightening devices (i.e. turning vanes) to re-direct the gas flow after a turn or from the design of the ductwork itself (the ductwork in question angles down in the direction of gas flow and up to one side across the gas flow).

Other internal obstructions that may create difficulty are turning vanes, both upstream, in terms of spray lance installation obstruction and water spray impingement, as well as downstream, in terms of unevaporated water spray impingement.

Also, in this case, the ductwork is supported from beams and hung from them, rather than being supported in the traditional way from underneath. This poses additional difficulties due to the fact that the support beams run along the top of the spray lance locations and that precise location of the interference points is difficult.

Since the duct is fitted with NH_3 and SO_3 probes, care must be taken so that the water from the spray lances does not impinge on the probes and that the injected gases don't interact adversely with the injected water (as would be in the case of localized sulfuric acid deposits).

Equipment Supply and Installation

Water Injection System

Concerning in-duct humidification systems, the rules that must be followed are many. They concern droplet size, spray orientation, water distribution, water flow, water spray velocity, water temperature, gas distribution, gas velocity, gas temperature, gas composition, dust distribution, dust particle size, dust characteristics, duct geometry, internal obstructions,

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evaporation treatment time (residence time), etc. A spray system cannot be engineered only with respect to a few of these criteria, but needs to take them all into account and respect all of the laws of physics in order to be successful.

A water injection system (normally, spray lances and accessories) is required for delivery and evaporation in order to control temperature and humidity at the inlet of the ESP. In a full-scale in-duct humidification system, the nozzles required for full evaporation of the injected water must have low water injection flow rate capacities and they must be distributed in relation to the gas volume and temperature. Should the gases not be even at the point of injection,the water that is evenly distributed in the cross section of the ductwork would be biased with respect to the gas flow cross section and cause cold spots in the gases. Should this occur, free water may still be present at the outlet of the spray system, causing impingement of dust and flyash buildup on the ductwork walls.

In order to avoid this condition, and due to the gas flow and temperature inequality, the spray lances furnished on this project were supplied with two water inlets, one feeding the top 4 sprays, the other supplying the bottom 5 sprays, for a total of 9 spray nozzles. This allows for the ducting to be split up not only right to left, but also top to bottom, allowing the control system to feed more or less water to each of 4 zones feeding a total of 8 spray lances. The temperature control valves on the valve rack feed 2 common headers from each side of the duct. These headers are split in the middle by ball valves that allow central spray lances to be switched from one temperature control zone to another, allowing for a 4:4 or a 5:3 side-to-side spray lance split.

The spray lances furnished have been carefully laid out to take into account internal duct supports. The spray lance locations and spray lance nozzle densities have been determined by analysis of the duct structural support obstructions and the amount of heat and gas mass in the ducting. In some cases, the actual desired nozzle density may not be met due to these internal obstructions. This means that the sprays located in the ducting may not be able to cool the gases enough, limiting the efficacy of the spray system in reducing resistivity, opacity and gas volume.

Point by point, the issues that could affect the spray system negatively follow.

Spray nozzle density

a) Spray nozzles density may not be installed in hottest section of the duct

- Gases not cooled to design
- Gases not being cooled may have caused poor ESP performance
- Gases not cooled did not achieve desired gas volume reduction

b) Sprays in hot zone were overdriven in order to attempt to cool hot gases:

- May could cause droplet enlargement and longer evaporation times

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- This could be the case in those systems where nozzle densities have not been optimized, resulting in overcooling of the gases in some zones and undercooling in others

c) Nearby sprays may need to be re-directed toward hot spots:

- Gas directly in front of redirected sprays may not cooled
- May cause impingement of droplets, causing enlargement
- May caused spray to impinge on duct wall or support

Spray Lances

a) May be improperly installed in the duct

b) May not adjustable in terms of axial in/out dimension or rotational angle

c) May not have correct spray nozzle distances:

- May cause neighboring sprays to overlap
- May over cool in location of spray lance
- May be too long, causing bad water distribution due to pressure differences from top to bottom

Air Pressure (if no controller provided for air pressure)

a) Uncontrolled air pressure may be biased to go through nozzles with low flow

- Air will tend to take path of least resistance in low flow nozzles
- High water flow nozzles may be starved for air, causing larger droplets
- May be causing evaporation times to be higher than calculated
- Would most strongly affect droplets from sprays in hot zone of duct

Valve Rack

A valve rack is an assembly of measurement and control components, usually composed of a pump set, a temperature and an atomization controller (typically a PLC), a water and an air flow control valve, a water flow meter, pressure transmitters, on/off permissive valves, manual maintenance valves and pressure indicators.

One of the control components that is most important and often overlooked is the air pressure controller. Control racks may not be fitted with the air flow control and permissive valving (controls the ratio of atomizing air to water pressure and ensures that the system does not run in the absence of atomizing air). Though this is not usually a problem, with bad nozzle densities or distribution of spray cooling water, the need to overdrive the nozzles in some locations in order to achieve cooling, may cause the air to preferentially follow the path of least resistance and be

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unfavorably biased toward the low flow nozzles. This should not affect the spray droplet sizes considerably, but may lengthen somewhat the evaporation times in the overdriven portions of the system.

List of components installed (or missing) that may cause difficulty with equipment:

* Water flow control valves

a) Water flow control valves may be improperly sized and provide poor control

b) Valve positioners may malfunction and cause poor temperature control

* Air flow control valves

a) If missing, valve rack would not provide ratio control (air to water)

b) Air pressure may be too high for low water flow, causing high wear

c) Air flow control valves may be improperly sized and provide poor control

d) Valve positioners may malfunction and cause poor atomization control

e) Air flow could be following low resistance path in low flow nozzles

f) If manually biasing water injection locations (some spray more water than others due to bad spray distribution), air flow in high water flow nozzle locations may not be sufficient

* Water flow meters

a) Make sure they are adequately and properly sized for all flow conditions

* Filtration

a) Filtration must be located at valve rack and at each spray lance

b) Make sure not to forget that air side will also require filtration (strainers with fine mesh screen will suffice) at each spray lance to catch any welding slag that my be present in piping.

c) It is preferable to install stainless steel piping on the water side if there is a potential that a proprietary chemical may be injected sometime in the future.

Control System

A humidification control system is required in order to regulate the amount of water injected in

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the evaporation chamber. A second control element is normally provided to control the quantity of air for proper atomization, and ultimately, assure the complete evaporation of the injected water. In the case of many test systems, the air control loops are missing from the supply.

A temperature control system is required to provide a control signal to the water flow control valve, in order to increase or decrease the water injection rate as a function of gas temperature and volume. Should the temperature control system not be properly tuned, the control system will have problems controlling the temperature, oscillating about its set point, sometimes more than is tolerable for the system to prevent the formation of free water in the ducting.

An atomization control system is required to provide a control signal to the air flow control valve, in order to increase or decrease the air pressure to the nozzles as a function of the water pressure resulting from the water flow required for temperature control. Should the atomization control system not be installed, the air pressure will have to be fixed at its highest value.

No discussion of a control system would be complete without touching on the elements that provide the controller feedback on the Process Variable (PV). The PV is read by the controller (e.g. temperature), it is compared to set point by the controller, and a signal called the Control Variable (CV) is sent to the final control element (in this case, the water flow control valve), to increase or decrease its output (in this case water flow).

If the element that reads the PV is not selected with the process response times in mind, there is the possibility that the control system become unstable. This instability will force the operator to dampen the control algorithm (the mathematical formula that controls the output, which includes a time factor), typically by changing some or all of the control parameters, thereby slowing down the response of the controller to changes in the process.

PARTICULATE CONTROL TRAINING MANUAL

Time	Status
2:30 PM:	Test was started Temperature zones 1 and 2 were brought down from temperature (ranged from 350° to >380°) Stabilized setpoint at 320° for 30 min. and then down to 300° for remainder of day
3:30 PM:	Spray lances were adjusted to get more coverage in duct Due to internal and external obstructions, the spray lance nozzle densities and cooling water coverage inside the ducting were insufficient to achieve desired cooling and therefore desired effect on the ESP or fans Spray lances were re-oriented (angled toward the hot spots) in order to get more spray coverage in the duct. There is a danger that the sprays could impinge on each other (creating larger droplets that may not evaporate) and/or on ducting elements, resulting in deposits on the duct surfaces.
5:30 AM:	Atomization air compressor ran out of fuel Due to compressor failure, unatomized water was injected into zones 1, 2 and 3 of the duct for 1h 30m On loss of air, control valves were open until air was restored. Flowmeters and control valves were out of calibration by 0.2-0.4 GPM and no one knew that water was being injected. Install positive shut-off valves in front of each control valve for permissive with air alarming. Water flow rate into duct was between 75-150 gal. over the 1-1/2 hour period Later internal inspection showed hard flyash deposits on internal bracing and on wall near spray lances on hot side of duct
10:00 AM:	Returned air compressor into service and restarted testing Controller was re-programmed to fail safe when air is missing Temperature setpoint was lowered to 300°F
11:00 PM:	Shut the system off due to a report of problems in the 4A-precip hopper Service personnel cleaning out the hoppers found it difficult to vacuum out the flyash from one of the first field hoppers Ash was found to be moist, but not hard, suggesting more an issue with humidity than an issue with free moisture The outside temperature was near or below freezing at the time
11:00 AM:	System was returned into service The spray lances were removed and checked for poor atomization After system checked out OK, the spray lances were straightened out to spray in a direction parallel with the side walls of the ducting With the system spraying down to 315°F, and the SO_3 on, the ESP power was up and the opacity began to descend

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Sample Operating Sequence 1
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This situation is acceptable for most processes, which are due to their nature, slow and predictable. But in the case of in-duct humidification, the process response times are very fast, and the appropriate response within a given time frame is of critical importance. Process variable and controlled variable output response times in this case are adequate for proper and stable control of the temperatures at the inlet of the ESP.

Functionality of components installed:

Temperature controller

a) Is fitted with multiple T/C (or mA) inputs capability

b) Carries out basic functions:

- Controls different zones on user selected T/C
- Alarms on low temperature at T/C
- Alarms on T/C burnout

Air pressure controller

a) Is fitted with multiple pressure transmitter (mA) inputs capability

b) Carries out basic functions:

- Controls air pressure based on a water pressure signal
- Alarms on low available system air pressure
- Alarms on pressure transmitter burnout

Thermocouples

a) Are rapid response (+ or - 3 seconds for full change)

b) Ensure temperature reading is real-time

PARTICULATE CONTROL TRAINING MANUAL

11:00 AM continued	At full load (560-585 MW) with EGC system in operation and SO_3 on, the opacity on the A side hovered around 20% with little difference due to load changes At reduced load (approx. 300 MW) with EGC system in operation and SO_3 on, the opacity on the A side hovered around 15% It is unclear how much improvement would occur with the spraying system operating as designed (i.e. not hampered by field modifications due to internal and external interferences). It is unclear that due to the immediately preceding point, that the opacity in duct A would ever be able to be decreased more than 15%. Keep in mind that further improvement may be achieved if all of the A box ESP fields are in service
6:15AM:	The SO_3 system was shut down Testing begun with the SO_3 injection system out of operation At full load (560-585 MW) with EGC system in operation and SO_3 off, the opacity on the A side hovered around 20-25% with little difference due to load changes When looking at historical data, at full load (560-585 MW) with EGC system off and SO_3 on, the opacity on the A side hovered around 10-25% higher with opacity swings due to load changes
7:45 AM:	Lowered the temperature set point down from 315°F to 300°F With the system spraying down to 300°F, and the SO_3 on, the ESP power was up and the opacity began to descend Opacity leveled off at 17-20% (see chart and graph below)
6:15 PM:	EGC system was shut down in order to determine load limitation due to I.D. fan - 586 MW The boiler operator was able to reach 586 MW before Westinghouse WDPF II system in automatic backed down the
	boiler due to 100% position on I.D. fan damper position
6:35 PM:	EGC system was turned back on in order to determine load limitation due to I.D. fan - 590 MW After the boiler was stabilized for a few minutes, the boiler operator was able to reach 590 MW before Westinghouse WDPF II system in automatic backed down the boiler due to 100% position on I.D. fan damper position These tests are not considered definitive or long term but do indicate some increase in MW. It is unclear how much improvement would occur with the spraying system fully capable of cooling the fan gases down to design temperatures (i.e. not hampered by field modifications due to internal and external interferences, thus not allowing for complete cooling in hot gas stream locations)
6:50 PM:	After testing on fan horsepower was completed, the system was turned off so that the Unit could be taken off line for a Mini-outage

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Sample Operating Sequence 2
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c) Allow for precise temperature control

Pressure transmitters

a) Pressure transmitters are reliable

b) Accuracy is + or - 1% of full scale or better

c) Are installed on the valve rack

System Operation

General Comments.

As has already been mentioned, the success of a humidification system is its implementation in the existing ductwork and the ability of the controls to regulate the water flow for temperature control and the droplet size for complete evaporation. When any one of the required design requirements is not met, the potential for catastrophe exists, and will more often than not be realized.

Figures:

Sample Operating Sequence (1 & 2)

enumerate a sample operating sequence from a test, and the observations that could be made during evaluation. The sample system is installed on a single duct and has 4 temperature control zones.

Typical Operating Sequence and Maintenance

PARTICULATE CONTROL TRAINING MANUAL

Date	MW	Avg temp	Status (on-off)	1A Fan Amps x10	1A Box KW	A Opacity Min	A Opacity Max	B Opacity Min	B Opacity Max
11/22/00 9:00	575	360	OFF	532	240	35	40	17	22
11/22/00 21:00	575	356	OFF	530	260	32	37	17	19
11/27/00 9:00	565	351	OFF	530	340	25	30	17	18
11/28/00 21:00	560	349	OFF	520	320	30	40	12	15
11/28/00 9:00	565	355	OFF	500	320	27	32	14	17
11/28/00 14:30	562	355	OFF	510	335	25	29	14	16
11/28/00 20:00	578	320	ON	530	390	18	22	13	17
11/29/00 3:00	578	320	ON	510	390	19	21	13	17
11/29/00 9:00	558	362	OFF	500	300	29	36	14	16
11/30/00 9:00	565	350	OFF	510	330	22	31	12	14
11/30/00 13:00	565	320	ON	510	380	17	19	12	13

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Plant Operation Data.
(Courtesy of EnviroCare)

Test Data

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Operating data from the plant information system was analyzed for various parameters. Extrapolated from the bulk of the data were the pertinent parameters enumerated in **Figures:**

Plant Operation Data

and

Graphical Plant Data

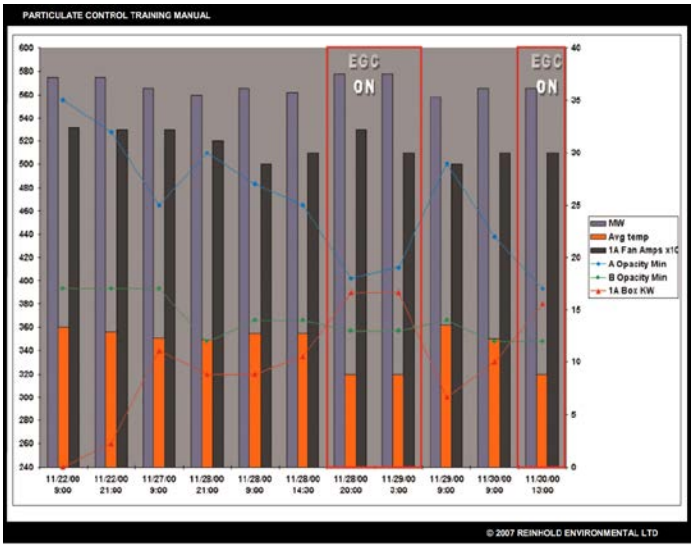
. What the data show is that, over time, and with the SO_3 system running, the power levels increased, the opacity was reduced and load was maintained.

Note: The efficacy of the EGC system to lower fan operating power is difficult to quantify and determine given the length and circumstances of the test. If further testing is to be carried out, the gas flow balance between side A and side B fans must be able to be regulated or determined, and the spray system must be brought back into the design parameters (it is presently being overdriven in some areas).

Figures:

Additional Operating Data (1 & 2)

show more operating data from the plant information system for a time period just before plant shutdown. The data shows that the spray system has a marked improvement on both opacity and unit kW. Note that while load in increasing, and B opacity is increasing, that A opacity is decreasing, and A power levels are increasing.



Graphical Plant Data
(Courtesy of EnviroCare)

System Implementation and Correction

General Comments

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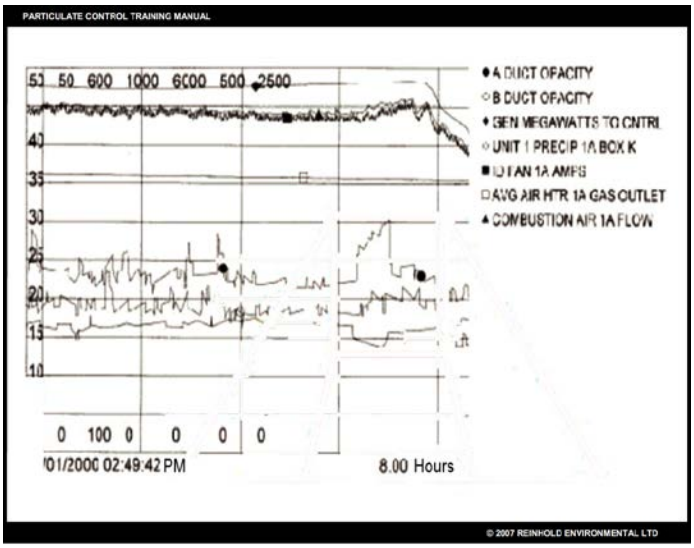
As has already been mentioned, the success of a humidification system is in its implementation in the existing ductwork and the ability of the controls to regulate the water flow for temperature control and the droplet size for complete evaporation.

We must emphasize and remind ourselves of the requirement to design and install the spray system while the unit was on-line and the short time available for execution of the project. Despite the difficulties in designing the system without full confirmation of the project details and the short execution time, the system design, supply and installation has met most of the fundamental points that are critical to long-term trouble free operation.

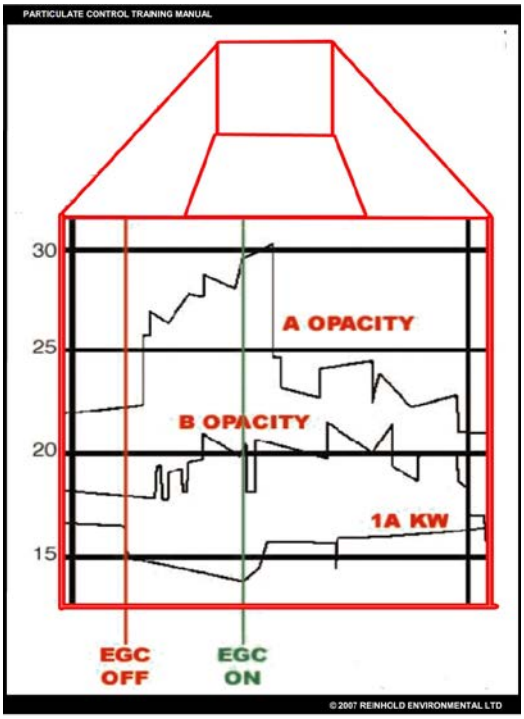


Additional Operating Data 1
(Courtesy of EnviroCare)

Difficulties During Testing

Some difficulties will always be encountered during operation of any equipment. In our test case, they were the product of two key elements: 1) the loss of air, and the inability of the controller to shut off the water flow control valve, resulting in injection of unatomized water, and 2) the internal obstructions that prevented the water sprays to be installed in the hottest zone of the duct cross sectional area. These are probably the two most common elements of a malfunctioning system.

In our example case, some flyash build-up was found on the internal bracing on the side wall of the ducting on the warm side of the airheater rotation. It is clear from the nature of the build-up that the bulk of it was caused by the loss of air to the nozzles. This is determined by close examination of the nature of the build-up. Had the build-up been a gradual and smooth mounding of flyash, as is typical in build-up caused by impingement of finely atomized and partially evaporated water, it would have indicated incomplete evaporation of the droplets. The coarse and stalactite



Additional Operating Data 2
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nature of the build-up, however, indicates a deposit caused by free running and fully unevaporated water hitting a surface, mixing with the flyash to produce a muddy, slurrylike substance, and yet allowing enough heat into the mixture to dry it onto the obstruction. This means that the problem can be corrected by way of a more sophisticated control system and more instrumentation. Had the buildup been more fine in nature, then the cause of the failure in a well designed spray system may actually have been in the control system (the process controller, control valving or instrumentation).

When the spray nozzles lose atomizing air, not only does the water leave the spray lance in very large droplets (500- 5000 micrometers), but the angle of atomization goes from a very narrow and contained spray cone, to a very wide angle (greater than 90°) and a diffuse, uncontrolled spray.

It is possible that some of the build-up in the ducting was also caused by an attempt to cool the gases not being cooled due to missing water sprays by re-orienting (angling toward the hot spots) some of the spray lances. This re-orientation could cause impingement on the longitudinal trusses or on the x-braces.

In light of this build-up, and to prove that these deposits are not due to the inadequacy of the ducting to handle the evaporative load, it is important to re-evaluate the ability of the gas stream to evaporate any additional water that may be injected throughout the ducting, and especially on the warm side.

Further evaluation may be required to determine if the existing spray nozzle density is sufficient on the warm side of the ducting (plant north) to cool the gases evenly, and to see if 300°F (149°C) is required in order for the ESP to see marked improvement in flue gas characteristics.

The delivery system (spray lances) can be easily modified by relocating the spray mounting boxes in those locations where there are signs of overcooling, and moving them to where there is evidence in the precipitator operation and the temperature sensors that there is inadequate cooling.

The control system must be designed for unsupervised operation in order to possess all of the characteristics of a full-scale and well-designed humidification system. It is clear that, a well configured system, with a reliable air supply system, will perform very well over the long-term.

Conclusions and Recommendations

In general, the effectiveness of the EGC system in lowering opacity at maintained high load cannot be denied. The quantification of a long-term usage with respect to these and other advantages may be unclear at first, but will become evident with continued operation and design or control optimization. Short duration testing may not suffice to determine the gravity of the difficulties encountered during operation, nor the potential optimization required for trouble-free

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operation.

In the case of the example system, qualitative results may be expressed as follows:

- A reduction of around 20 percentage points in the opacity from 35-45% down to 17-22% with SO_3 injection.

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- An increase of around 5 percentage points in the opacity from 17-22% up to 22-27% without SO_3 injection.

These results certainly warrant further examination. In particular, the eye should be on the long-term opacity reduction, operational flexibility, long-term operation without build-up in the duct, fan horsepower reduction, and load increase within opacity limits.

Further testing may be accomplished with a properly functioning SO_3 system (the existing system may have plugged ports on the injection probes). The humidification system may, in this case, be utilized to enhance the performance of the SO_3, by providing equalized temperature conditions, thus allowing the injected gas to condense onto the flyash particulate and lower its resistivity.

Other options may be to look at defined zone cooling (where only the hot zones are cooled), and proprietary chemical injection, which may further enhance the operation of the ESPs. These additional chemicals may only require to be injected during peak power requirement periods, when maximum plant output results in greatly increased earnings.

Spray Lance
(Courtesy of EnviroCare)

Horizontal Duct Showing Spray Lance Mounting Boxes
(Courtesy of EnviroCare)

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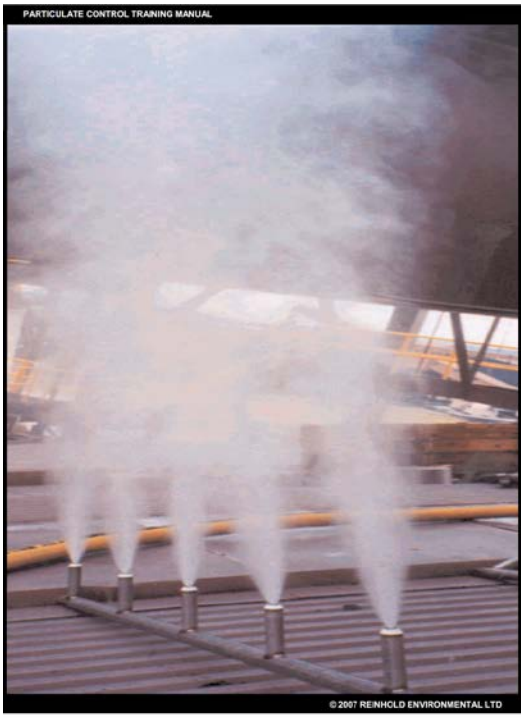

Spray Lances in Operation Outside Ducting
(Courtesy of Envirocare)

Spray Lances Shown Installed in Ducting
(Courtesy of Envirocare)

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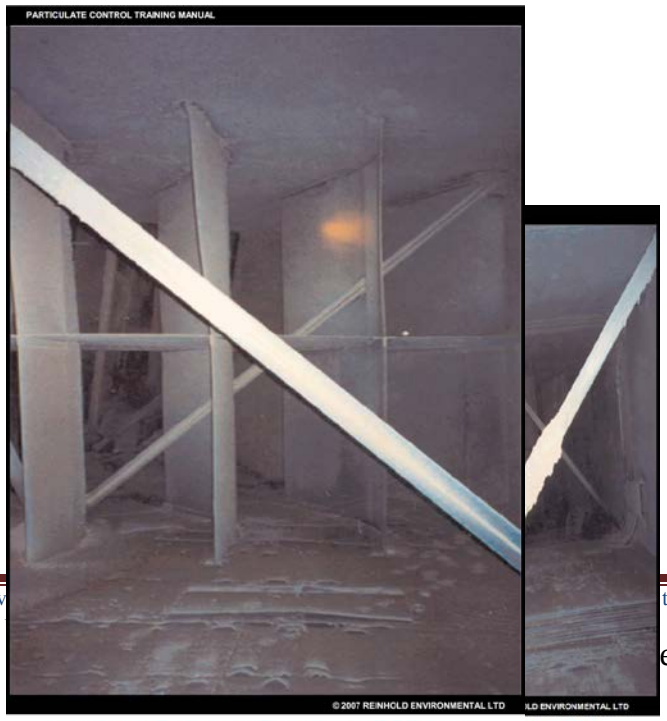
Various Build-up Details at ESP Inlet Turning Vane with No Significant Build-up Showing 2 (Courtesy of EnviroCare)

Detail of Spray Build-up on Cross-bracing Supports Showing Large Droplet Impingement
(Courtesy of EnviroCare)



Various Build-up Details at ESP Inlet Turning Vane with No Significant Build-up Showing 1 (Courtesy of EnviroCare)

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Various Build-up Details at ESP Inlet Turning Vane with No Significant Build-up Showing 3 (Courtesy of EnviroCare)

More Details of Build-up at ESP Inlet Turning Vanes and Cross-bracing
(Courtesy of EnviroCare)

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Build-up Details at ESP Inlet Thermocouples-This is Not Serious
(Courtesy of EnviroCare)

Detail of ESP Inlet Perforated Plates Showing No Significant Build-up
(Courtesy of EnviroCare)

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6.5 Chemical Additives

The most common flue gas conditioning chemicals are sulfur trioxide (SO_3) and ammonia (NH_3). They are often used together in dual conditioning, where the SO_3 reduces resistivity and the NH_3 reduces re-entrainment. There have been many other chemicals that have been successful in improving ESP performance to some degree, but were not widely accepted because of limited success or because of economics. They include ammonia, sodium, sulfur, and/or phorphorus compounds. These conditioning agents have been applied to both hot side and cold side ESPs. Some have been applied to the coal prior to combustion, while others have been injected into the flue gas ahead of the ESP.

Some advantages to proprietary aqueous additives are:

- Inexpensive injection system
- Non corrosive
- Saleable ash
- Acts as an agglomerator, thus helps reduce LOI problems

But there may be some possible disadvantages to these aqueous additives such as:

- Cost of additive over a life of plant
- Shelf life
- Presence of sophisticated flowmeter system to reduce over conditioning

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What will determine which flue gas conditioning system a utility plant purchases is the plant's answer to questions related to cost and application such as:

- What is the size of the plant?
- Will the unit be base loaded or cycled?
- Is the FGC system being purchased for the remaining life of the plant or as an immediate compliance solution?
- Is it possible to condition several units with one system?
- How much additive will be needed?
- Does the ESP benefit from additional agglomeration?
- Is the coal source stable or does the type of coal vary constantly causing varied conditioning needs?
- Is the opacity problem related to ambient temperature, thus making the opacity problem seasonal?
- How far is the plant from the source of the additive and what will the transportation costs be?

Coal Treatment with Sodium

Ash resistivity is determined by many factors, including ash chemistry, temperature, and moisture. For low sulfur coals, it has been well established that the sodium content of the coal and ash is critical. The sodium content of the coal is even more critical in hot side ESP applications. Low sulfur coals with sodium contents above 3% are relatively easy to collect. However, there may be boiler fouling and slagging problems with these coals. When the sodium content falls below 3% in low sulfur coals, the ash becomes more difficult for the ESP to collect. Thus, conditioning with sodium compounds has been relatively successful, particularly in hot side ESP applications.

Although liquid and dry injection of sodium compounds into the flue gas steam ahead of the ESP has been used, there are many difficulties that have made this approach unacceptable. The most common and easiest approach to sodium is to treat the coal prior to combustion. Generally either sodium sulfate or sodium carbonate is used. There are several units in the US that use this technique effectively. There economics must be evaluated based of the availability and cost of the sodium chemicals.

Proprietary Conditioners

Currently there are several major suppliers of proprietary chemical conditioners. Because the suppliers consider these conditioners proprietary, it is difficult to know their exact chemical composition. Many of the suppliers require the user to sign a confidentiality agreement not to divulge the chemical composition or to have the conditioner analyzed. Most of the conditioners are believed to be single chemicals or combinations of sulfur, sodium, ammonia, and phosphorus

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compounds. Different formulations are offered for hot and cold side applications to reduce resistivity and reentrainment. These materials often provide agglomeration, which increases particle size and improves cohesiveness.

One vendor's proprietary conditioner has ammonium nitrate and sodium nitrate in it as well as a proprietary conductive polymer to reduce resistivity.

These proprietary chemicals are generally injected as liquids into the flue gas ahead of the ESP. Typically an arrangement of lances and commercially available air atomization nozzles are used to produce a fine droplet mist. To avoid wetting and duct accumulation, these droplets must have enough time to evaporate prior to impinging on duct obstructions such as bracing, turning vanes, and perforated plates. The droplet size, temperature, and volume of conditioner are critical factors in the evaporation time. In general, the evaporation time is 0.1 to 0.5 seconds. The quantities of conditioner vary greatly and are given in various units, but a typical injection rate is 0.1 to 1.0 pounds of conditioner per ton (0.22 to 2.2 kg/metric ton) of coal burned.

Economics

The capital cost of proprietary chemical conditioning systems or coal treatment systems is sometimes substantially less than for SO_3 conditioning systems. Few and simpler components are required. The economics are driven be the amount of chemical conditioner required and its cost. The economics must be evaluated for each specific case. Situations where low capital costs are favorable and where the chemical usage may be economically acceptable are

- Smaller boiler units
- Cycling boiler units
- Variable coal sources, only some requiring conditioning
- Short boiler or ESP life expectancy
- Seasonal ESP performance problems

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CHAPTER 7 - SPECIFICATION AND ERECTION STRATEGIES

This chapter discusses the following issues relating to specifications and erection strategics:

- ***Preparing Specifications and RFQs***
- ***ESP Erection Strategy and Contract Management***
- ***Performance And Application For Particulate Control Equipment Sizing and Proposal Preparation Form***

Installing Plates with Roof Open

7.1 Preparing Specifications and RFQs

Introduction

Specifications for new control equipment or major rebuild should have about the same content. To simplify this description of specification (spec) preparation, we will restrict the description to a major rebuild.

The user can, of course, issue a performance spec, an equipment spec or something in between. However, even if the user elects to issue a performance spec, they should follow most of the steps described herein because they will need to know what equipment will work and what won't.

To make this description of spec preparation broadly applicable we will assume that a coal change is to take place.

Approach the Tasks of Writing Specs and RFQs Backwards

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The user must carefully consider and decide on:

1) What exactly do you wish the end result to be? What is the absolute minimum result, which will satisfy this need. No optimism should be reflected here. The absolute minimum will ordinarily be the environmental regulation covering this equipment.

2) Over this absolute minimum final result, a well considered margin of safety should be added which will provide additional performance over the absolute minimum which is acceptable in the event that actual operating conditions deviate in some unanticipated way from the conditions specified. Do not inject an allowance for such deviations in every sector of the specification. Instead it should be put here in one easily identifiable lump. Keep the specification as an honest estimate of what the expected conditions are to be.

3) Is the specification to be a performance spec or a detailed equipment spec? Each has its own drawbacks.

- A performance spec leaves you open to irresponsible vendors who will supply inferior equipment, which will result in high maintenance and operating costs and costly downtime not apparent in their proposal.
- A detailed equipment spec will tend to restrict the innovative vendor from using his particular skills in offering a novel approach to the problem, which is employed would result in adequate performance at a lower cost.

A specification is generally favored, which combines these two approaches, which will result in a performance spec with some minimum equipment features to protect you from irresponsible vendors.

The better the specification, the better the overall contract. So time spent on the spec is time well spent.

Preparation of the specification should be an "inclusive" process with involvement and input from all major departments, i.e. Control & Instrumentation, Electrical, Engineering and Training. Special attention should be given to compatibility to existing plant and space holdings.

With a performance based specifications, special attention should be given to boundary conditions with all information passed on. Additional information that could be critical but that is not available, should be dealt with so that the plant is available to the bidder for any special tests they might wish to perform. This should be clearly stated. Coal, ash, etc. should have minimum, typical, and maximum values. The design should be for a probable worst case scenario.

Performance specs should clearly state desired results (with a margin i.e. performance slightly better than limits) and the performance guarantee should be large enough to retain the bidder's interest. Certain ground rules should also be clearly stated, especially on things that affect price

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(i.e. plate thickness, plate area etc. in the case of ESPs). This will apply to the "Main Offer". Alternative offers, not in compliance, should be considered and this allows for greater innovation from bidders.

A well defined performance "Acceptance Test" should take place after about one year service, say about 8000 hours operation, with no special attention (special tweaking etc.) to the plant at least 100 hours prior to the test. The 8000 hour Acceptance Test should be done as near as possible under specified conditions (volume flow rate, the largest influence, can be adjusted to close to specified volume flow) and be preceded by an "Information Test" soon after the Plant Acceptance Test. This will allow the bidder to identify and correct any differences related to performance. Other defects will already have been remedied prior to acceptance.

The format of the bid should be specified with detailed spreadsheets of components and itemized costs. Further, a detailed program of sequence of events, showing critical paths etc., should be included in the bid. Unforeseen costs can be accommodated as "compensation events" but these should be kept to a minimum. Delays caused by the bidder being disorganized should be penalized.

The section of this manual dealing with guarantees, outlines thoughts regarding safeguards, which are believed necessary to obtain assurances that the required performance will be attained.

Vendor Qualification

In preparing a list of qualified vendors for new equipment or a major rebuild some substantial work should be done.

Some suppliers are essentially parts brokers. They do not have any manufacturing capability and subcontract the fabricating, manufacturing, and even the detailed engineering to others. Consequently, they often have a very low net worth, and are not worth suing in the event of project failure. For this reason alone it is necessary to know who the people who perform the work are.

The people who are going to be working on your job should be experienced, capable and understand the your business. These people should have done what you wish done successfully in the past. The company name has little to do with the quality of the job. It is the people who are important and there is no substitute for successful experience.

Substantive conversations with these experienced people should be held in advance of specification preparation. Their inputs to the specification are valuable, and every advantage should be taken of their people experience.

In a situation where coal switching is required, elaborate information must be included in the specification.

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Users can diminish their risk of poorly executed contracts by proper vendor selection. Suppliers can avoid profitless contracts and excessive un-recovered pre-contract expense by selective quoting.

- Vendors should not quote any project unless the content and timing fit their organization. Until they feel they have a superior ability to execute the particular contract and a very good chance of earning the award, they should not quote.
- Users should not put vendors on the bid list unless they have been recently qualified. The qualification should include an examination of the experience of all the key people that will be assigned to execute their project, and a demonstrated record of bringing contracts to satisfactory conclusion.

Selection of an erector by the utility or the equipment supplier requires special attention. The erector must be designated and then properly qualified by the user before a contract is placed. There are various standard items that should be checked to qualify equipment suppliers.

7.2 ESP Erection Strategy and Contract Management

Introduction

A user purchasing erection services needs to understand certain things about analyzing, planning, organizing and executing an erection or rebuild project. Without this understanding the user cannot:

Removal of Plates with Roof Off

- Schedule for all work activities (engineering, manufacturing erection) in detail.
- Identify problems at the early stage where they can be corrected with minimal impact.
- Anticipate conflicts with other contractors and or other projects during the outage.
- Understand their obligation to provide project support (and the timing of that support) i.e. material storage, lay down area, crane locations, temporary water and power, safety regulations, inspection, etc.

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Analysis

Installing Plates through Hopper Crotch

Before the contractor puts his proposal together he will visit the site and evolve an erection concept. When erecting new equipment each major supplier has a fairly standard erection approach which is modified only when site conditions require adjustments. With new equipment the analysis simply requires full input from the utility engineers and operators.

In the case of a rebuild the analysis gets complicated because there are a wide variety of rebuild approaches to match up with various site conditions. For ESPs, internals can be accessed from:

- The top - remove the roof or a portion thereof or slot the roof.
- The inlet or outlet nozzle - remove or slot from any direction.
- The bottom - remove hopper or slot the hopper.
- The side of the casing

Installing Rigid Discharge Electrodes

When erection is the responsibility of the supplier, the erection analysis will always consider shop assembly of various components. This is more difficult to organize if the user purchases equipment and erection separately. This separation can be the major cause for back charges, project delays, and major project cost overruns.

Plan

Once the erection concept/strategy has been developed, the erector should develop a detailed plan such as this one for an ESP:

- Select and organize the lay-down area so that new materials are stored in a pattern from which they can

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easily and efficiently be moved to the precipitator in the order in which they are needed.

- Plan work which can be done in advance of the actual shutdown, scaffolding, erection access, temporary elevator, welding machines with temporary wiring, lagging and heat insulation removal, temporary lights, hoses for washing or grain or grit blasting access for debris removal, air tuggers and hoists and air compressors and hoses.
- Pick crane locations. If tower crane start erection prior to outage.
- Locate offices, shanties, restroom, tool cribs, trash disposal etc. Arrange for gravel as required.
- Plan removal, storage and reinstallation of equipment such as TR sets, HT switches, insulator compartments, rappers and insulators, which are to be reused.
- Plan removal of materials to be replaced. This is frequently neglected to the detriment of schedules. Collecting plates, rigid wire frames and RDEs are often difficult to economically remove with a minimum of time consuming metal burning. Consider hydraulic bolt cutters and shears and pneumatic nibblers.

Preparing to Install Plates through Roof

- Careful planning of the hauling of new materials to the precipitator and coordination with debris removal can save time, trucks and prevent traffic jam delays
- Plan the erection sequence carefully once a cell is emptied of electrodes. It is often an economical practice to store new plates and RDEs in the vertical position inside the casing before plate supports or wire frames are installed. The position in which they are stored often has an impact on schedule.
- If additional TRs are to be installed or if TRs are to be replaced it is often worthwhile to place them in a new location either on flue roofs or cantilevered platforms. Careful planning can permit this work to be done before the shutdown is taken.
- Planning and investigation can often permit reuse of existing wire and conduit as well as switch gear for service not originally intended.
- Finally planning the QA work carefully with inspection before shipment of plates, RDEs, TRs and controls can often avoid field delays. Inspections as site installation proceeds can also nip problems in the bud, as well as ultimately assure a quality installation

Organize

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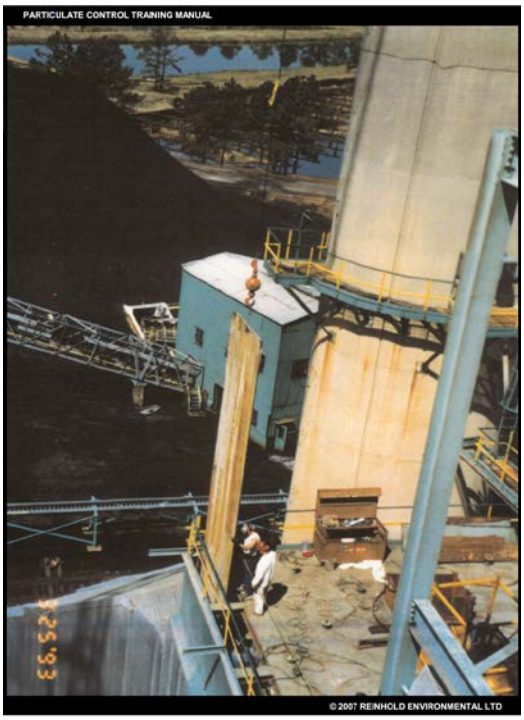

Installing Plates through Roof Slot

Upon receipt of an order it becomes practical for the contractor to put some serious money and manpower into refining the plan and organizing the project. Intensive communication with plant, personnel should occur at this point. Major considerations in organizing the project are as follows:

- Set and have agreed to by all parties a realistic schedule which is achievable, and which can be modified only with extreme justification.
- The owner or his single agent must coordinate the erection plans of various contractors long in advance to prevent conflicts from developing in the first place
- Avoid interference by or with other contractors on site. Two cranes cannot be located on the same spot, certain work cannot be done with people below. Contractors employing the same trades can't offer widely different overtime incentives a final arbitrator must be appointed to quickly settle these issues.
- The operating people should be allowed to observe the installation so they understand how it goes together. As soon as substantial sections of the work are completed operator and maintenance training should start so that when the unit goes into service these people will be as familiar as possible with it.
- This is the time, with new equipment, to get operators to do routine like maintenance instead of mechanics newer equipment is designed with this in mind.
- Make sure that line supervisors in operation and maintenance use the construction period to understand the equipment.

Installing Plates with Roof Open

Execution

Execution of the erection portion of a project has certain critical stages that should be checked by the user engineers:

- We have mentioned quality assurance previously but we should emphasize that

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a satisfactory installation that produces continuous longterm compliance can only be achieved two ways:

1) Careful quality control at every step of process from design to manufacturing to erection.

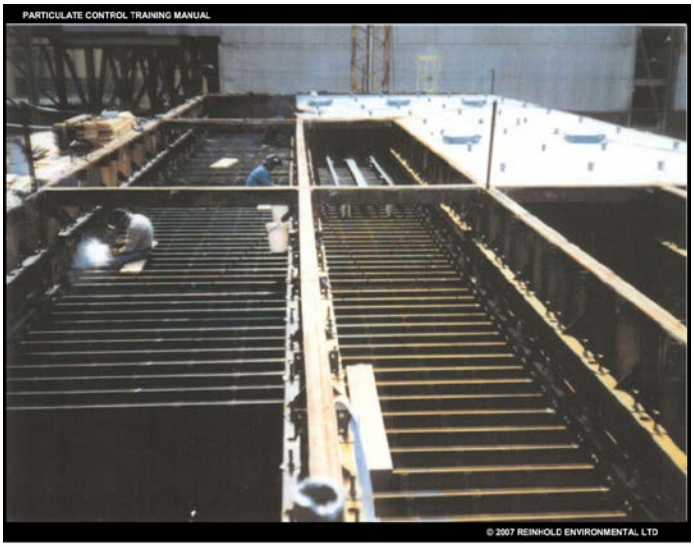
2) Good Luck

We would rather have both, but if we can only have one, we want the first.

- You cannot make a silk purse out of a sows ear. We must have properly fabricated parts to start with.
- All parts delivered to the job must be checked for adherence to tolerances and quality showed on the drawings.
- The casing components and the casing must be square and plumb to maintain the required alignment of the internals.
- Daily project review meeting with plant, vendor and all contractors addressing work conditions and schedule progress is a must.

Closing the Contract

Very detailed contract scope must be defined in the early stages of a project. This provides the basis for both purchaser and supplier to gather and disseminate all information required for:



Final Welding

1) A punch list of items to be completed

2) Resolution of extra work issues

For the close out to proceed properly the contract must

include a well defined "Acceptance by Owner" clause.

1) Completion of scope

2) Compliance with guarantee

3) Compliance with warranty

Both purchaser and supplier must have systems and procedures in place to:

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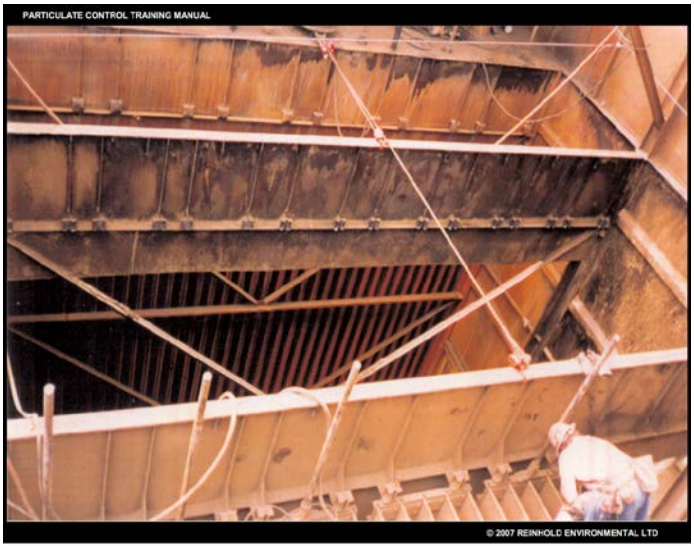
1) Keep necessary records and hold appropriate progress meetings

2) Record all agreements reached at progress meetings signed by both parties.

Summary

The erection of new equipment or a major rebuild is a partnership of sorts. Both parties must understand what is required of them. If the erector and the user work together and help each other, both parties can satisfy their goals. Without the understanding and cooperation, the project will almost certainly miss the completion date and/or overrun the budget. Quality will also be placed in jeopardy.



New Internals with Roof Off

7.3 Performance And Application

See attached Performance And Application For Particulate Control Equipment Sizing & Proposal Preparation Form.

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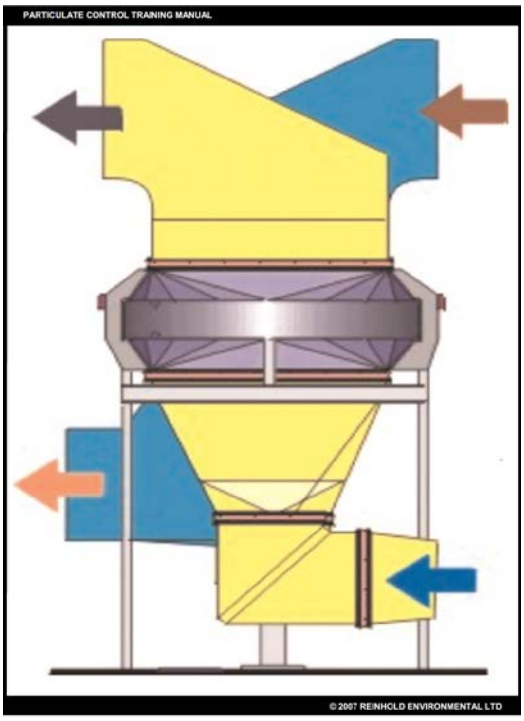
CHAPTER 8 - AUXILIARY EQUIPMENT AFFECTING PARTICULATE COLLECTION

This chapter discusses the following auxiliary equipment which affects particulate collection:

- *Air Preheaters: Factors That Affect ESP Performance*
- *Duct and Casing Design for Long Term Reliability*
- *Fly Ash Handling System*
- *Fans*



Rothemuhle Air Preheater with a Rotating Heating Element Matrix

8.1 Air Preheaters: Factors That Affect ESP Performance

Introduction

The most important factor in gas temperature distribution in cold side precipitators is the design and condition of the air preheater. This Section discusses the air preheater and its effect on cold side precipitators. It also discusses air heater considerations in the conversion of hot side installations to cold side operation. These considerations are vital to a successful outcome of the conversion.

Air Heater Design

There are two basic designs of air pre-heater. By far the most common is the regenerative air heater where flue gas is used to heat metallic elements, which store the heat and release the stored heat to the combustion air. In the United States and in much of the world the most common regenerative air preheater is the Ljungstrom design, followed by a distant second, the Rothemuhle air preheater. The marked advantage of regenerative air heaters is their simplicity

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and space economy. The disadvantage is air leakage from the combustion air into the flue gas, which can be considerable. Another disadvantage is variation in temperature in the flue gas from side to side of the air heater.

The other design of air heater is the tubular air heater, which is non-regenerative with the heat from the flue gas being transferred by convection and conduction through the tubes and the gas and boundary layers to the combustion air. The principal supplier of tubular air heaters in America is the Babcock and Wilcox Company. Overseas there are a number of suppliers including Deutche Babcock, English Babcock and Wilcox and the Skoda Works. The major advantage of this air heater design is its freedom from air leakage when properly maintained. Its major disadvantages are its proneness to plugging and corrosion as well as its bulkiness. It generally has two forms, single pass and usually downflow, or double pass usually a downflow pass followed by an upflow pass. These air heaters are usually used on cyclone boilers where the high differential pressures between combustion air and flue gas tend to cause substantial leakage of air into flue gas with the use of regenerative air heaters. They also produce temperature differentials in the flue but usually not as severe as in regenerative air preheaters.

Regenerative air heaters of the Ljungstrom design can take several forms depending on coal moisture and plant design. The air heater functions are to supply heated combustion air to the furnace, improving the thermal efficiency of the boiler and to dry the fuel, external to the furnace in pulverized coal units.

In all furnaces the combustion air is divided into two or three classes. In most furnaces the air is injected as primary air, which goes in with the fuel and starts the first stage of combustion of carbon-to-carbon monoxide and hydrogen to water. The secondary air is introduced to complete the oxidation of carbon monoxide to carbon dioxide and provide an excess of oxygen to insure complete combustion, leaving as little unburned carbon and carbon monoxide as possible.

In newer boilers and in high boilers designed to minimize nitrogen oxide formation the use of tertiary overfire air is used so combustion takes place in three stages or more to minimize flame temperature to reduce nitrogen oxide formation, which is dependent on flame temperature. This practice is called staged combustion. It often results in higher fly ash combustible content.

If the moisture content of fuel is high as in low ranked coal such as lignite and sub-bituminous in pulverized coal furnaces, it is necessary to have high primary air temperatures to adequately dry the coal in the mills before injection through the burners. This prevents plugging in the mills and coal pipes to the burners and roping in the coal pipes (non-uniform mixing of coal and primary air to burners).

With high rank coals such as Eastern and Midwestern, this does not cause additional problems.

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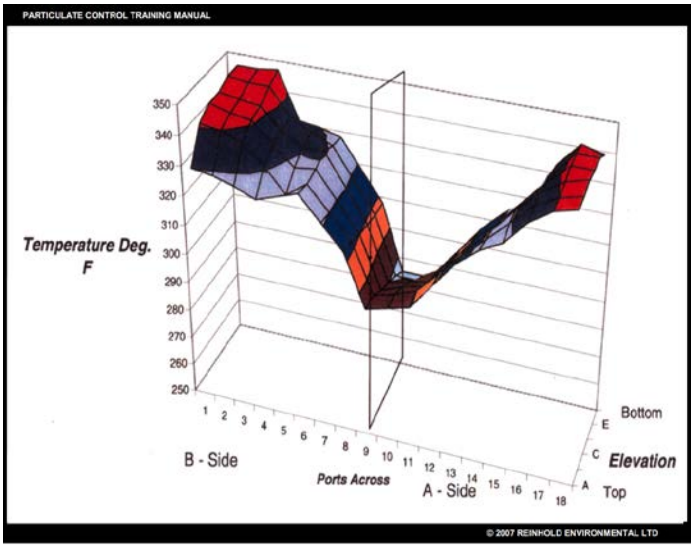
With low rank fuels, the first solution was to use separate primary and secondary air heaters producing secondary and primary air at different temperatures and result in flue gas temperatures, which vary in temperature between the primary and secondary air heaters. With a good flue design, the separate flue gas stream can be mixed to improve temperature equality.



Precipitator Inlet Temperature Profile

In a later design, the tri-sector Ljungstrom was developed. In an ordinary air heater, the sector plate separates the combustion air flow from the flue gas flow with the heating elements or baskets in a rotor moving between them. In the trisector air heater the sector plate has three sections, primary air, secondary air and flue gas. The rotor baskets, newly heated by the flue gas, move first to the primary sector and then to the secondary sector. The rotation produces a flue gas differential temperature with the coldest flue gas emerging from the section just emerging from the air side where the heat has been extracted and the hottest flue gas emerging just before the rotor enters the air side. The temperature differential is greater with greater air heater diameter and is further increased with tri-sector air heaters.

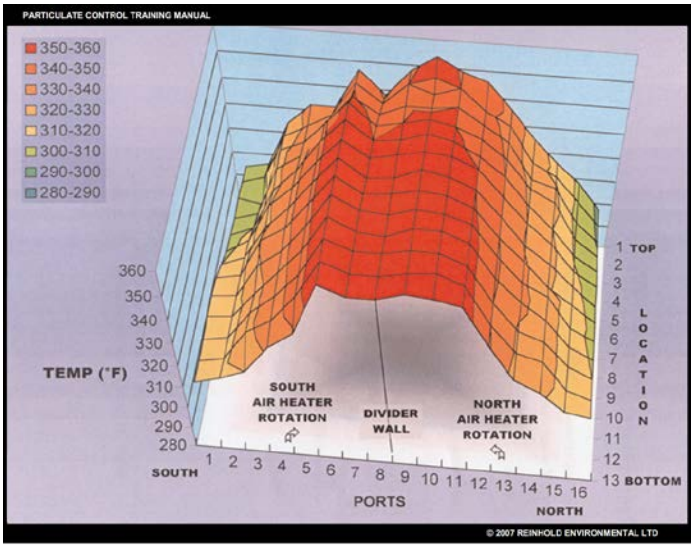
Figures:

Precip. Inlet Temperature Profile

and

Precipitator Inlet Gas Temperatures

show the flue gas temperature profile entering a precipitator preceded by a Ljungstrom Air Heater. The air heater rotors turn in opposite directions in both cases. The rotation is such that in the first figure the two hot spots are on the outer walls. In the second figure, the rotation causes the two hot spots in the center of the precipitator to merge into one.



Precipitator Inlet Gas Temperatures
(Courtesy of EnviroCare)

The differential in **Figure:**

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Precip. Inlet Temperature Profile

is 60°F (33°C) and in **Figure:**

Precipitator Inlet Gas Temperatures

is 55°F (30.6°C).

In another case where ESP specific current data is available, but no graphics, the temperature differential is 78°F (43.3°C) and the specific current ranges from 67 microamps/ft2 in the cold area to 2.8 microamps/ft2 in the hot area. This is due to the increase in resistivity in hot areas.

All three of these units required derates due to excessive stack opacity in hot weather and often even in cooler weather.

In a further complication, the Ljungstrom air heater can have either a horizontal or a vertical shaft, and depending on the flue arrangement, the temperature differentials may be both vertical and horizontal.

In a tubular heater differentials are usually vertical, especially in single pass air heaters.

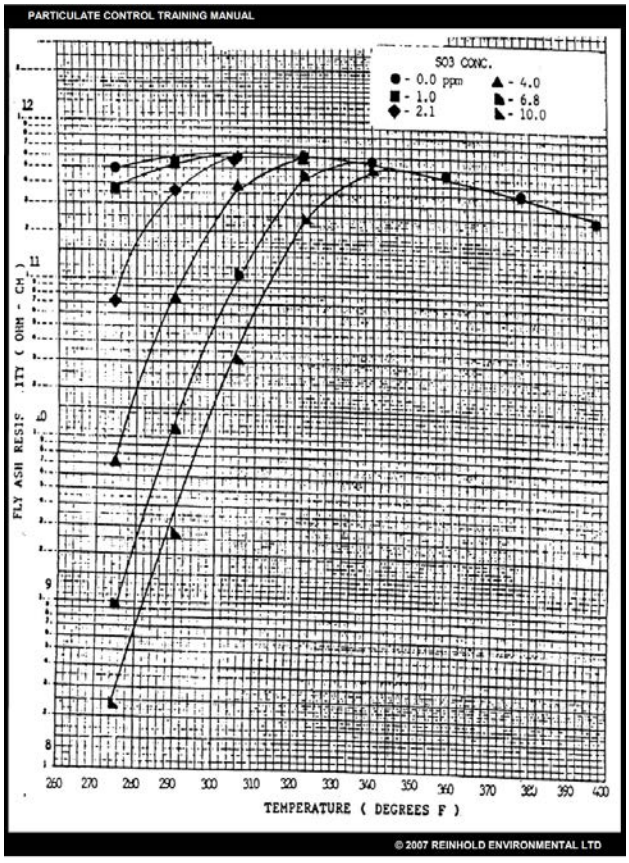
Resistivity

The electrical resistivity of fly ash is dependent on gas temperature gas sulfur trioxide and moisture content and the fly ash composition. With lower sulfur, coal ash resistivity is very sensitive to gas temperature.
Figure:

Predicted Fly Ash Resistivity for Jim Walter Coal

shows a typical fly ash resistivity.

Ash resistivity controls the power input to the precipitator. Power input determines the collection efficiency in a given precipitator. Different gas temperatures result in different portions of the precipitator.



Predicted Fly Ash Resistivity for Jim Walter Coal

Figure:

Predicted Fly Ash Resistivity for Jim Walter Coal

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shows this graphically. The particular fuel is a low sulfur Eastern coal with an ash high in silica and alumina. This type of ash is extremely temperature sensitive and illustrates the temperature effect on resistivity of glass non-absorptive ashes. This effect is, of course, present with all fly ash but is especially pronounced in high silica, high alumina, low calcium, low iron ash.

Summary

The example shown in this section shows the adverse effects of poor gas temperature in one case. In many cases similar problems have occurred.

In two Northeast U.S. power stations, cross ducting has been installed which equalized temperature distribution.

In the case of a Southwestern U.S. power station installation, addition of additional heat transfer surface, changing the rotation of one air heater and speeding up the rotation permitted operation without gas conditioning and resulted in a heat rate improvement of just under 500 Btu/kwhr over the rate of hot side precipitator converted to cold side.

In the case of a Midwestern U.S. power station, superheater surface was added.

There are many ways to overcome the bad effects of gas temperature distribution problems caused by air heaters.

Also, improvements such as self adjusting air heater seals and dense pack baskets have improved the situation and reduced maintenance. Deteriorated air heaters and deferred maintenance remain a major source of poor precipitator performance.

Great performance improvements in cold side precipitators can often be made in beginning with a temperature and power input analysis such as done at Monitour station. In the analysis of precipitator problems one of the most common mistakes is not determining the actual temperature differentials across the precipitator face. The single or two air heater outlet temperature displayed on the unit computer can be misleading.

Case Study

Description of Installation

Plant A, Unit 2 is a 750 MW pulverized coal fired steam electric generating unit. The steam generator is a Combustion Engineering tangential fired boiler rated at 5,700,000 lbs/hr (2364 metric tons/hr) of superheated steam.

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The precipitator system, serving this boiler, was supplied by the Western Precipitation Division of Joy Manufacturing Company. The system consists of two-four chamber electrostatic precipitators in parallel, arranged in a "chevron" design. Each chamber consists of 40 gas passages nine (9) inches (225mm) wide by 30 feet high by twenty four (24) feet long. The length is divided into four (4) - six foot fields.

The system is rated to treat 2,260,000 ACFM (3,834 gas m3/hr) of flue gas at 303°F (150°C). At this flow the velocity through the precipitator is 5.25 ft/second (1.60 m/sec.) and the residence time is 4.58 seconds.

The collecting electrodes are 20 gauge Western Precipitation module fin plates.

The discharge electrodes were originally a Western Precipitation design using one tensioning weight for two wires. These were replaced, in about 1978, with 0.1055 inch (2.7mm) Ø plow steel wires with shrouds top and bottom and individual weights. A lower steadying frame and steadying insulators in the hopper were added when this modification was made.

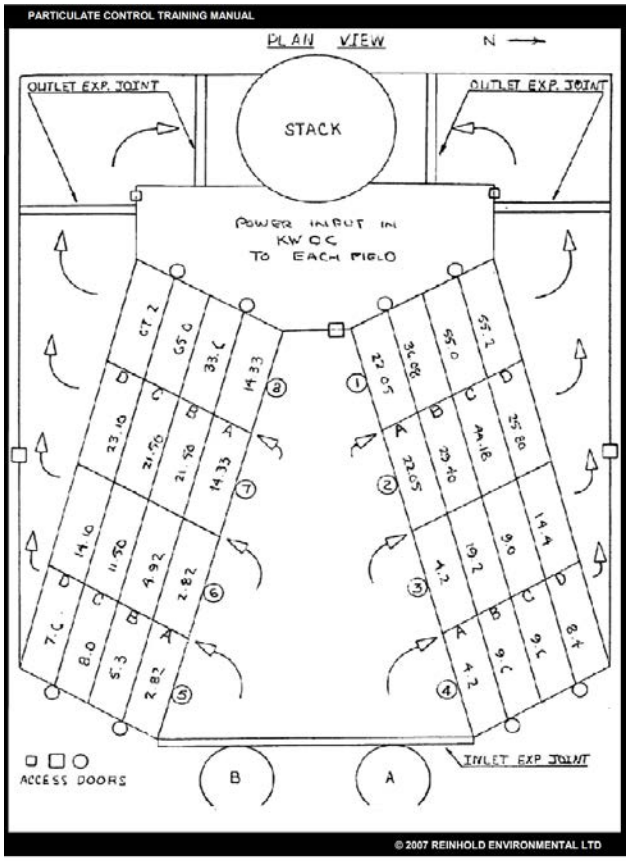
The discharge electrode and collecting plate rappers were originally P-150 electric vibrators, two per discharge electrode frame and six per field-cell for cleaning collecting plates.

Changes were made to the collecting plate rappers in an effort to improve effectiveness. Magnetic rappers are now installed.

The electrical energization was supplied to this installation by 16 full wave silicon rectifiers, all 45kv DC average voltage output; 8 rectifiers were rated 900 MA, 63.7 KVA and 8 were rated 1300 MA, 92 KVA. Controls were Western Precipitation transistomatic saturable reactor automatic spark rate controls.

Twelve (12) additional rectifiers have been added to the installation.

There are a total of 460,800 ft2 (42832 m2) of collecting electrodes in the installation so there are now 14,400 ft2 (1338 m2) of plate per rectifier in the B, C & D fields and 28,800 ft2 (2677 m2) in the A fields.



Current Density Section by Section

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The comparable numbers for discharge electrodes, where total length is 307,200 linear feet (936,585 linear meter), are 9600 linear feet (2927 linear meter) per rectifier in the B, C & D fields and 19,200 linear feet (5854 linear meters) per rectifier in the A fields.

Analysis of Operation

A review of the precipitator operating logs, with a unit load of 755 MW, shows a power input of 684 KW DC. This power input computes to 303 watts per 1000 ACFM of gas. This is acceptable provided power distribution is equalized.

In **Figure:**

Current Density Section by Section

, the individual section power inputs are shown on the fields.

Note that the power input to the B precipitator is higher than to the A precipitator and that the chambers nearer to the chimney (1, 2, 7 & 8) absorb much more power than the chambers closer to the air heaters.

The collecting plates were extensively tested with a "D" meter to measure their thickness and permit an estimate of their remaining life. A summary of the thickness readings at the bottom first panel of selected plates is shown in **Figures:**

Plate Metal Thickness 1

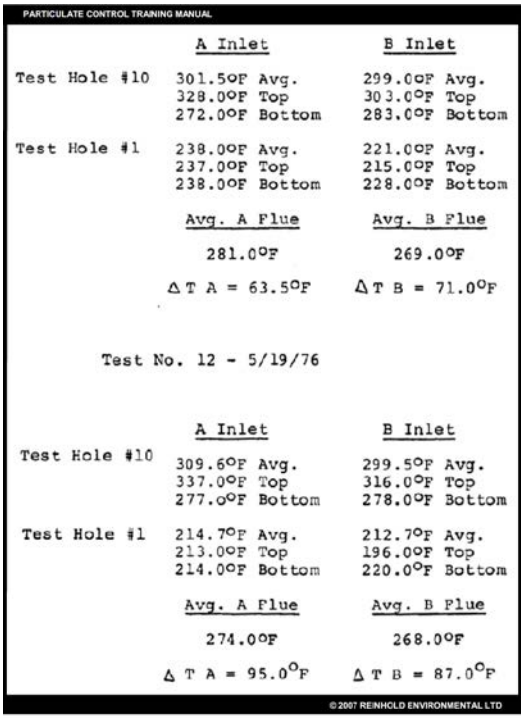
and

Plate Metal Thickness 2

(readings taken 1' up from the bottom of the plate).

These graphical representations show the overall condition of the collecting plates.

Analysis of Gas Temperatures


PARTICULATE CONTROL TRAINING MANUAL

	A Inlet	B Inlet
Test Hole #10	301.5°F Avg. 328.0°F Top 272.0°F Bottom	299.0°F Avg. 303.0°F Top 283.0°F Bottom
Test Hole #1	238.0°F Avg. 237.0°F Top 238.0°F Bottom	221.0°F Avg. 215.0°F Top 228.0°F Bottom
	Avg. A Flue	Avg. B Flue
	281.0°F	269.0°F
	ΔT A = 63.5°F	ΔT B = 71.0°F

Test No. 12 - 5/19/76

	A Inlet	B Inlet
Test Hole #10	309.6°F Avg. 337.0°F Top 277.0°F Bottom	299.5°F Avg. 316.0°F Top 278.0°F Bottom
Test Hole #1	214.7°F Avg. 213.0°F Top 214.0°F Bottom	212.7°F Avg. 196.0°F Top 220.0°F Bottom
	Avg. A Flue	Avg. B Flue
	274.0°F	268.0°F
	Δ T A = 95.0°F	Δ T B = 87.0°F

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Flue Gas Temperature

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A review of the raw data from the test series permitted computation of the temperatures at selected points in the inlet flue. The raw data we used in our analysis is shown in **Figure:**

Flue Gas Temperature

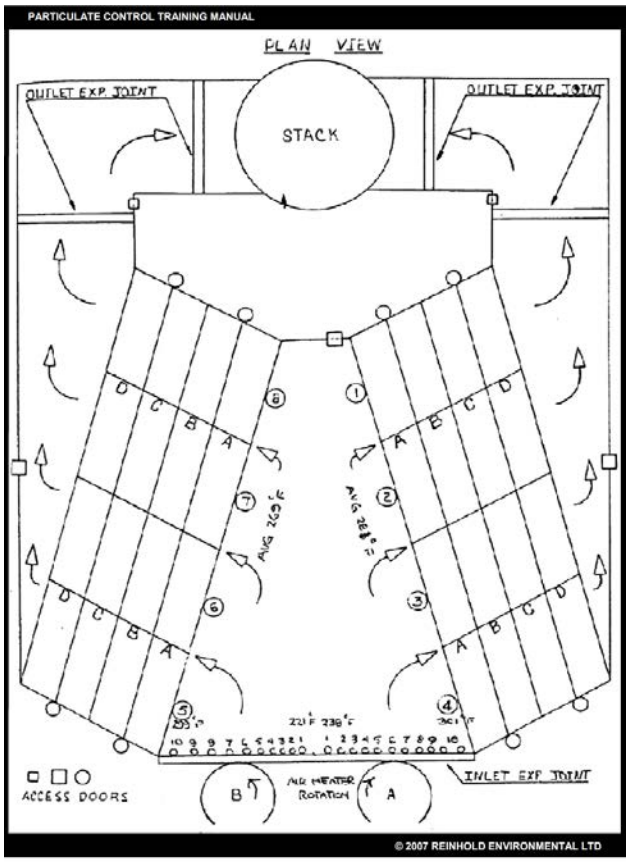
.

Also shown is the analysis made for two weeks. This demonstrates the wide temperature differentials across the air heater gas outlet ducts, which is certainly reflected in the precipitator gas inlet conditions.

Chambers 1 and 8 must be running at close to dew point or below dew point conditions at times.

For the sake of clarity, the locations of test holes 1 through 10 on both the A and B sides are shown with the actual average temperatures at points 1 and 10. These are shown in **Figure:**

Flue Gas Temperature Graph



Flue Gas Temperature Graph

.

The review of gas temperatures and conclusions reached are borne out in the previous section regarding the electrical operation of the precipitator.

When the condition of the collecting plates is compared with those in Plant A, Unit #1, it is obvious that Unit #2 is in poorer condition. In many areas the plates are nearing the end of their useful life.

The summary of plate thickness measurements indicates that the loss of plate material is extremely serious. These are shown in **Figures:**

Plate Metal Thickness 1

,

Plate Metal Thickness 2

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and

Metal Thickness Coupon

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The Influence of Regenerative Air Preheaters on ESP Operation

Most of the big coal fired boilers are equipped with an air preheater. By means of the air preheater the air temperature to the furnace is increased; at the same time the flue gas temperature is decreased close to the sulfur dew point, the lower limit on the flue gas side of the boiler process. The preheated air allows a better incineration of the fuel and the drying of the coal during the grinding process. All these effects lead to a better usage of the fuel, i.e. an increased efficiency of the boiler. See **Figure:**

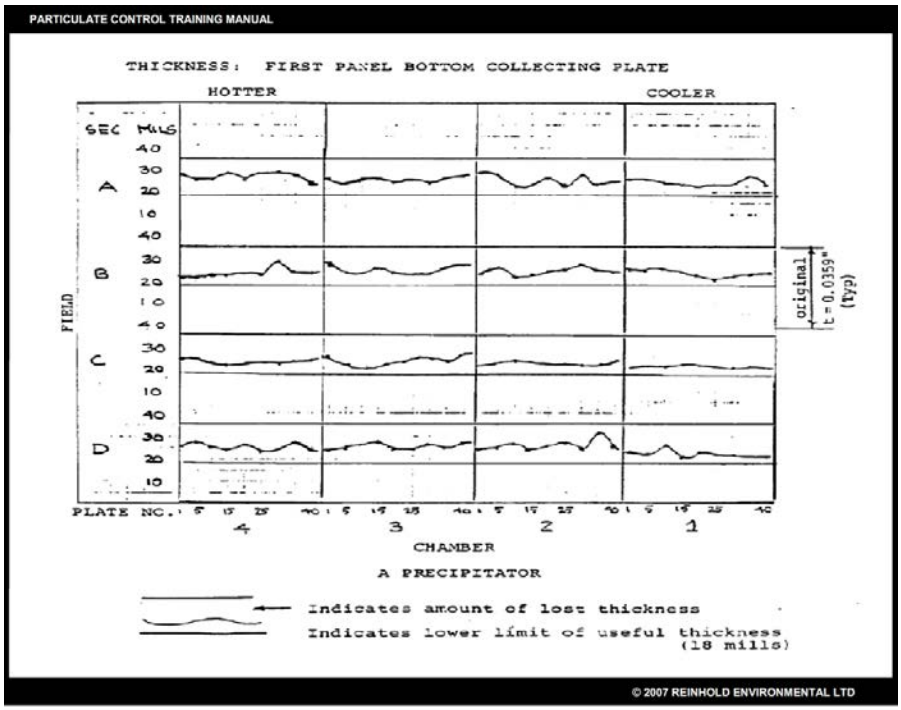

Plate Metal Thickness 1

The Air Preheater as Part of the Air-flue Gas System of a Coal Fired Boiler

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Air preheaters are gas-gas heat exchangers. They suffer from poor heat transfer coefficients compared to the heat transfer coefficients in the liquid phase or to coefficients known from condensation on surfaces. Therefore, the big volume flow of air and flue gas in a boiler will need a huge volume for the implementation of an air preheater.

Due to the compact arrangement of heating surfaces, regenerative heat exchangers can reduce the necessary volume to approximately 25 % of the volume, which is necessary for a recuperative heat exchanger dedicated to the same task. An extremely compact design could be performed by the development of a rotating regenerative air preheater providing a continuously working regenerative heat exchanger in one machine.

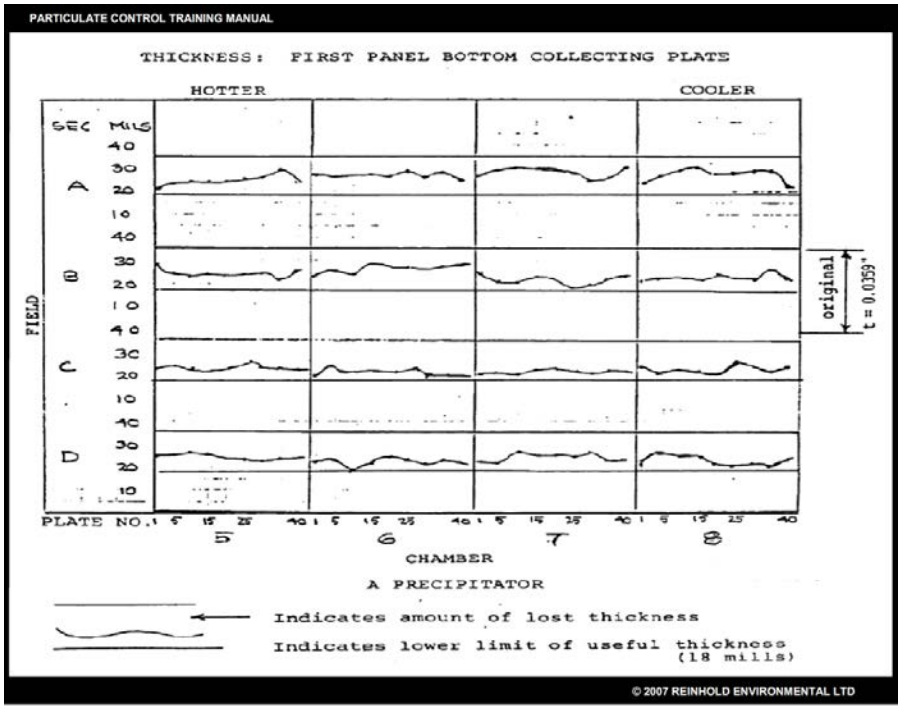

Plate Metal Thickness 2

Furthermore the operational experience proves that regenerative air preheaters have a very high reliability, as they are not sensitive to erosion from dust. Their efficiency is hardly influenced by dust layers on the heating surfaces. Because of these qualities regenerative air preheaters are the common equipment for big boilers,

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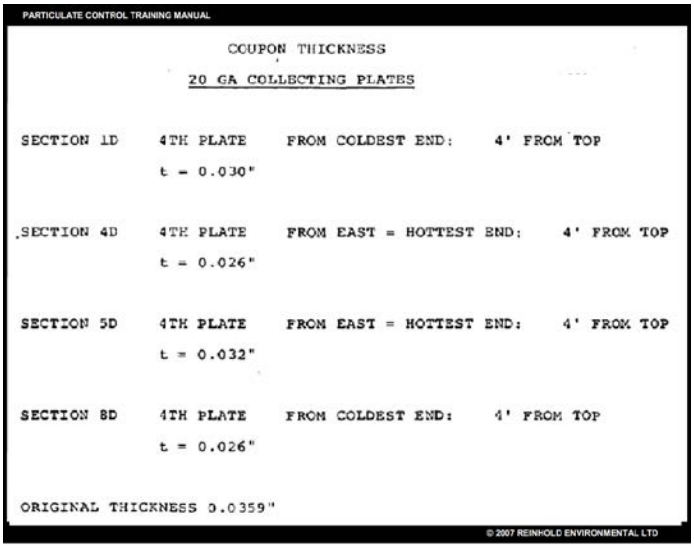
whereas recuperative heat exchangers are limited to small units or special boiler designs.

The regenerative heat exchanger influences the operation of the ESP mainly by three parameters

- temperature profile
- leakage
- chemical reactions in the air preheater



Metal Thickness Coupon

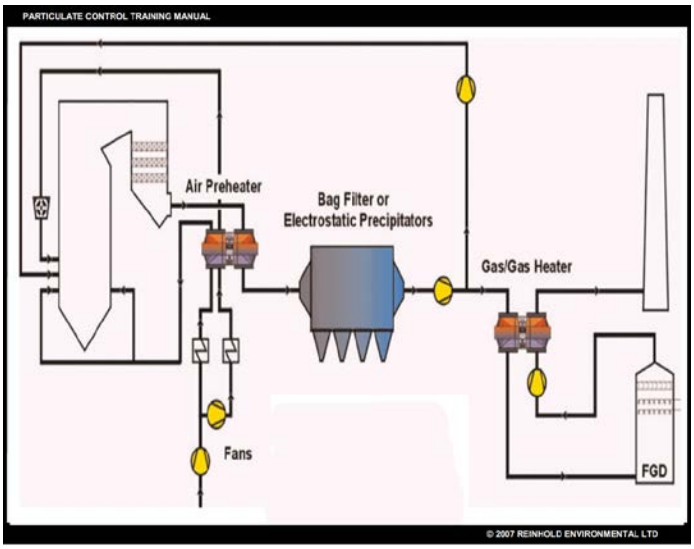
Temperature Profile

The temperature of the flue gas coming out of the air preheater is not evenly distributed. As with recuperative heat exchangers, the outlet cross section has a colder and an opposite hotter side. The difference from cold to hot side comes up to approximately 50°C (90°F). However the indicated design temperature for the ESP will normally be the average temperature of the air preheater outlet.

To a great extend the performance of the ESP depends on the specific resistivity of the dust on the collecting electrode. The specific resistivity of the ash in a coal-fired boiler is mainly determined by the chemical components of the ash and the temperature. Especially in the temperature range below approximately 170°C (338°F) the specific resistivity of the ash changes because of surface effects from SO_3 on the dust particulates. See **Figure:**

Specific Dust Resistivity Depending on Flue Gas Temperatures and Humidity

.



The Air Preheater as Part of the Air-flue Gas System of a Coal Fired Boiler

If the specific resistivity passes a range of about 5*1011 O cm, back-ionisation will occur tearing down the efficiency of the ESP tremendously.

The following figure shows an example where the difference of temperature from the

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regenerative air preheater causes a reduced efficiency of the ESP, as can be derived from the dust concentration measurements and the VI-curves.

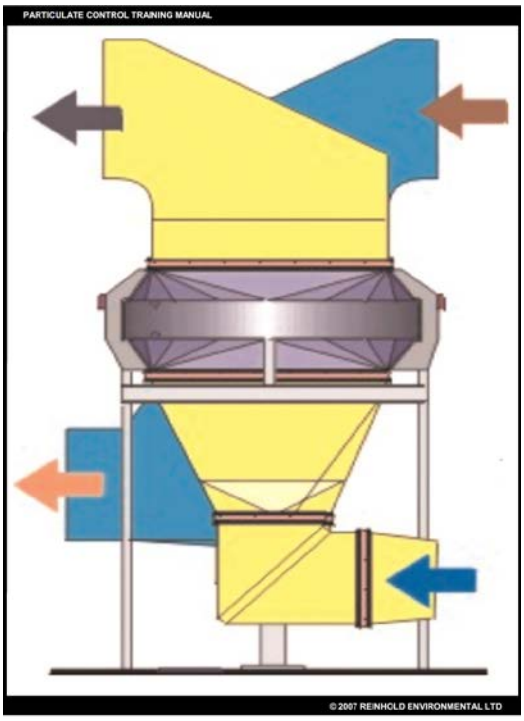
Figure:

Measurement of Temperature and Dust Concentration Profiles in Front and Behind an ESP Including the V1-curves

shows measurements regarding an ESP behind a lignite fired boiler in Greece. **Figure:**

Specific Dust Resistivity Depending on Flue Gas Temperatures and Humidity

is the corresponding curve of the specific resistivity of the ash. The coloured curves show calculated resistivity values according to Bickelhaupt. Though this method is used for the ash of a Greece lignite, and not of a bituminous coal as it should be, it seems to indicate the minimum level of resistivity compared to the measurements of the laboratory, the results of which are remarkably higher.



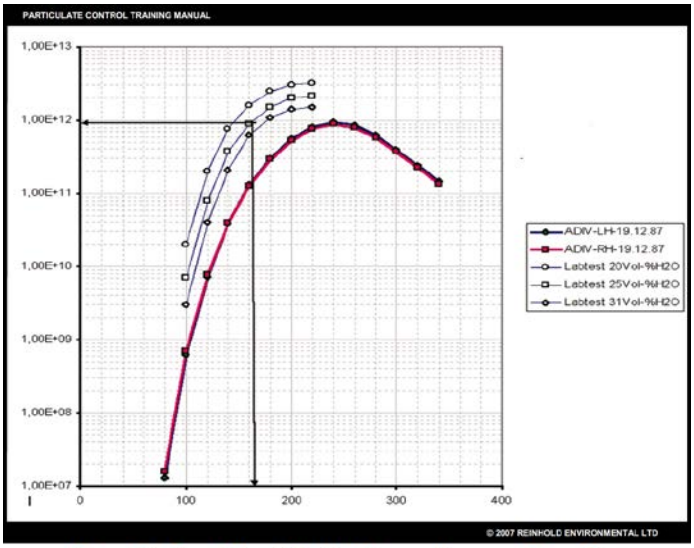
Rothemuhle Air Preheater with a Rotating Heating Element Matrix

Both casings see a flue gas stream entering with a clear temperature profile. The outer sides have a temperature level of about 150°C (302°F), whereas the inner sides indicate a level of approximately 180°C (356°F). Behind the ESP the same temperature profile still exists.

Both flue gas streams have an almost evenly distributed dust concentration, only the left showing a tendency to higher concentrations to the inner side of the duct.

The two ESP's are equipped with 6 TR-sets, each of the three sections having two sets in parallel. By these means the influence of temperature can clearly be observed:

- The first section is determined by a higher level of room charge and dust selection of lower specific resistivity. Under these conditions the colder fields show a sound VI curve with a break through point close to 50 kV. In the inner



Specific Dust Resistivity Depending on Flue Gas Temperatues and Humidity
(Courtesy of W. Frank)

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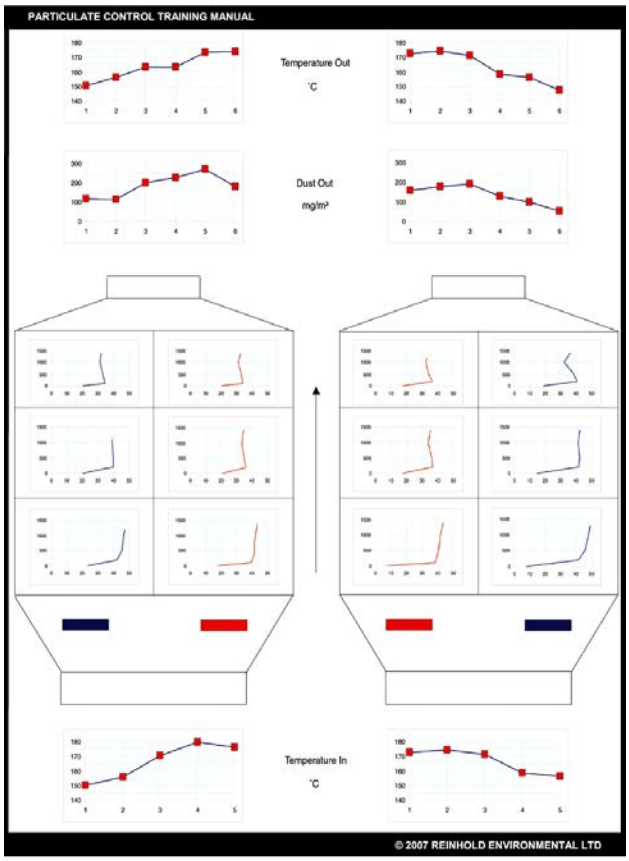
parts with a higher gas and dust temperature the VI-curves indicate a dust with a higher resistivity and a maximum tension limited to about 42 kV.

- The VI-curves of the following sections indicate clearly the behavior a back-ionization. Yet the outer parts with lower temperatures still can go up to a voltage of about 40 kV before back-ionization starts, whereas the higher temperature only allows some 35 kV maximum. In general the operation in the left hand casing is slightly worse than in the right. It might be that only the highest temperature level causes back-ionization; but, as it is always true for an ESP, the weakest electrical conditions direct the behavior of the total field.
- Consequently the clean gas conditions at the outlet of the ESP are obviously different. In the inner parts with higher temperatures dust concentrations range from 200 mg/Sm³ (0.087 g/Sft³) on right hand side to about 280 mg/Sm³ (0.122 g/Sft³) on the left hand side. The parts with lower temperatures are clearly better: They move from 50 mg/Sm³ (0.02 g/Sft³) behind the right to about 120 mg/Sm³ (0.052 g/Sft³) behind the left casing.



Measurement of Temperature and Dust Concentration Profiles in Front and Behind an ESP including V1 Curves (Courtesy of BHA)

The greater number of rotating air preheaters is built with a rotating heating element matrix. They have static connecting ducts on the flue gas and air side as shown in **Figure:**

Rothemuhle Air Preheater with a Rotating Heating Element Matrix

. With this design the downstream flue gas shows a stationary cold and hot side as described before.

Hamon Rothemühle Cottrell also builds a special type of regenerative air preheater with a static heating element matrix. Rotating hoods operate as a moving ducts. Simultaneously they form the link between the outside static air and flue gas ducts and the static heating element matrix. See **Figure:**

Rothemuhle Regenerative Air Pre-heater with Static Heating Element Matrix and Rotating Hoods

.

In big boiler units the heating element matrix weighs several hundred metric tons. The design with rotating hoods avoids this weight to be supported by one roller bearing only. Instead, the

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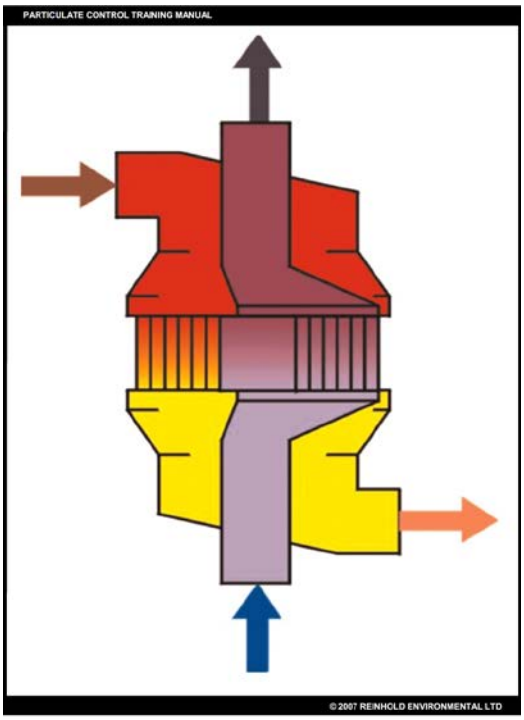
loads are supported in several points of the steel structure. This design is rigid enough also to bear further loads from adjacent ducts of the air and flue gas side.

The basic principal of the Rothemühle type of regenerative air preheater is identical, but here the rotating hoods create a rotating temperature profile in the flue gas duct to the ESP. Regarding ESP operation this means that the flue gas temperature inside the ESP casing changes according to the rotational speed of the hoods. Because of its relatively high heat capacity the temperature of the dust layer and the steel plates follows these changes with a reduced amplitude only. Consequently the temperature of dust layer, decisive if back-ionization occurs or not, is mainly the average flue gas temperature in all parts of the casing. A definite temperature profile as described before will not occur. Thus, with regard to critical kinds of dust, the rotating hoods of the Rothemühle type air preheater make the downstream ESP less sensitive for back, ionization as the weakest condition in the electrical field is not determined by the maximum but by the average temperature of the flue gas.



Rothemuhle Regenerative Air Pre-heater with Static Heating Element Matrix and Rotating Hoods

Leakage

The relative motions between rotating and static elements of both types of regenerative air preheaters make a leakage from air to flue gas side unavoidable. Sealing systems are to minimize this leakage.

A modern and a well maintained sealing system could keep the leakage below 5% of total flue gas volume flow. But if a revamping of a worn-out ESP is considered, probably also the air preheater is not in a good condition. Leakages might increase to a level of more than 20% of total flue gas volume flow.

The air preheater leakage causes both an increased air and flue gas flow. This means an increased power demand for the forced and for the induced draft fan. Important for the ESP operation is the increased flue gas velocity in the ESP. This effect will cause a remarkable effect on the separation efficiency of the ESP. See **Figure:**

Correction of Migration Velocity Depending on Flue Gas Flow Ratio

.

Furthermore, a concentrated local air leakage stream, with a lower humidity, can limit the maximum voltage at a lower level thus reducing the separation efficiency of the bus section.

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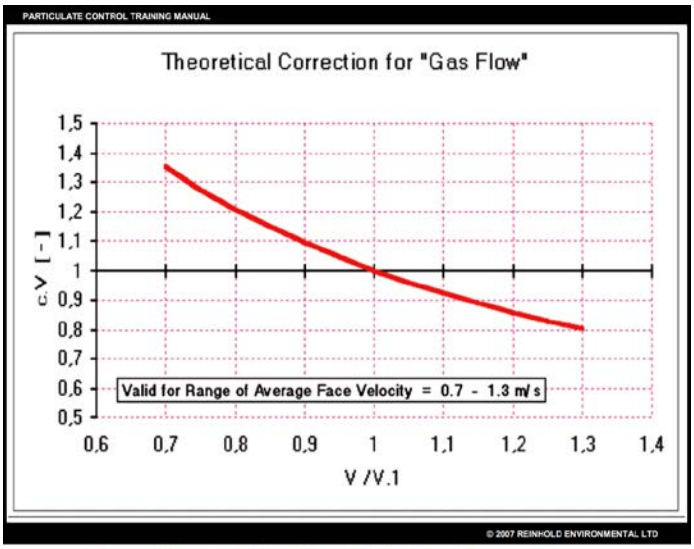
Consequently the air preheater should be checked before defining the measures of an ESP revamping. The reduction of leakages will be favorable for the efficiency of the plant on the whole and particularly for the performance of the ESP.



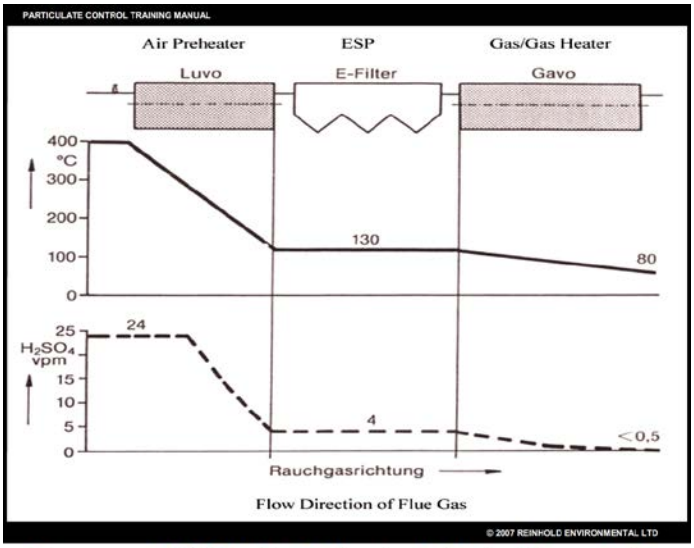
Correction of Migration Velocity Depending on Flue Gas Flow Ratio
(Courtesy of W. Frank)

Chemical Processes in the Air Preheater

The boundary conditions in the air preheater of a coal fired boiler are:

- The intensive mixing of flue gas and dust from the ash
- A temperature range from roughly 350°C (642°F) down to 130°C (266°F)
- Mainly basic qualities of ash from bituminous coal

Under these conditions in the air preheater a great portion of the acid components, especially SO_3, is bound chemically - and partly adsorptivly. Depending on the chemical components of the coal and depending on the air preheater operation the extent of chemical fixation will change. See **Figure:**



Decrease of SO3 in the Preheater Indicated through the Drop H2SO4
(Courtesy of Gutberlet)

Decrease of SO_3 in the Preheater Indicated through the Drip H_2SO_4

.

SO_3, however, is important for a high efficiency of the ESP. In a temperature range below about 170°C (338°F), surface effects on the ash particulates reduce the specific resistivity of the dust thus increasing the efficiency of the ESP. Correspondingly a low level of gaseous SO_3, due to little sulfur content of the coal or because of a high amount of SO_3 chemically fixed in the ash, will result in a poor performance of the ESP.

Sometimes the air preheater is operated as an acid trap. The outlet temperatures are definitely close to the acid dew point. Thus at the cold side of the flue gas stream, condensation takes place

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on the enamelled heating surfaces of the air preheater. But at the same time these measures can cause a restricted separation efficiency of the ESP, as the amount of available SO_3 is reduced.

On the other hand the remarkable reduction SO_3 in the air preheater lead to the idea to bypass the air preheater with a part of the flue gas. In a catalyst an additional part of the SO_2 is oxidized to SO_3 and used for a SO_3-conditioning of the main flue gas stream.

Conclusion

Especially with regard to revamping an ESP it is recommended to consider the operation and state of the upstream regenerative air preheater. The evaluation of the influence of the temperature profile to the ESP, the check of the leakage and the analysis of the chemical transformation in the air preheater often show low cost measures to improve the efficiency of both the boiler and the ESP.

8.2 Duct and Casing Design for Long Term Reliability

General

In 1995, the American Institute of Civil Engineers published "The Structural Design of Air and Gas Ducts for Power Stations and Industrial Boiler Applications". This publication is the first comprehensive work covering all phases of the design of ductwork used in power plants.

In general, the structural design of ESP casings and associated ductwork, in an air pollution control system, has been done using standards established by the manufacturers of the pollution control equipment. Likewise, the design of ductwork for power plants follow the standards established by utility companies, individual boiler manufacturers and/or A & E firms.

So-called project "Standard Specifications" to be followed often times cite every code imaginable, whether or not applicable to the project. Oftentimes, this has led to confusion and erroneous design considerations. In 1993 the Institute of Clean Air Companies (ICAC, formerly IGCI), a trade organization of air pollution control equipment suppliers, published Technical Specification, EP8, "Structural Design Criteria for Electrostatic Precipitators." This technical specification was an attempt to unify the widely varying design criteria and to have all suppliers designing for the same conditions.

The specs often do not address some of the design possibilities that should or could produce the most realistic or economical design. Examples of this, are duration of excursion temperature or pressure; is this a temporary load, for which the allowable stresses can be reduced? Or, how much dust should be considered in the ESP hoppers when designing for seismic condition? Is it

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realistic to assume that all hoppers are full of compacted ash, when an earthquake occurs? Many of these questions are still not addressed in the "Standard Specs" and are left to the individual project engineer.

Today, with the use of computers to solve numerous simultaneous equations, some firms have many design considerations that may not be realistic. But the thinking is "it doesn't take much time with the computer". This only adds to the volumes of unnecessary output data. The only loading situations that should be evaluated are those that can realistically occur. Only then can we produce a safe, practical, economical design of the ESP casings and ductwork.

In addition to the loading conditions that have been used in the past, consideration must now be given to the effect of retrofitting an SCR in an existing ESP system. Except for consultants and equipment suppliers, and the ASCE compendium of papers referred to herein, the codes and guides have not been updated for this relatively recent operating situation.

With these thoughts in mind we offer the following guidelines for consideration when doing the structural design of ESP casings and ductwork.

Objective

The purpose of this section is to offer guidelines to consider when designing ductwork and ESP casings, including:

- Applicable codes, documents and publications
- Allowable stress and Modulus of Elasticity
- Design loads

Applicable Codes, Documents and Publications.

- "ASD Manual of Steel Construction", published by the American Institute of Steel Construction" (AISC) - This manual provides applicable material specs from ASTM and the allowable stresses used for design of steel at ambient temperatures. The formulas and application of structural principals are applicable.
- "Steels for Elevated Temperature Service", published by United States Steel Corp. (USS) - This booklet provides info to develop allowable stresses and modulus of elasticity for steels at elevated temperatures.
- BOCA, UBC and ASCE 7-98 (or, latest rev.) - These codes provide occupancy and geographical loads, such as; live loads, snow, wind, seismic, etc.
- Institute of Clean Air Companies, Inc. (ICAC), Publication EP-8 - "Structural Design Criteria for Electrostatic Precipitator Casings". This publication establishes criteria for the design of electrostatic precipitator casings, with the aim of ensuring that these are structurally sound. It provides loading nomenclature and recommended loading combinations and load factors.

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- "The Structural Design of Air and Gas Ducts for Power Stations and Industrial Boiler Applications", published by American Society of Civil Engineers (ASCE) - This is a compendium of papers covering all aspects of the design of ductwork.
- In-house design criteria. Most, if not all, consultants serving the industry have developed their own tables of allowable stresses, loading conditions and standard design criteria. Many of the documents listed above were used as guidelines.

Allowable Stress and Modulus of Elasticity

The allowable stress and modulus of elasticity of the materials used must be determined for the casing and ductwork design. These elements are always critical, particularly in the design of so-called "hot side" ESPs which generally operate over 500°F (260°C), but less than 800°F (427°C). "Cold side" units normally operate between 300°F (149°C) and 400°F (204°C).

The material specification to be used is generally selected in the bidding stage, based on the operating temperature and other operating conditions. Usually the platework is ASTM A36 or ASTM A242, where greater corrosion or erosion resistance or operation at high temperature is expected. The stiffeners and columns are almost always made of ASTM A36 steel.

Using the selected material and given the operating temperature (or design temperature) the structural engineer selects the allowable stress and modulus of elasticity. These values are selected from tables developed by the "supplier" and are based on empirical formulas from publications like the USS steel pamphlet referred to above and other historical data that they have developed. The values will be used to calculate the actual stresses and deflection of the platework and structural members.

Design Loads

In addition to the material, the "applications" and/or operations personnel provide arrangement drawings of the system and associated equipment along with the design criteria.

At this stage the ductwork is sized and generally routed. In cold side units the routing will be from the air preheater (AP) outlet, to the ESP inlet, then through the ESP to the ID fan inlet, then through the fan to the inlet to the chimney. In hot side units the routing will be from the boiler to the ESP inlet, then through the ESP to the AP inlet, through the AP to and through the ID fan, then on to the inlet of the chimney.

In addition to the routing, the auxiliary equipment like, expansion joints and dampers and a schematic of the support structures are depicted on the arrangements.

With this data the structural engineer does the following:

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- Reviews the drawings to determine if the ductwork and ESP are free to move during changes in temperature. Note: ESPs and ductwork are not designed to resist thermal forces.
- Determines or confirms points of fixity on the ESP and ductwork.
- Establishes the support points, and types: fixed, "sliding", hanging or toggle. Note: Support structure(s) may or may not be in the scope of work of the supplier.
- Insures that expansion joints are sufficient to take full movement at excursion temperature, in all directions, in which the duct and/or ESP can move.
- Establishes the loading combinations using the documents referred to above and company's own historical data.
- Designs the ductwork and casing, checking for stress and deflection.

Conclusion

It is not the purpose of this discussion to teach structural design. It is assumed that whoever designs ductwork and ESP casings has the fundamental knowledge and training to do the job properly. However, the design of these structures is unique. The application of loads, the type of loads, the stresses used because of temperatures well above ambient, and the configuration of the members, and their analysis, are not taught in school.

Many of the components of the ESP are designed as plate girders. The ductwork itself is in many cases a box girder capable of spanning a substantial length. It was the intent to consolidate the information available to simplify finding the data that is commonly used by experienced personnel in the industry.

8.3 Fly Ash Handling System

Introduction

Dry fly ash handling is primarily accomplished by pneumatic or mechanical conveying or a combination of the two. This fly ash is accumulated in hoppers and discharged into the ash conveying system. The boiler back pass ash and fly ash are accumulated in the hoppers and discharged into the respective ash conveying system.

Pneumatic Conveying

Pneumatic conveying uses an air flow stream through a piping system as the conveying medium for the ash. It can be one of two types, a pressure system or a vacuum system. In the pressure

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system, the conveying piping system is arranged with a blower at the beginning of the conveying line. The piping system operates at a positive pressure. It is routed beneath each ash disposal hopper and includes an air seal system at every ash feed point.

The ash is conveyed to a storage bin or silo which includes a discharge filter for the fine ash particulates from the discharged conveying air, plus the air displaced when filling the silo. See **Figure:**

Pressure Type Conveying System

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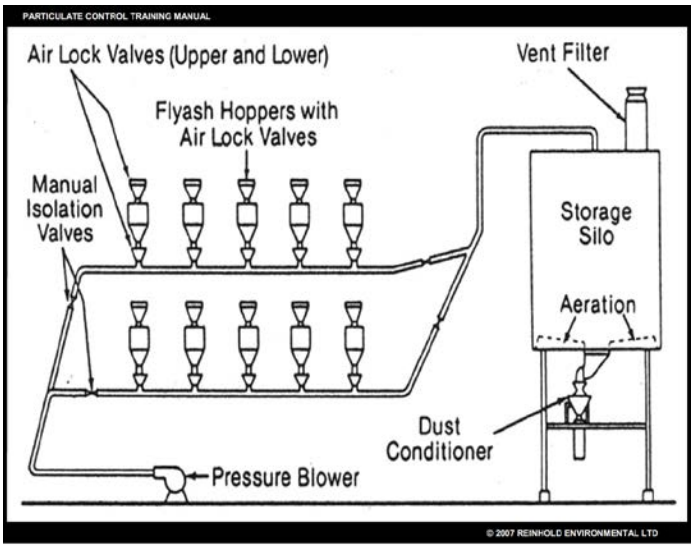

Pressure Type Conveying System
(Courtesy of B&W)

In the vacuum system, the conveying air producer is at the discharge, or silo, end. This creates a negative pressure in the conveying piping. A blower or a steam or water educator can be used as the motive air producer. Because the conveying lines are at a negative pressure, a single valve is used for isolation and feed control at each ash pickup point. The ash conveying line enters a primary collector, then a secondary collector. These separate the ash from the conveying air and discharge it into the silo. See **Figure:**

Vacuum Type Conveying System

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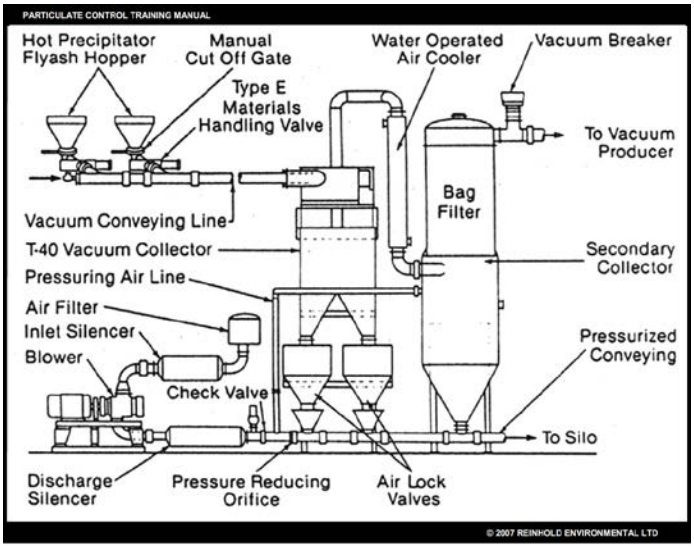

Vacuum Type Conveying System
(Courtesy of B&W)

When selecting a pneumatic system, the design should specify the system capacity for added capacity to accommodate surges and to provide some down time to perform minor equipment maintenance. Another consideration in specifying the ash system is redundancy of conveying air blowers to assure maximum system availability. Because the ash conveyed is an abrasive material, the conveying piping is normally abrasion resistant.

The pneumatic systems discussed above are of the dilute phase, which means a high conveying air/solids ratio. A variation of the pressure system is the dense phase transport or conveying

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system. In this system design, a much lower air/solids ratio is used. The ash from the hopper is discharged into a dense phase conveying pot. The pot is pressurized with high pressure conveying air and the ash is conveyed as a dense slug. The dense phase concept is typically limited to small particle size material such as fly ash. Larger particle size material can be dense phase conveyed, but is limited to shorter conveying distances.

Mechanical Conveying

Mechanical conveying of the dry ash streams can be accomplished using a combination of drag chain conveyors, en masse conveyors, screw conveyors or bucket elevators. Due to the high temperature and dusty nature of the ash stream, belt conveyors are not applicable.

Drag chain conveyors are very similar in design to the SCC used for bottom ash handling and move the ash horizontally or on an incline. The chain and flights are totally enclosed in a dust-tight housing with ash feed through openings in the top of the housing. Air lock devices, such as rotary seal feeders or tipping valves, are used to seal the internal positive or negative pressures of the boiler gas stream. The volume of ash conveyed is normally determined by the height of the flight bars. En masse conveyors are similar in design but move an entire pile of material which totally fills the conveyor cross-section.

It is highly recommended to limit the use of screw conveyors in ash handling to conveyor lengths that will not require intermediate hanger bearings due to the highly abrasive nature of ash and the resultant wear. The alternative is to select screw conveyors of sufficient diameter keeping the level of fill of ash low enough so that bearing exposure is minimized. This oversizing typically makes screw conveyors economically unattractive in this application.

Mechanical Versus Pneumatic Transport Considerations

Mechanical conveyors have very low drive power requirements compared to the blower drive requirements of a pneumatic system. Mechanical systems normally operate continuously, yet the cumulative power consumption on a 24-hour basis is less than the intermittently operating pneumatic system. However, pneumatic systems offer much more flexibility in design due to the easier routing of piping versus conveyors.

A combination of mechanical conveying to a small intermediate storage hopper with pneumatic conveying from the intermediate hopper to a storage silo provides the benefits of continuous ash removal with the flexibility and simplicity of a pneumatic system.

The mechanical handling of ash is advantageous for boilers firing fuels that result in significant levels of unburned combustibles in the various ash streams such as wood-fired or refused-fired boilers. These hot unburned combustibles can ignite when exposed to the air stream of a pneumatic conveying system and result in explosions or continued burning in the system and

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storage silo.

Mechanical conveying systems more readily accommodate large ash particles which can result from unit operation excursions. A pneumatic conveying system is prone to plugging from oversized ash particles. An ash stream which may be high in moisture content, such as from a flue gas scrubber, can plug a pneumatic system during moisture level excursions.

8.4 Fans

General

The induced draft (ID) fans are usually located downstream of the precipitator or fabric filter and place them under suction. In plants without induce draft fans (pressurized boilers), precipitators or fabric filters are under a slight positive pressure. Because of problems with outleakage, many formerly pressurized units have been retrofitted with induced draft fans.

In cases where the ID fans follow the precipitator or fabric filter these fans have little or no effect on them. In a few cases, plants with poorly designed flues control equipment may be affected by drumming or pulsations in gas flow or fan vibration. Usually these problems are dealt with early because of the damage they cause to the flues, not the control equipment.

In a few cases, the induced draft fans are ahead of the control equipment. If they are fairly closely connected to the fan, gas distribution problems may result.

The gas flow in the evase of a single inlet fan takes the form of a corkscrew spiral. In a double inlet fan evase, there are two counter rotating corkscrew flows. If the spiral flow enters the control equipment, serious gas distribution problems occur. The effects shift as the unit load changes.

Straightening out this type of gas distribution problem is extremely time consuming and expensive since the high velocity zones move around depending on unit load.

This problem is best dealt with in the plant design phase, since trying to remedy it on an operating unit is a task of the first magnitude.

Finally insufficient fan capacity can be a problem in plants with two units discharging into a common chimney. We have noted that the gases spiraling to some extent, impinge on each other after they exit the chimney breeches. Pressure drop in this area has been reduced by as much as two inches wc by the addition of a baffle set at 45 ° to the breeches, extending 15 feet or so above the top of the breeches.

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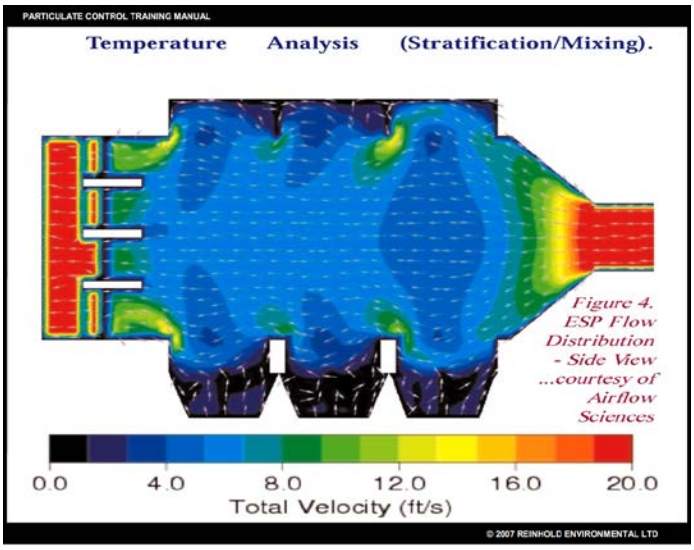
CHAPTER 9 - MODELING, CFD & MASS SAMPLING METHODS

This chapter discusses modeling, CFD and mass sampling methods:

- ***Bickelhaupt Resistivity Model***
- ***ESP Performance Models***
- ***Computational Fluid Dynamics (CFD)***
- ***Physical Models***
- ***Mass Sampling Methods***



ESP Flow Distribution - Side View
(Courtesy of Airflow Sciences)

9.1 Bickelhaupt Resistivity Model

Original Model

Dr. Roy Bickelhaupt, who was at Southern Research Institute (SRI) at the time, developed a "resistivity model" in the 1979 as a tool to predict ESP performance. The model, labeled Model 1, included the effects of temperature, moisture, electric field strength, and SO_3 vapor concentration. The ash samples used to correlate the data were taken from frequently burned U.S. coals.

Between 1980 and 1985, laboratory data taken from tests conducted on ash with high concentrations of calcium and magnesium indicated that the resistivity model was sensitive to water vapor concentration. This newly found deviation was incorporated into the model, producing Model 1A.

Model 2 was developed as a result of research done on 10 new ashes. These ashes were characterized both chemically and physically in order to better understand the influences of SO_3 on resistivity. The parameters investigated included flyash composition, sulfuric acid concentration (1 ppm to 10 ppm), water concentration (5% and 10%), temperature (115ºC to 200ºC), and field strength intensity (2kV/cm to 12 kV/cm). The principal type of experiment was the determination of resistivity at three temperatures for three concentrations of sulfuric acid vapor (1, 4, and 10 ppm).

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In 1990, Dr. Bickelhaupt, now working for Clean Air Engineering, released his final version of his resistivity model: Model 2A. The new computer model took into account the effects of the combined concentrations of magnesium and calcium. The trigger set points were altered by the concentration of calcium resulting in better prediction capabilities.

New Model Development

Recently, an expanded database has been generated by SRI, which has been used to develop an improved predictive model. The goal of this effort is to eliminate extreme sensitivity to modeled results to small compositional variations for some ashes.

9.2 ESP Performance Models

Introduction

The coming of Compliance Assurance Monitoring (CAM) has caused a surge of interest in ESP modeling as a means for determining whether-or-not an ESP is in compliance. A modern ESP model, if set up correctly, can accurately simulate the performance of a full-scale ESP. Changes in operation of the ESP, which affect the emissions, will show similar changes in the model.

There are several ESP models currently in use, each having its own strengths and weaknesses. Each, under certain conditions, will accurately predict an ESPs performance. What are the models? What is their history? What are the capabilities? How might they be used for CAM in addition to their more traditional uses for design, upgrading, and ESP troubleshooting?

CAM Ruling

The Compliance Assurance Monitoring (CAM) rule, being put into effect in the US, will allow certification of compliance for an ESP if it can be shown that it is in good operating order and is being operated within design or defined indicator ranges that have been related to measured emission limitations. Modern ESP models, when calibrated to an ESP, accurately correlate particulate emissions with changes in easily measured operating parameters (e.g. voltages). Thus the model has the potential to indicate, without a direct connection, the ESP's performance and whether it is in compliance.

As the appreciation for the ability of models to accurately portray the operation of precipitators has grown, so has the ESP community, in increasing numbers, been using models for their

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design, upgrading, and troubleshooting. With the coming of CAM and the ability to use easily measured ESP parameters as input to a model, it is likely that even more interest will develop. To help, this section will provide the background history of the major models currently available, their characteristics, abilities, and limitations. It will provide information to make a more intelligent decision on how to apply it to CAM. It should be noted that all of the major ESP models in current use have either been developed with support by the US Environmental Protection Agency (EPA), or are based upon them. The major development was at Southern Research (SRI) and Research Triangle (RTI) Institutes.

What is an ESP Model?

Models have reached a very high stage of sophistication allowing them to accurately represent the operation of an ESP. Two developments have contributed to this.

- The first is the increased understanding of the physics occurring within the ESP described in rigorous mathematical terms.
- The second is the computer which allows finding the solutions to the mathematical expressions

The heart of the modern ESP model is the famous Deutsch-Anderson equation, which in its rigorous form computes the probability that a particle traveling in the turbulent interior of an ESP will enter the laminar layer at the collecting surface. If the particle entering the laminar layer is charged, and an electric field exists at the collecting surface, then its migration velocity, which is a variable in Deutsch-Anderson, assures its collection.

Many of the readers are familiar with Deutsch-Anderson used in its non-rigorous form in which a single pseudo migration velocity, sometimes called a rate parameter, is used to represent all of the particles in the gas stream regardless of their size. When applied in this non-rigorous format Deutsch-Anderson has been used as a simple, easily calculable means for ESP design.

In the modern computerized model Deutsch-Anderson is used in its rigorous form. It requires that all of the particles, for which it is performing the calculation, have the same migration velocity, which in this case is the true migration velocity and not a rate parameter. To handle this requirement the particle size distribution is divided into a number of narrow size increments, for each of which the migration velocity is computed. The computed migration velocity is the maximum velocity attained by the charged particle in the electric field, subject to the viscous drag of the gas.

Prior to computation of the migration velocity the charge of the particles in each size increment is determined. Depending upon the particle size the model uses either diffusion or field charging or some combination of both. In addition the computation is divided into a number of ESP length increments, usually one for each electrode element. For each of the length increments the particle charge corrected for charging time and the migration velocity are recomputed.

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In the recent, more sophisticated models changing electrical conditions from one increment to the next are accommodated in the calculations. Finally, a double summation, for both the particle size and length increments are performed to give the overall ESP collection and efficiency.

The EPA/Southern Research Institute (SRI) Models

The basic model just described characterizes the EPA/SRI series, which appeared in various versions between July 1972 and January 1991. The objective in developing this series of models was part of the attempt to change ESP design from an art to a science. The earlier versions in this series performed their computations on main frame equipment. As the newer versions were developed, they were adapted to desktop computers. To the basic model were added computational methods to handle the wire/duct geometry, and empirical treatment of non-ideal factors including sneakage, velocity distribution, and re-entrainment.

As the series developed, data from actual ESPs were used to validate and improve the accuracy of the models, and computational time was decreased. This series achieved its ultimate capability with the release of the final version in 1991, the Self-Consistent Deutschian Model (SCD), which more rigorously included the space charge in the computations and its effect upon ESP performance and consequently provided the greatest accuracy.

The main characteristics and operation of the EPA/SRI series of models, that differentiate them from the EPA/RTI series are related to the electrode configuration that they handle and electrical voltages and currents. The electrode configurations that are modeled are evenly spaced, round wires. ESPs with unevenly spaced electrodes; non-round, rigid electrodes must be simulated by an array of evenly spaced wires. This has the potential for introducing some inaccuracy.

A useful proprietary program from EPRI called ESPert has roots that go back to the EPA/SRI series. It contains an expert system for performing electrostatic precipitator performance diagnostics. It also contains an ESP model, which is one of the versions of the EPA/SRI series that predates SCD.

The ESPert™ program uses a version of the SoRI model that was revised October 1991 to include calculations of PM10 and PM2.5 emissions. It does not, at present, use the Self-Consistent Deutschian (SCD) model developed by Southern Research Institute (SoRI). At that time, a decision was made to use Version 3 of the SoRI model instead of the SCD model because of the extensive studies showing the validity of the Version 3 model and because it was found that the SCD model produced different results only in unusual cases with high dust loadings.

Version 3 was also selected because it runs much faster on a PC than the SCD model. An automated ESPert™ program (Version 5.5) is now operational that accepts real time data and produces real time emission and opacity calculations. The program accumulates the important

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parameters affecting precipitator operation and can show on a real time basis whether a precipitator is functioning properly without the need for operator inputs.

The EPA/Research Triangle Institute (RTI) Models

The next stage in the evolution of ESP models was the EPA/RTI series known as ESPVI. The objective was to develop a program that could perform all the computations of the EPA/SRI series, plus model the various electrode configurations both in commercial use and being developed. Version 1.0 (Interactive ESP Computer Model) was released in September 1986. The ESPVI series went through Versions 2.0, 3.0, and 3.2 which were developed and tested, but not released. In June 1992 ESPVI 4.0 was released, followed in January 1996 by ESPVI 4.0a.

The ESPVI 4.0 and 4.0a series, in addition to the computational equations of the EPA/SRI models, includes the solving of Poisson's equation, which relates electric field and space charge. This allows introduction of both particle and ionic space charge, current and electrode geometry. The ESPVI models, for given high-voltages, electrode configuration, and particle characteristics, calculate the corona current. ESPVI will always use the computed current for the performance prediction calculations rather than the actual ESP current.

As far as the ESPVI models are concerned the calculated currents are the only useful currents within the ESP. If actual ESP currents differ from the calculated currents it means that either the model has not been set up properly, or some problem exists within the ESP.

Like in the EPA/SRI models, the ESP is divided into a length increment for each electrode element. This allows space charge to be computed very rigorously, increment by increment, and electrode by electrode. The rigorous computation of the space charge effect by ESPVI 4.0 and 4.0a allows them to actually match the corona current suppression, which causes the lower currents seen in the inlet sections of ESPs.

A major difference between ESPVI 4.0 and 4.0a is the use of improved particle charging algorithms including the effects of bipolar charging such as experienced with back corona. ESPVI 4.0a provides data as an output that allows calculation of collection by particle size. A number of additional features have been added to improve operation and accuracy. ESPVI 4.0a is superior to and is the successor to ESPVI 4.0.

An important ESP performance prediction model is ESPM, which is a proprietary model commercially marketed by EPRI. Very much like ESPVI 4.0a whose antecedent is ESPVI 3.2. so is ESPVI 3.2 the antecedent of ESPM. Prior to ESPM's development by RTI, EPRI requested and obtained EPA's permission to use the ESPVI 3.2 algorithms.

ESPM has many of the capabilities that are inherent in ESPVI 4.0a. A major difference is the requirement of ESPM, that all corona discharge electrodes be inputted as the same round wire diameter and be set for equal spacing, very much like the EPA/SRI series. ESPM does have

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some additional features, useful to the electric utility industry, such as an internal resistivity calculator for coal ash.

What the Various ESP Models Can Do

The essential elements of the various ESP performance prediction models have been presented. The preeminent and most advanced models in the two lines of model development are the EPA/SRI SCD, and the EPA/RTI ESPVI 4.0a and the related model, EPRI's ESPM. SCD and ESPVI 4.0a are in the public domain and are available from various sources. ESPM is a propriety model available only from EPRI.

These models have the capability, under circumstances specific to the model, for accepting data from an operating ESP and accurately computing the performance of that ESP. Thus if certain data, such as the electrode voltage of a section, changes enough to affect the performance of the ESP, that same voltage provided as input to the model will indicate the same change in emissions.

The specific circumstances under which each of the models will provide accurate performance will be discussed.

Each of the models require physical ESP parameters and operating data as input. The models vary in the amount of input data required. Generally, the input data needs of a model increases with the ability of the model to match a wider range of ESPs. SCD requires the least amount of data, which not surprisingly suggests that it has the least ability to accurately match a wide range of ESPs. Loading of data to the model is cumbersome, requiring an auxiliary software program for doing it.

The EPA/RTI ESPVI 4.0a and EPRI's ESPM, which use the same internal algorithms for computing, will provide similar accuracy and results for modeling ESPs with equally spaced corona discharge electrodes. The data requirements for both models, when operating with round equally spaced electrode mode are greater than for SCD. These models, in-turn, have a wider range of applicability to differing ESPs and operating conditions. To take advantage of this increased flexibility requires more skill on the part of the person performing the modeling to assure that the model is truly representing the ESP. ESPVI 4.0a and ESPM use menus and entry forms for ease of data loading.

The state-of-knowledge of ESP physics and computer models using the mathematical relationships that describe the physics has reached the level of development that allows the ESP performance to be accurately predicted. Once the model has been set up to represent the ESP, changes in its operating characteristics, which cause a change in emissions, will show a corresponding change in the model prediction. In addition to their historic use for ESP design, upgrading, and troubleshooting, they should also be considered for a new role in CAM.

Using an ESP Model for CAM

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The following is a possible approach that could be the likely procedure for using an ESP model for CAM. The approach is presented as a multi-step procedure on the part of the ESP operator.

1) Perform the necessary measurement tests upon the ESP to provide the data to properly calibrate the model so that they accurately relate to each other, and to allow choosing the proper indicator parameter.

2) Test changes of the indicator parameter in both the ESP and the model to assure that changes in the ESPs emissions are reflected in the model.

3) Using the QA/QC and other procedures prescribed by the regulatory agency perform the necessary tests that will be used to prepare the protocol that will be used for CAM.

4) Identify other ESP parameters that could change during operation, test in the model, and if possible the ESP, and include in the protocol how these would be accounted for.

5) Submit the protocol to the regulatory agency as the next step in the certification procedure.

For a model such as ESPVI 4.0a the data needs are:

- Mechanical - ESP dimensions , collector area, SCA
- Electrode configuration
- Electrical conditions
- Gas conditions-flow rate, temperature, composition
- Particle characteristics - size distribution, inlet mass loading, density, resistivity
- Non-ideal factors - sneakage, velocity distribution, rapping re-entrainment, etc

If all of the data that the model requires is available it is a routine matter for an experienced user to input it into the model and produce results.

Additional Comments

A few comments are needed to help clarify the current state of ESP model development.

The EPA model, ESPVI 4.0a, uses operating voltages but not operating currents. The currents used in the performance calculation are theoretical currents produced internally by the model. This philosophy introduces opportunities for errors for the following reasons.

Of necessity, approximations are used to estimate voltagecurrent relationships for complicated (ideal) discharge electrode geometries. To state or imply current models rigorously solve the equations involved in electrostatic precipitation is misleading - all the models, of necessity,

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contain approximations. There are a number of assumptions and approximations used in ESPVI 4.0a to derive the voltage current relationships for complicated discharge electrode geometries. They are all reasonable approximations, but they are never-the-less approximations.

The reality is that the ideal geometries approximated in the new models are rapidly lost in an operating ESP as a result of misalignment and electrode buildup (among other things).

In fact, both the older Southern Research Institute model and ESPM have been used to predict the performance of ESPs with a wide variety of electrodes. This success probably results from the physical averaging that takes place in a full-scale ESP. This evidence suggests that it is not necessary to approximate the details of the discharge in the vicinity if the discharge electrode to make estimates of ESP performance with satisfactory accuracy.

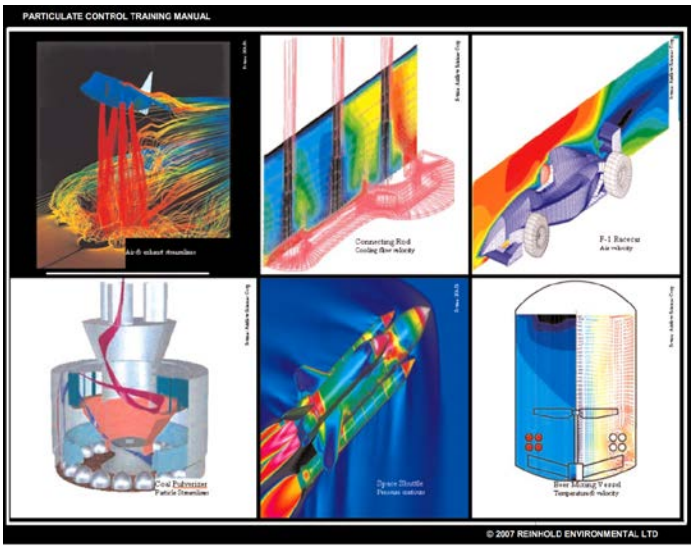
Back to the real vs. calculated current question. It is necessary to recognize the presence of back corona in an operating ESP and not to use voltage and current data contaminated with back corona to estimate ESP performance. Using theoretical voltage/current relationships does not solve this problem.

In fact, it has never been demonstrated that any model can accurately predict performance of an ESP operating in back corona. It is better to estimate back corona in an ESP (since it is highly unlikely that back corona improves ESP performance and most likely wastes power), determine voltage and current operating points that are not affected by back corona and use this data to calculate ESP performance.

9.3 Computational Fluid Dynamics (CFD)

Background

Computational Fluid Dynamics is a method of simulating the physics of fluid flow and heat transfer via computer. Practical applications of CFD first appeared in the aerospace industry, where it has been used since about 1970 in the design of spacecraft and aircraft. Over the years, CFD has been applied to a broad range of fluid flow problems in the power, automotive, food processing, and other industries. **Figure:**



CFD Examples
(Courtesy of Airflow Sciences)

CFD Examples

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provides a sampling of CFD applications. CFD results characterize flow properties (velocity, pressure, temperature, chemical concentration, particle trajectories, etc.) in great detail.

CFD was first used to examine the flow within an electrostatic precipitator in 1985. Since that time, 75 ESPs have been modeled using CFD. Like any new technology, it is taking a while for CFD to be recognized as a beneficial design tool. Although still used less frequently than physical flow models, CFD is growing in support.

The application of CFD to ESPs, FFs and other real-world engineering design projects is expected to steadily increase in the future. A key element in CFD's expansion will be the computer technological advances made each year. CFD requires high-speed, high-memory computers in order to solve the complex equations of fluid flow and heat transfer. As this equipment improves, the number and complexity of CFD applications will increase. Also, the CFD software itself continues to advance. There are a large number of private, government, and university personnel currently developing improvements to CFD modeling methods.

Methodology

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The basic equations that govern the motion of fluids have been known for over a century. These coupled, nonlinear, differential equations express and relate the laws of conservation of mass, momentum, and energy. Unfortunately, closed form solutions of these equations prove impossible to find for most realworld configurations. However, the advent of high-speed computing and advances in numerical methods have made it possible to develop highly accurate approximations to such a solution, even for extremely complex geometries.

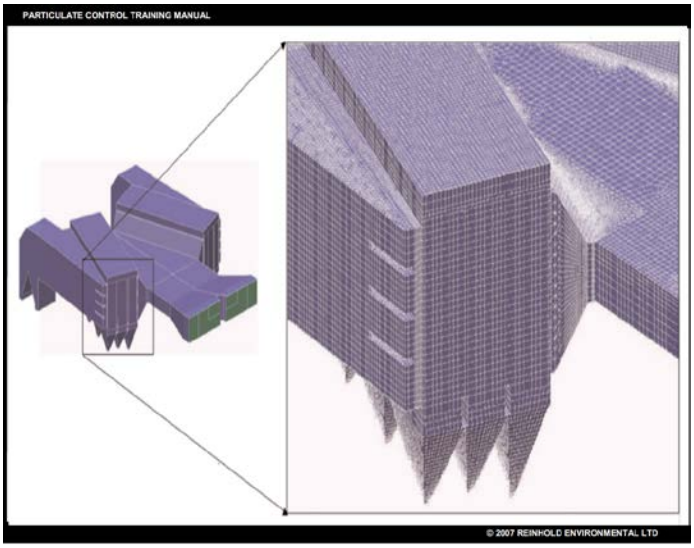
One such numerical method is the Control Volume formulation. In this approach, the domain of interest is divided into a number of small control volumes, or cells. Assuming fixed fluid properties over each cell, the computer creates a set of linear equations that express the requirement of conservation over each cell. This set of equations is then solved and the fluid properties are updated. This process is continued iteratively until all conservation equations are satisfied simultaneously and all fluid properties are stable for every cell.

It is not uncommon for a CFD model of an ESP to have 500,000 to 1,000,000 control volumes. This results in a highly detailed understanding of the flow within the ESP since the velocity, pressure, temperature and chemical species concentration are known at every cell. It would be prohibitively expensive to obtain this amount of data through testing of an actual ESP or via physical flow modeling.

Figure:

CFD Computational Mesh for an ESP Model

shows a CFD model of an ESP that contains 450,000 computational cells. The model is fully threedimensional and represents the full-scale geometry and operating temperature. Thus, no scale or density correction factors need be applied to the results to obtain an accurate flow characterization. All important internal geometry features (duct walls, vanes, perforated plates, baffles, etc.) are included in the model in full scale. This allows very intricate geometries, including details such as rigid electrodes or Opzel plates, to be properly represented.



CFD Computational Mesh for an ESP Model
(Courtesy of Airflow Sciences)

A CFD model will typically begin at the air heater or economizer outlet (depending on ESP type), or at a plane where actual test data from the plant exists. Flow inlet conditions are set at the select model inlet to define total flow rate and velocity/temperature profiles.

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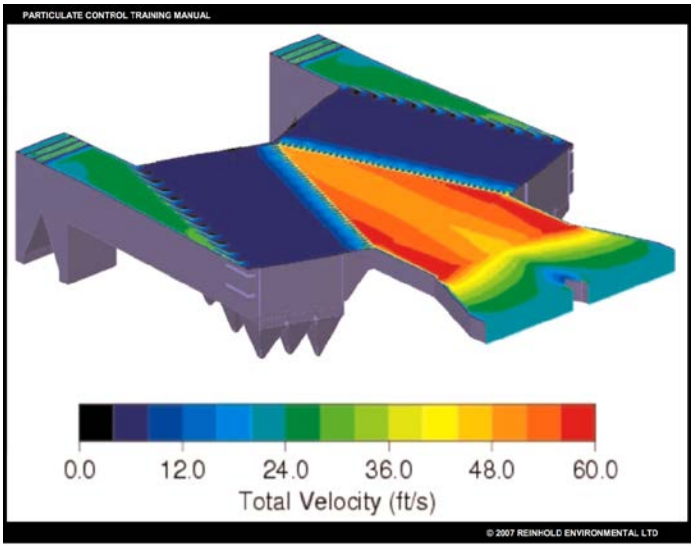
When the computer iteration and calculation process is complete, the solution to the conservation equations can be displayed in a number of ways. Typical is the use of color contour plots, which show two-dimensional slices of the three-dimensional model. Particle or fluid streamlines can also be displayed.



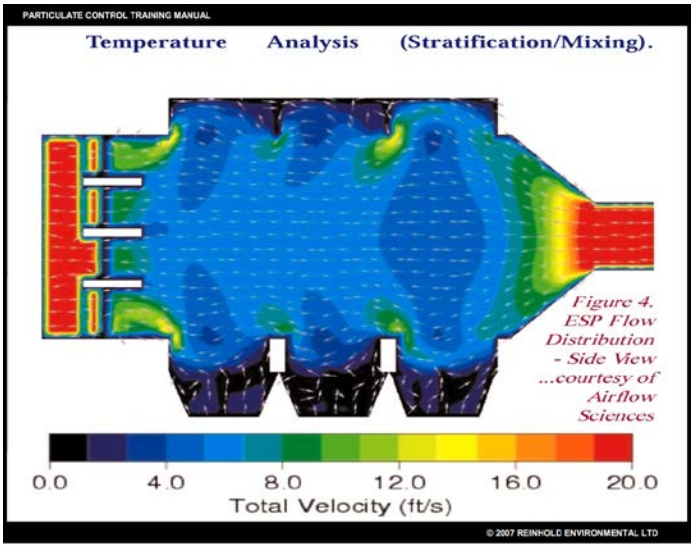
ESP Distribution - Plan View
(Courtesy of Airflow Sciences)

The geometric features within the CFD model are fairly easy to manipulate and modify. Thus, CFD is well suited as a design tool. The internal features (location and geometry of vanes, perforated plates, baffles, etc.) can be varied and a flow simulation performed for each design configuration. The influence of each design modification can thus be quantified until a final design is achieved.

The iterative nature of CFD allows a further optimization strategy for the design of flow control devices. Instead of the user varying the geometry manually and then evaluating each configuration, a target flow distribution can be specified and the computer instructed to define the optimal geometry to achieve the goal. For example, the computer can be programmed to vary the location of turning vanes and/or the porosity of perforated plates until a desired ESP flow profile is met. This can greatly reduce the engineering effort and eliminate trial-and-error development that may lead to a sub-optimal design.

Applications

Gas Flow Modeling of ESPs



ESP Flow Distribution - Side View
(Courtesy of Airflow Sciences)

The gas flow characteristics within the inlet/outlet ductwork and through the ESP are generally the most important elements of a modeling analysis. Flow control devices within the system (perforated plates, turning vanes, baffles, etc.) are generally designed to achieve a number of different goals:

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- Uniform (or specified) gas flow distribution within the collecting region. ICAC Specification EP-7 is a current industry standard.
- Minimum system pressure drop.
- Minimum potential for fly ash fall-out within ductwork or the ESP.

Each of these can be examined via the CFD model. **Figure:**

ESP Flow Distribution - Side View

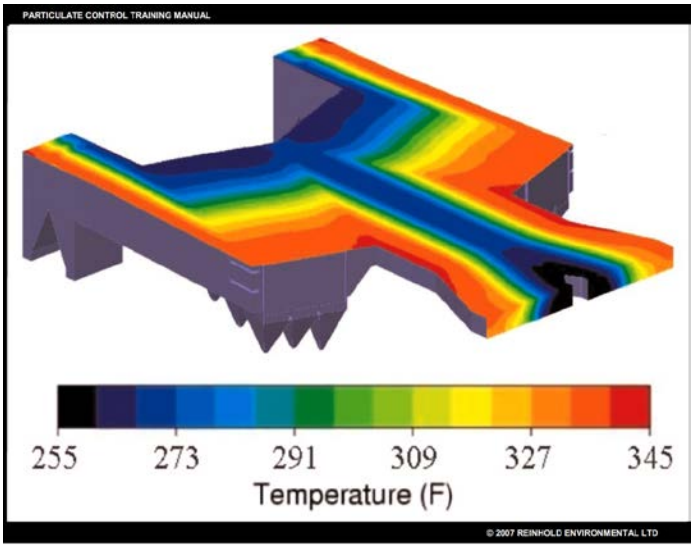
shows the velocity profile in a horizontal plane within a chevron-style ESP. The flow exits two air heaters and travels into two separate ESP boxes then to the I.D. fans. The red regions indicate high velocity zones (greater than 55 ft/sec). The flow through the ESP is relatively uniform in the side-to-side direction.

Figure:

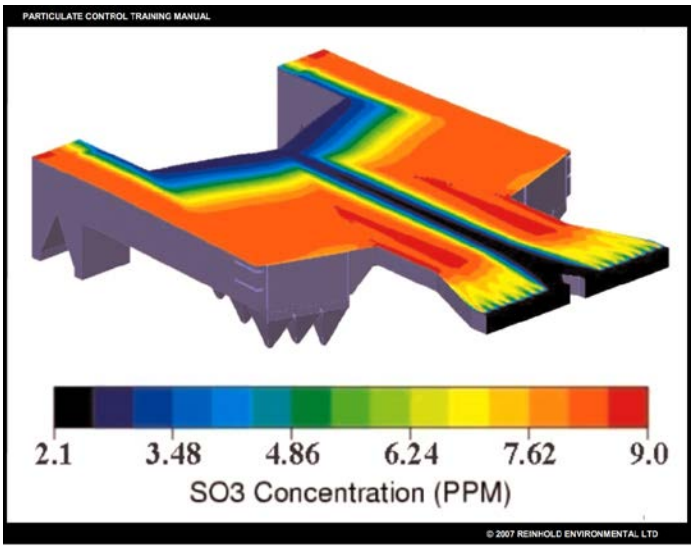
Temperature Mixing within ESP

shows the flow through the same ESP in a side view through the collection region (note that a different color scale is utilized). Significant velocity non-uniformities are evident, especially in the way the flow expands into the hoppers and above the collection plates. The potential for ash sneakage and sub-optimal capture efficiency within this ESP is high.

Thermal effects can be easily incorporated into any CFD flow simulation. The Conservation of Energy equation is solved using the same iterative procedure used to calculate velocities and pressures. This allows the CFD model to simulate the physica of convective, conductive, and/or radiative heat transfer. Thus, CFD is an ideal tool for examining temperature stratification through an ESP due to an upstream heat exchanger (such as an air heater).



Temperature Mixing within ESP
(Courtesy of Airflow Sciences)



SO3 Injection System Simulation
(Courtesy of Airflow Sciences)

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The thermal mixing of non-homogeneous flow streams, plus the heat loss to any walls or heat exchangers, is calculated for the full-scale temperatures. No scaling or reduced temperature corrections are necessary.

An example of an ESP model with temperature prediction is provided in **Figure:**

SO_3 Injection System Simulation

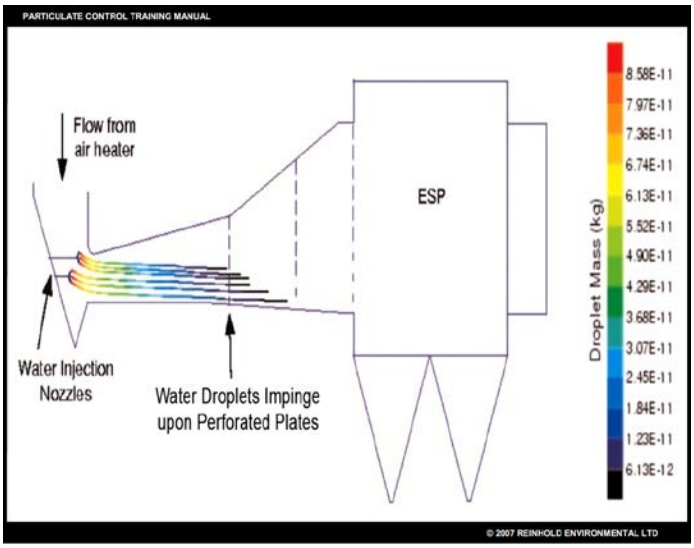
. This is the same chevron-type ESP as shown above. A temperature gradient of 105°F, measured by plant instrumentation at the air heater outlet, was incorporated at the model inlet. The short residence time of the gas in the inlet duct (less than 2 sec) results in very little temperature mixing before the flow enters the ESPs. A maximum gradient of 80°F exists across the ESP inlet face.

Once a baseline prediction is completed, the CFD model can be utilized in design mode to minimize the impact of the temperature stratification on ESP performance. Design efforts may include developing flow mixing devices, examining different chemical injection strategies, or assessing air heater operation modifications.

Chemical Injection (SO3, Ammonia, Humidification)

Additional physical processes that can be simulated by CFD are chemical reaction and chemical species transport. This is accomplished by incorporating the proper reaction equations or chemical properties into the CFD model. Thus, ESP gas conditioning systems can be analyzed in detail; this includes SO_3, ammonia, and water injection systems. For SO_3 and ammonia, tracking of the injected gas is generally the primary goal. For water injection, it is important to calculate the evaporation of the droplets. This allows the correct temperature distribution to be predicted while analyzing the droplet trajectories to avoid water impingement on internal walls or structure.

Figure:



Humidification System Simulation Results
(Courtesy of Airflow Sciences)

SO_3 Injection System Simulation

provides an example of SO_3 injection modeling. The SO_3 concentration is shown to vary from 3 to 9 ppm at the ESP inlet face.

Figure:

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indicates water droplet trajectories from a humidification system. In this particular case, water droplets are shown to impact the ESP inlet perforated plate before complete evaporation takes place. This results in a severe ash deposition and pluggage issue within the ductwork.

Electrostatic Forces

Another set of physical equations that can, in theory, be added to the CFD simulation is those defining electrostatic forces on the particulate. It is mentioned here for completeness only, as few researchers have examined this complex phenomenon for an ESP, and no published results exist to date. The possibility remains, however, that in the future the CFD model may incorporate electrostatic effects, including such elements as resistivity, re-entrainment, and rapping. Hopefully, the CFD model will one day incorporate The ESP Performance Model, as discussed in Chapter 11, Section 2.

9.4 Physical Models

Physical models should be created on as large a scale as possible. One-sixth actual size is desirable for good prediction of full-scale gas flow. A scale of 1/8th is about the lowest limit for reliable results. Ideally, the model should be a scaled down copy of the full-scale ESP in every dimension.

For exact dynamic similitude, the Mach, Reynolds, Froudand Weber numbers must be the same in the model and the full sized ESP.

!Mach Number (M=V/C): The Mach number is the ratio of fluid velocity to the local speed of sound. It is a measure of the ratio of inertial forces to elastic forces. This ratio is an important correlating parameter only when the fluid velocity is near or above the sonic velocity.

- Reynolds Number (Re=VO/μ): The Reynolds Number is the ratio of inertial to viscous forces. A critical Reynolds Number differentiates between laminar or turbulent flow in flues, in boundary layers near flue surfaces, and around totally immersed objects such as pipe trusses situated in the flue gas stream
- Froude Number (Fr=V2/gL): The Froude Number is the ratio of inertial forces to gravity forces.
- The nature of open channel flow depends upon whether the Froude Number is greater or less than unity. It is useful in calculations of hydraulic jump in the design of hydraulic structure and in ship design.
- Weber Number (We=V2L?/d): The Weber Number is the ratio of inertial forces to surface tension forces. It becomes an important factor only when a gas-liquid or liquid-liquid interface is present within the flow system.

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To assure that airflow through the modeled ESP chambers remains in the turbulent flow regime, one needs to guarantee that the average Reynolds Number not go below 4,000. This allows for valid modeling of flow-starved gas passages channeling only 75% of the average precipitator velocity.

When specifying model test procedures, an appropriate starting point is the ICAC Publication #EP-7 (See Appendix 5).

9.5 Mass Sampling Methods

EPA Method 5

Method 5 is a procedure for measurement of particulate concentration. The particulate mass is determined gravimetrically after uncombined water is removed from the sample.

This method relies on the isokinetic extraction of a dustladen gaseous sample from a duct or stack with subsequent collection of the ash by a filter while a sample volume is monitored. Method 5 does not consider the condensable fraction in the impingers so any suitable condenser will do. The condenser or impinger must be followed by a drying tube to prevent moisture from reaching the dry gas meter and pump.

The gas sample to taken from the gas stream through a nozzle which is designed with thin walls and sharp edges to minimize gas flow disturbances. Glass probes are preferred over metal probe liners, but steel probes are allowed for probe lengths longer than 2.5 meters. A thermocouple must be attached to the probe for monitoring stack gas temperature.

Gas velocity is monitored by an S-type pitot tube to ensure isokinetic sampling velocities. The glass fiber filter should be at least 99.95% efficient in collecting 0.3µm dioctylphalate smoke particles. The four impingers in the mass train remove water, gases, vapor and condensable particulate matter. If a condenser is used, it should be followed by a silica gel drying tube to collect remaining moisture and protect the vacuum pump and dry gas meter. The sampling box should be maintained at 248 ± 25ºF (120ºC ± 14º C).

Calibration requirements are discussed in the EPA maintenance procedures.

ASTM Method

The ASTM Method is very similar to EPA Method 5, except for two main areas:

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1) The use of in-stack filter

2) No restrictions on the sampling flow rate allowed

The ASTM Method uses a thimble-shaped filter to collect the particulate material. This enables it to collect high mass concentrations and large amounts of flyash. Although external heating is not required, one needs to make sure that the filter has a temperature equal to the process stream - usually preheating 30 minutes will accomplish this.

EPA Method 17

Method 17 is sometimes used in place of Method 5. It uses an in-stack filter in place of the cumbersome glass-lined probe and heater filter holder assembly used in Method 5. The in-stack sampling system procedure is applicable within acceptable temperature limits. Like ASTM Method, the filter needs to be preheated. Care should be taken to ensure that the nozzle is pointed downstream and the sampling lines are closed off until ready to begin sampling.

ASME Performance Test Code for Determining Concentration of PM (PTC)

This testing procedure was developed by the American Society of Mechanical Engineers (ASME), with final approval in 1980. Different arrangements are allowed to be used with this method making it similar to Method 5 for some sampling trains and comparable to Method 17 for other. Use of ASME test procedures for performance testing is usually disallowed by regulatory agencies.

EPA Method 9

EPA Method 9 covers the determination of plume opacity by human observers. The method includes procedures for the training and certification of observers, and procedures to be used in the field for determination of stack plume opacity.

EPA Method 1 and 2

EPA Method 1 and 2 are used together to determine gas velocity and volume flow rate, include procedures for flue gas temperature measurement.

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CHAPTER 10 - TROUBLESHOOTING - COLLECTING PLATES

This chapter shows pictures of various problems relating to ESP collecting plates and suggested solutions.

Problem:

Collecting electrode and discharging electrode corrosion caused by introduction of excessive volume of unheated insulator purge air for NT support insulators.

Solution:

After replacement of corroded parts use proper volume (100 CFM per insulator) heated to 300 degrees F.

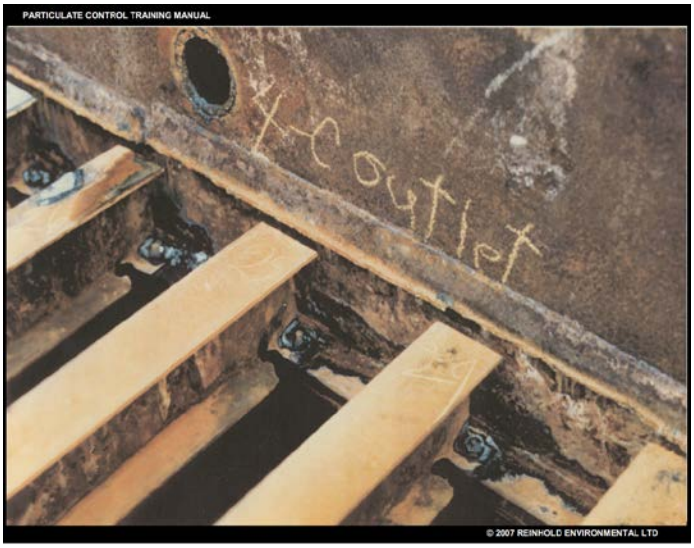
Collecting Electrode and Discharging Electrode Corrosion

Problem:

Corroded collecting electrode wide flange beams where insulator compartment is heat sink due to excessive volume of unheated purge air.

Solution:

After repair adjust purge air quality and heat to 300 degrees F.



Corroded Collecting Electrode Wide Flange Beams

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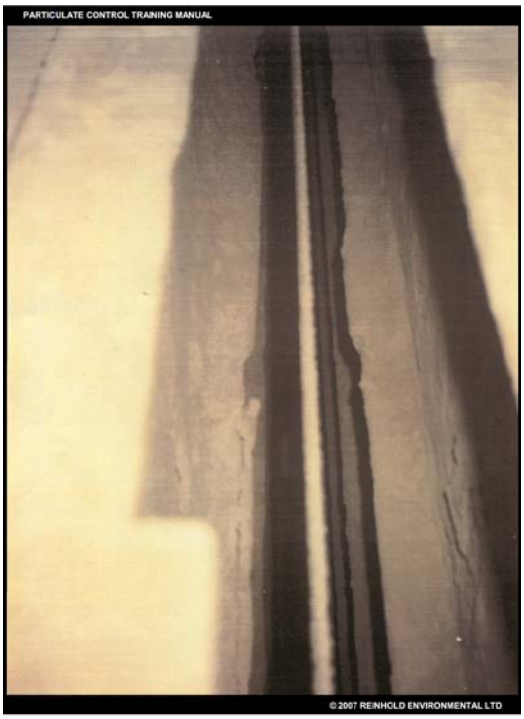
Problem:

Collecting electrodes are dirty.

Solution:

Precipitator must be washed or sand or grain blasted. Rapper design must be checked.



Collecting Electrodes are Dirty

Problem:

Badly misaligned rigid frame discharge electrodes.

Solution:

Realign.

Badly Misaligned Rigid Frame Discharge Electrodes

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Problem:

Space above plates.

Solution:

Check for loose wires in masts, rivets pulling or cracking out of plates, and cracked welds.

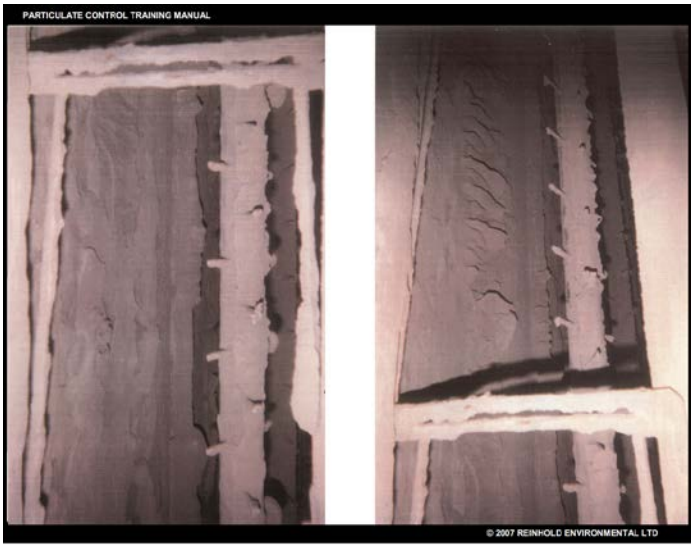
Space above Plates

Problem:

Badly fouled collecting plate. Rapper hammers fell off.

Solution:

Fix rapper hammers and hand clean plate.



Badly Fouled Collecting Plate

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Problem:

Rigid frame discharge electrode assemblies, collecting electrodes removed due to warpage.

Solution:

Replace collecting electrode panels making sure they are never in compression.

Rigid Frame Collecting Electrodes Removed due to Warpage

Problem:

Scouring in front of collecting plate.

Solution:

Work on improving distribution to eliminate high velocity area.

Scouring in Front

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Problem:

Bent collecting plates.

Solution:

Plates were placed in vertical compression. Straighten with heat or replace plates. Make sure plates are loose in spacers and free to expand in startup transient.

Bent Collecting Plates

Problem:

Crack in plate.

Solution:

Clean, patch and weld.

Crack in Plate

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Problem:

Lower plate restraint missing, plate jammed, C clamp used as plate restraint (lower right hand corner).

Solution:

Free plate. Properly repair or replace plate guides.

Lower Plate Restraint Missing, Plate Jammed

Problem:

Lower plate retaining clip has come off and been replaced. Wires have arced into plate when it was allowed too much travel before restraint was restored.

Solution:

Repair or replace retaining clips carefully and properly. Restrain plate movement per supplier's specification.

Wires Have Arced into Plate

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Problem:

Lower side spacer adjustment jammed and not working properly.

Solution:

Free plate and adjuster. Check at annual inspections.

Lower Side Spacer Adjustment Jammed

Problem:

Midpoint space bar clips are spreading.

Solution:

Replace midpoint spaces with a more rugged design.

Midpoint Space Bar Clips are Spreading

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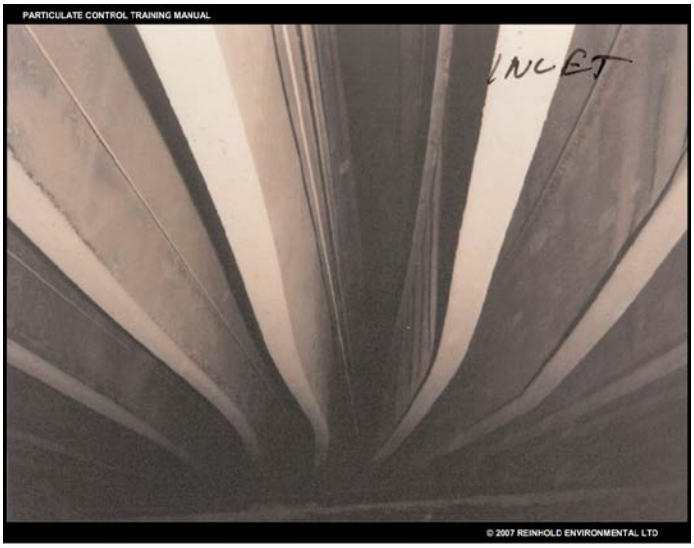
Problem:

Badly bowed collecting plates.

Solution:

Replace plates and discharge electrodes. Make sure new plates are loose in spaces and are free to expand down.



Badly Bowed Collecting Plates

Problem:

Bowed plates.

Solution:

Straighten plates with heat or hickey bar. Make sure plates are loose in spacers so they can expand down. Plates bow because they are placed in vertical compression.

Bowed Plates

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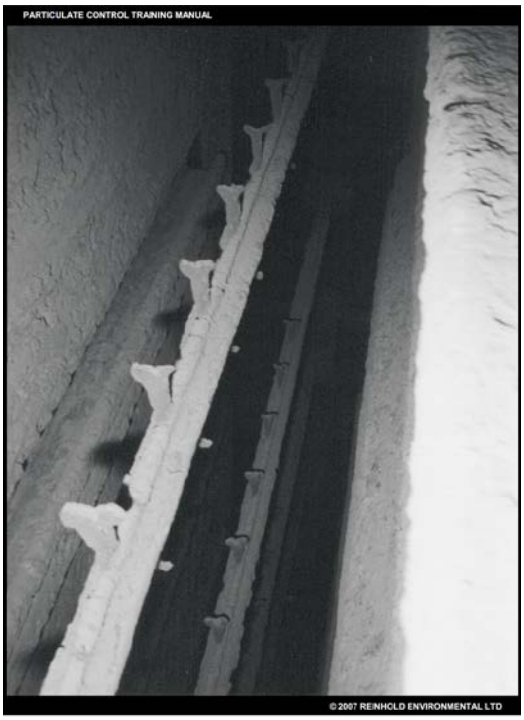
Problem:

Moderate buildup on RDEs and plates.

Solution:

Slightly increase frequency of rapping. Leave intensity alone.



Moderate Buildup on RDEs and Plates

Problem:

Heavy buildup on collecting plates and RDEs.

Solution:

Check for air and water inleakage. Make sure rappers are functioning. Increase frequency and intensity of rapping.

Heavy Buildup on Collecting Plates and RDEs

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Problem:

Heavy buildup on collecting plates and discharge electrodes.

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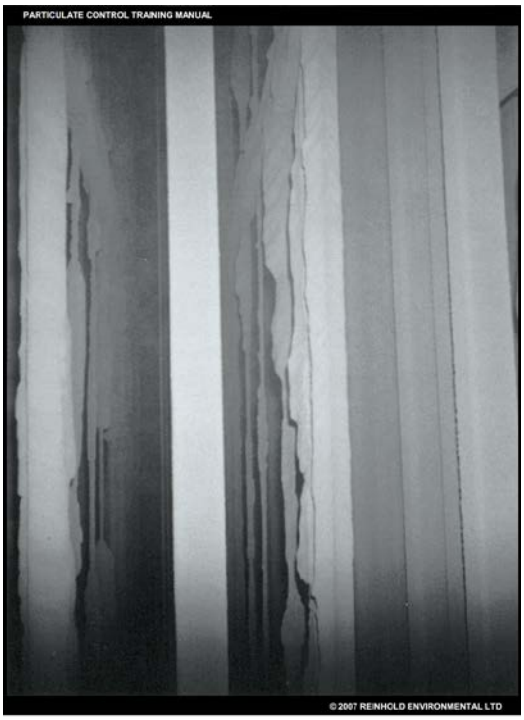

Heavy Buildup on Collecting Plates and Discharge Electrodes

Problem:

Heavy collecting rate buildup, RDEs are functionally clean.

Solution:

Make sure plate rappers are functioning and delivering energy to plates. Increase frequency and intensity of rapping.

Heavy Collecting Rate Buildup, RDEs are Functionally Clean

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Problem:

Inter duct (gas passage) explosion in precipitator bending plates and shorting section.

Solution:

Temporary - remove discharge electrodes from the bad ducts and blank off area to prevent gas flow. Permanent - replace damaged plates and reinstall discharge electrodes.

Inter Duct (gas passage) Explosion Bending Plates

Problem:

Localized fire of combustible material on precipitator collecting electrode.

Solution:

Temporary - remove discharge electrode and blank off gas passages in damaged area. Permanent - replace damaged plates and reinstall new discharge electrodes.

Localized Fire of Combustible Material

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Problem:

Plate bank positioner not engaged in plate spacer assembly permitting whole bank to shift out of alignment.

Solution:

Reposition to engage.

Plate Bank Positioner Not Engaged in Plate Spacer Assembly

Problem:

Plate spacer jammed in positioning device, destroying plate rapper effectiveness.

Solution:

Loosen and recenter (it is off to one side).

Plate Spacer Jammed in Positioning Device

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Problem:

Plate spacer fastened to shell, destroying rapper effectiveness.

Solution:

Cut loose.

Plate Spacer Fastened to Shell

Problem:

Plate spacer positioner too loose, allowing whole plate bank to swing.

Solution:

Tighten and center, but not too tight.

Plates Spacer Positioner Too Loose

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Problem:

Collecting plate spacer fastened to casing, sneak baffle fastened to vertical column and to last (or first) plate dampening rapping.

Solution:

Cut spacer from shell. Cut sneak baffle from plate.

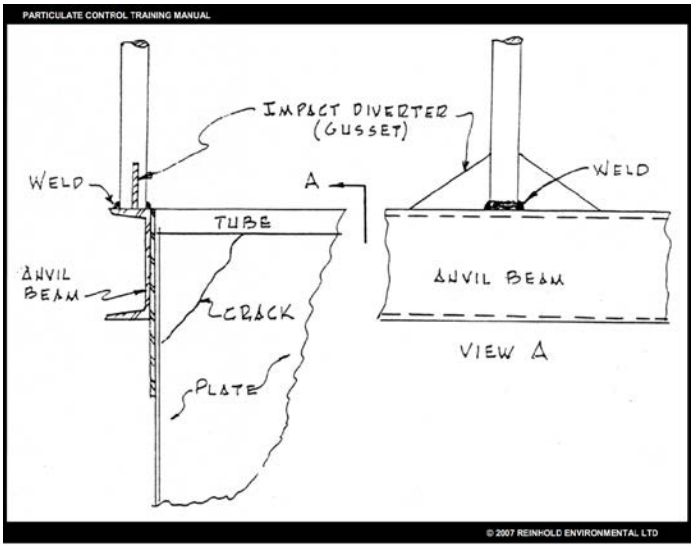
Spacer Fastened to Casing

Problem:

Collecting plate failure in area of rapping bar.

Solution:

Repair and reinforce.



Failure in Area of Rapping Bar

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Problem:

Holes cut in collecting electrodes.

Solution:

To prevent arcing from sharp edges of grounded electrode, remove the discharge electrodes within 10 inches of the holes.

Holes Cut in Collecting Electrodes

Problem:

Bent plates and bent wires, no help from plate to plate spacer installed in center.

Solution:

Remove bent wires or straight wires where plates are bent and cannot be straightened. Rebuild sections if problems are extensive.

Bent Plates and Bent Wires

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Problem:

Broken or soon to be broken collecting plate at fastening to anvil beam, note proximity to plate rapper bar.

Solution:

Repair and reinforce, maintaining electrical clearances.

Broken or Soon to be Broken at Fastening to Anvil Beam

Problem:

Plate alignment problems due to deformed lower plate spacers.

Solution:

Repair or replace lower plate spacers and align plates and discharge wires.

Alignment Problems Due to Deformed Lower Plate Spacers

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CHAPTER 11 - TROUBLESHOOTING - PERFORATED PLATES AND TURNING VANES ASH BUILDUP

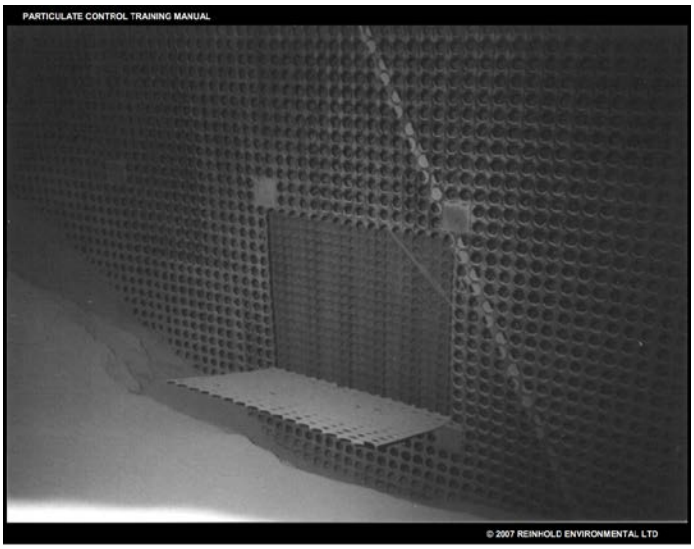
This chapter shows pictures of various problems relating to ESP Perforated Plates and Turning Vanes Ash Buildup and suggested solutions.

Problem:

Door in perforated distribution plate left open ruining gas distribution.

Solution:

Carefully check everything before closing flue of precipitator access doors.



Door Left Open, Ruining Gas Distribution

Problem:

Due to heavy buildup on flue floor behind it, perforated distribution plate is bulged into collecting plates.

Solution:

Remove perforated plate, straighten and stiffen it. Remove fly ash. Reinstall plate with rappers. Add soot blower to flue floor.

Due to Heavy Buildup, Plate is Bulged into Collecting Plates

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Problem:

Perforated distribution plate bulged out due to buildup behind it.

Solution:

Straighten plate, slot bottom and add fish tail compressed air soot blower.

Plate Bulged Out Due to Buildup Behind It

Problem:

Perforated distribution plate heavily plugged.

Solution:

Add spring suspension and rappers.

Plate Heavily Plugged

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Problem:

Plugged perforated gas distribution plates.

Solution:

Add flexible suspension (springs) and rappers.

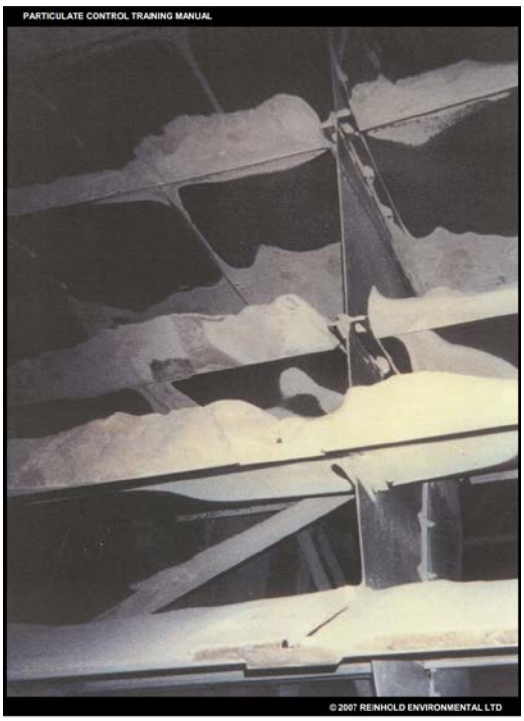
Plugged Plates

Problem:

Fouled turning vanes causing gas flow problem at precipitator inlet.

Solution:

Reduce vane coverage by cutting out some of horizontal vane or install sonic horns.



Fouled Turning Vanes Causing Gas Flow Problem at Precipitator Inlet

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Problem:

Buildup on turning vanes.

Solution:

Reduce horizontal surface of vanes.

Buildup

Problem:

Buildup on inlet flue floor.

Solution:

Improve distribution and add soot blowers.

Buildup on Inlet Flue Floor

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Problem:

Dust buildup of flue floor at precipitator inlet.

Solution:

Slot perforated distribution plate at bottom and increase blowers or add soot blowers.

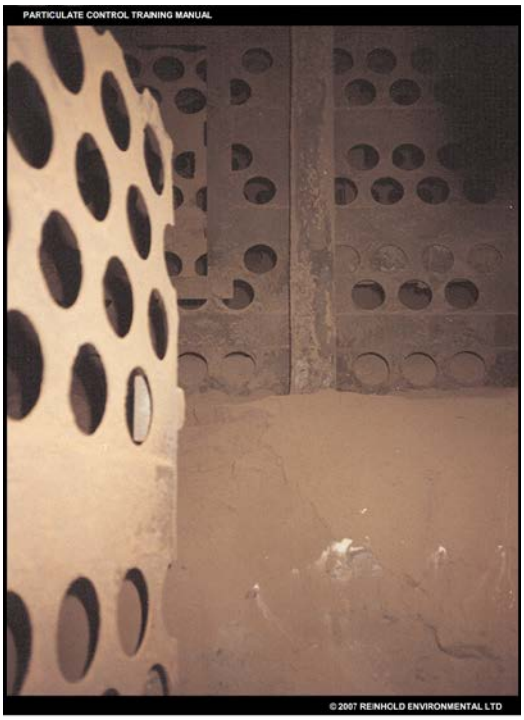
Dust Buildup of Flue Floor

Problem:

Buildup of flue floor between perforated distribution plates.

Solution:

Slot bottom of distribution plates to increase velocities on floor.



Buildup of Flue Floor Between Perforated Plates

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CHAPTER 12 - TROUBLESHOOTING - HT INSULATORS

This chapter shows pictures of various problems relating to ESP HT Insulators and suggested solutions

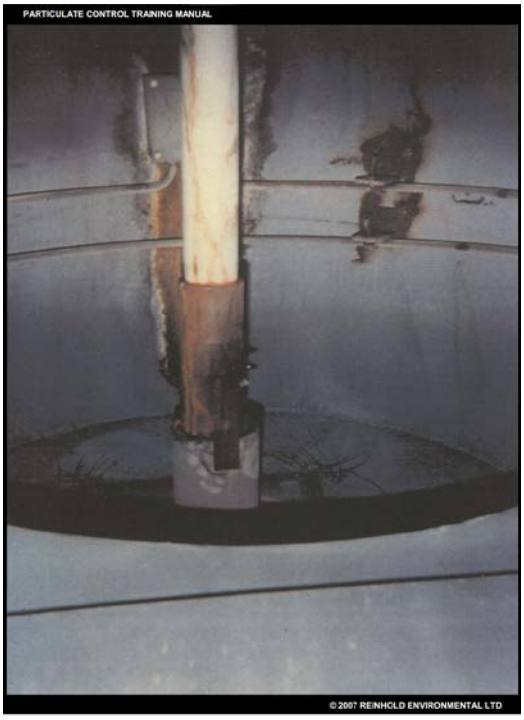
Cover Left Off When Insulator Compartment Door Shut

Problem:

Cover left off when insulator compartment door shut resulted in fouled insulator.

Solution:

Always check before doors are closed. Clean insulator and replace if tracked.



Tracked Rapper Insulator

Problem:

Tracked rapper insulator.

Solution:

Seal at top if leaking water from rain or snow. Repair seal and replace insulator.

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Problem:

Open hole in hot roof to pass HT hanger requires too much purge air.

Solution:

A closure made of insulator material is available in the after market to seal this hole.

Open Hole in Hot Roof to Pass HT Hanger

Problem:

Fouled HT support insulator showing vertical tracks due to condensation.

Solution:

Replace insulator and provide sufficient clean and hot purge air.

Fouled HT Support Insulator

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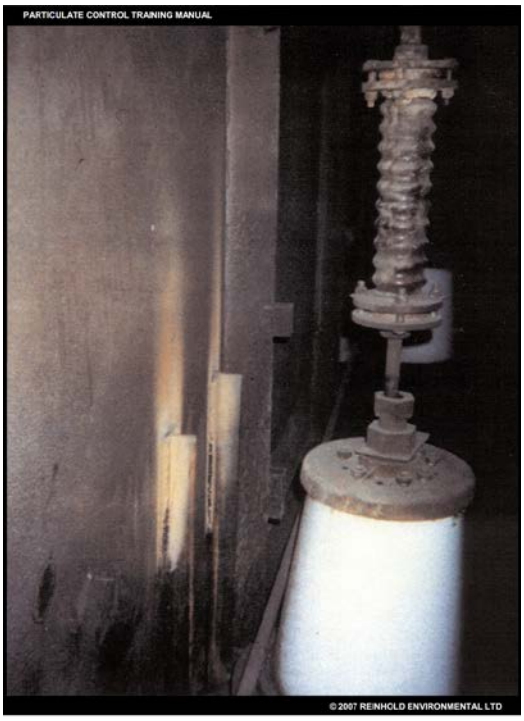
Problem:

Tracked HT rapper insulator.

Solution:

Replace water seal where rapper bar penetrates insulator compartment roof. Replace insulator.



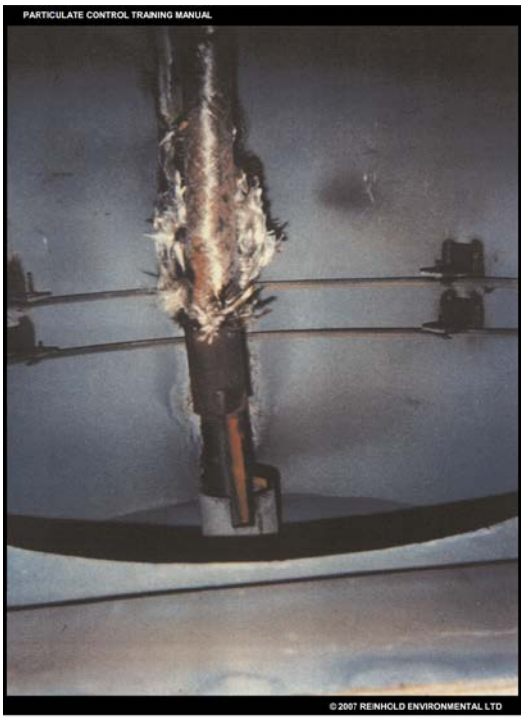
Tracked HT Rapper Insulator

Problem:

Failed FRP rapper isolating insulator.

Solution:

FRP not suitable at temperature. Use alumina or porcelin insulator.



Failed FRP Rapper Isolating Insulator

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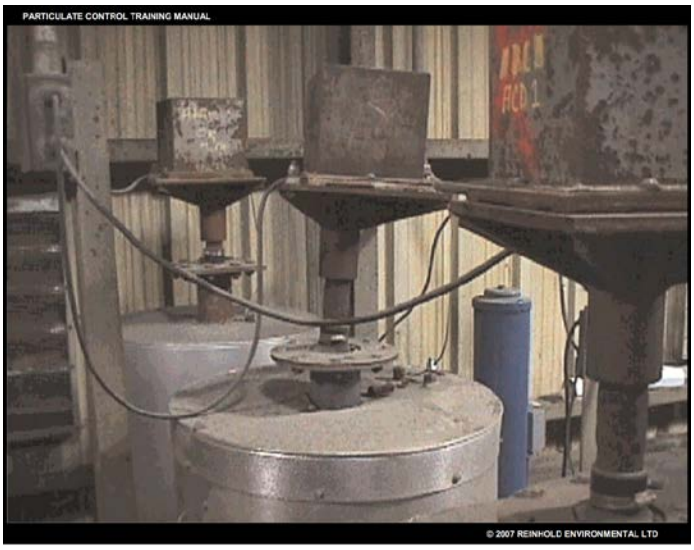
Problem:

The high tension rapper isolation insulator has failed or become loose.

Solution:

Replace welded and bolted connections with tapered shafts and sockets.



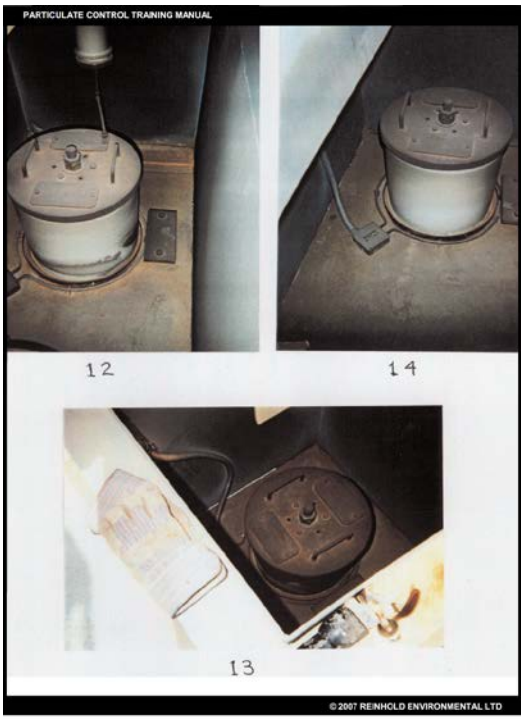
The High Tension Rapper Isolation Insulator Has Failed

Problem:

Evidence of electrical leakage (left).

Solution:

Keep insulators clean and warm. Provide heated purge air.



Evidence of Electrical Leakage

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Problem:

Broken support insulator (Joy Western Insulator).

Solution:

Replace insulator. Install closure around HT hanger pipe. Provide hot and clean purge air.

Broken Support Insulator

Problem:

Fouled insulator showing evidence of heavy electrical tracking and leaking.

Solution:

Improve quantity and quality of purge air. Make sure air is heated to 275 to 300 degrees F.

Fouled Insulator

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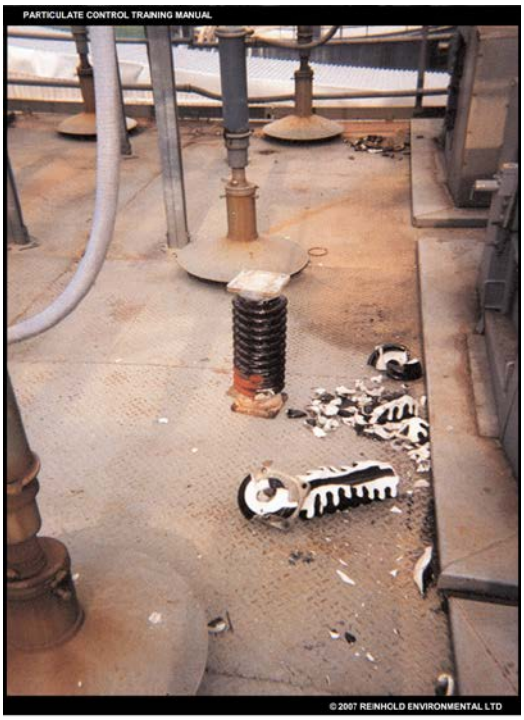
Problem:

Broken post type support insulator in Joy Western Precipitator.

Solution:

Ensure sufficient purge air. Replace with an alumina insulator.



Broken Post Type Support Insulator

Problem:

Support beams under insulator compartment floor corroded way tilting support insulators. Corrosion was due to excessive quantity of cold air purge.

Solution:

After repair, use proper quantity and proper temperature purge air. Filter air to prevent fouling insulators.

Support Beams under Insulator Compartment Floor Corroded

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Problem:

Failed high tension support hanger protector tube due to excessive quantity of cold purge air.

Solution:

After replacement adjust quantity and temperature of purge air.

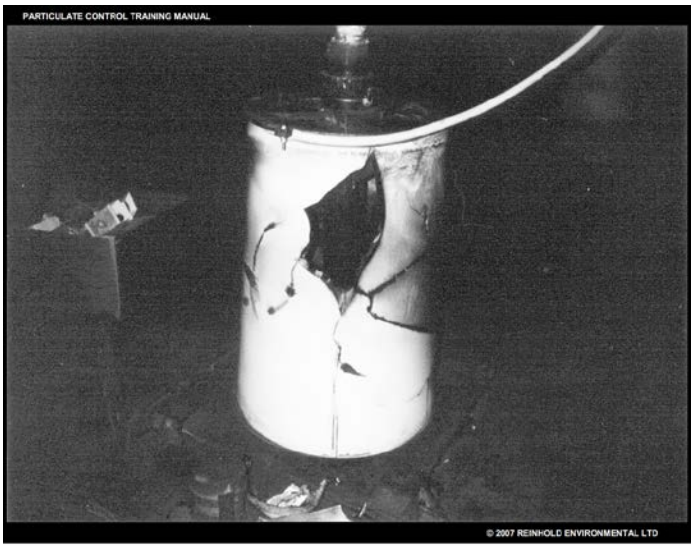
Failed High Tension Support Hanger Protector Tube

Problem:

Shattered insulator.

Solution:

Replace insulator with 85% alumina insulator. Provide sufficient flow of clean purge air.



Shattered Insulator

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Problem:

Large crack in insulator.

Solution:

Change insulator.

Large Crack in Insulator

Problem:

Small crack in insulator.

Solution:

Change insulator.

Small Crack in Insulator

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Problem:

Tracking and cracks inside support insulator.

Solution:

Change insulator and provide a sufficient volume of clean hot purge air.

Tracking and Cracks Inside Support Insulator

Problem:

Tracking, buildup and cracks inside support insulator.

Solution:

Change insulator and provide a sufficient volume of clean hot purge air.

Tracking, Buildup and Cracks Inside Support Insulator

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Problem:

Corona spots on base of insulator.

Solution:

Keep insulators clean and dry, and properly purged with warm air.

Corona Spots on Base of Insulator

Problem:

Corona points forming around clip on base of insulator.

Solution:

Reduce height of clip. Keep insulators clean and properly purged with warm air.

Corona Points Forming Around Clip on Base of Insulator

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Problem:

Broken anti-sway insulators - good source for misalignment and tracking.

Solution:

Replace insulators, perhaps with more flexible teflon material.

Broken Anti-sway Insulators

Problem:

Fouled and broken HT support insulator for a Joy Western Precipitator.

Solution:

Supply clean heated purge air.

Fouled and Broken HT Support Insulator

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Problem:

Broken connection from HT buss to HT frame open circuit.

Solution:

Replace with stainless steel braid. Do not use copper which is subject to sulfur corrosion and fatigue failure.

Broken Connection from HT Buss to HT Frame

Problem:

Corroded hole in insulator compartment floor due to heat sink of access ladder and excessive volume of cold purge air.

Solution:

After repair, adjust quantity and temperature of purge air.

Corroded Hole in Insulator Compartment Floor

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Problem:

Wear on HT wire button terminations.

Solution:

Replace when wear gets excessive.

Wear on HT Wire Button Terminations

Problem:

Inside of penthouse.

Solution:

Check support insulators, stand-off insulators, and insulators for HT rappers. Check HT connections.

Inside of Penthouse - 1

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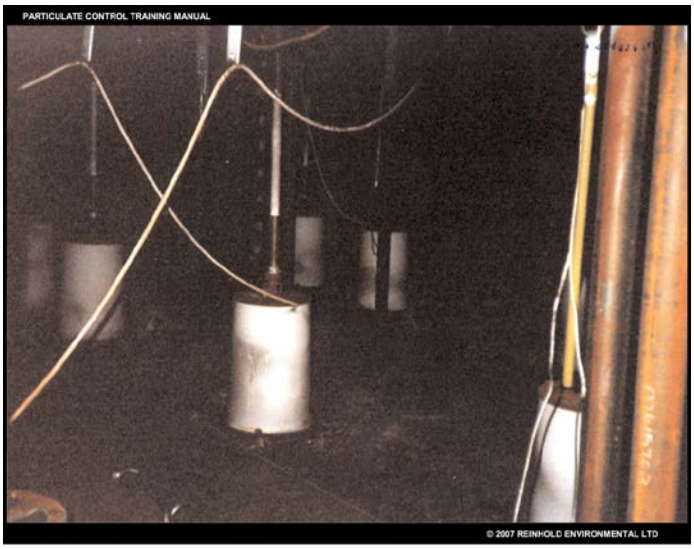
Problem:

Inside of penthouse. 2.

Solution:

Check support insulators, stand-off insulators, and insulators for HT rappers. Check HT connections.



Inside of Penthouse - 2

Problem:

Inside of roof girder.

Solution:

Check interior of insulator compartments for stand-off, support, and feed-through insulators, high voltage connections.

Inside of Roof Girder

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Problem:

Bus duct.

Solution:

Check centering of bus piping and interior of bus duct for protrusions, sharp points, etc.

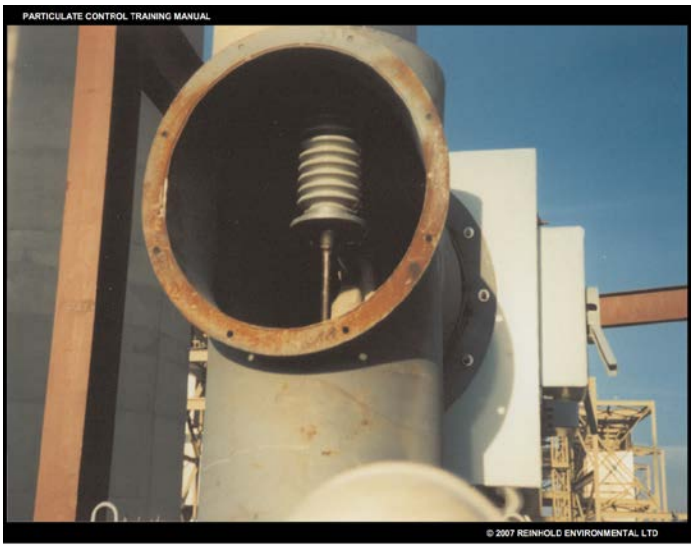
Bus Duct - 1

Problem:

Bust duct.

Solution:

Check stand-off insulators for damage and contamination.



Bus Duct - 2

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Problem:

Weather enclosure.

Solution:

Check TRs, bus duct, rappers.

Weather Enclosure

Problem:

Flyash build-up on tops of HT support.

Solution:

Clean out at annual outages to avoid excess build-up in the future which can cause problems.

Fly Ash Buildup on Tops of HT Support

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Problem:

Dirty and broken HT support insulator in insulator compartment.

Solution:

Keep insulator clean and dry with adequate purge air system.

Dirty and Broken HT Support Insulator

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CHAPTER 13 - TROUBLESHOOTING - ERECTION

This chapter shows pictures of various problems relating to Erection of ESPs and suggested solutions.

Pictured:

Removal of old collecting plates with roof off.

Removal of Old Collecting Plates with Roof Off

Pictured:

Material removed during rebuild.

Material Removed During Rebuild

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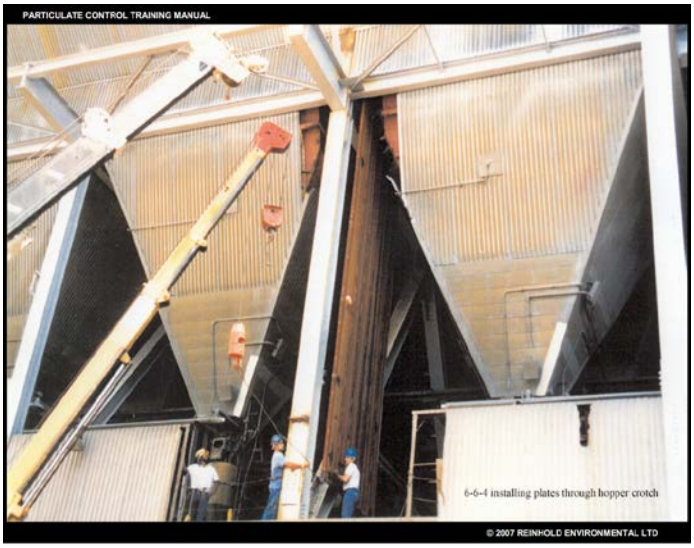
Pictured:

Major Rebuild with Hot Roof Removed and New Plates in Vertical Lifting Rack

Major Rebuild with Hot Roof Removed and New Plates in Vertical Lifting Rack

Pictured:

Installing New Plates through Hopper Crotch



Installing New Plates through Hopper Crotch

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Pictured:

Installing RDEs from Top with Hot Roof Removed

Installing RDEs from Top with Hot Roof Removed

Pictured:

Installing Plates and RDEs through Slots Cut in Roof which Remains in Place

Installing Plates and RDEs through Slots Cut in Roof which Remains in Place

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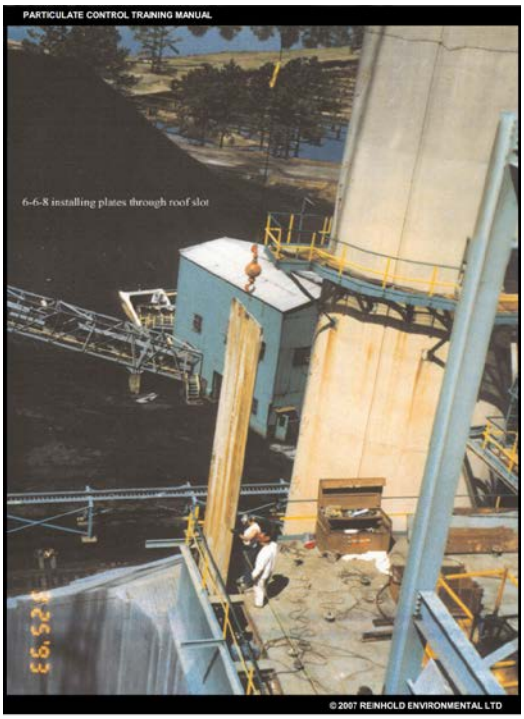
Pictured:

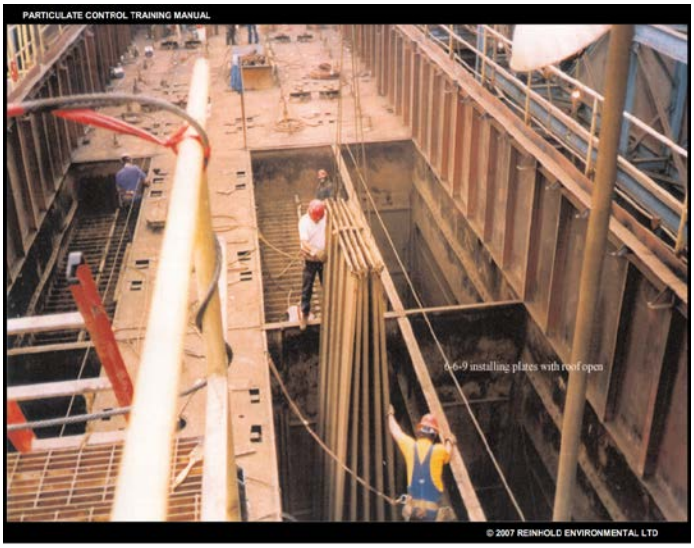
Installing Collecting Plates through Slots in Hot Roof and Cold Roof which Both Remain in Place



Installing Collecting Plates through Slots in Hot Roof and Cold Roof which Both Remain in Place

Pictured:

Installing Plates with Both Hot and Cold Roof Removed



Installing Plates with Both Hot and Cold Roof Removed

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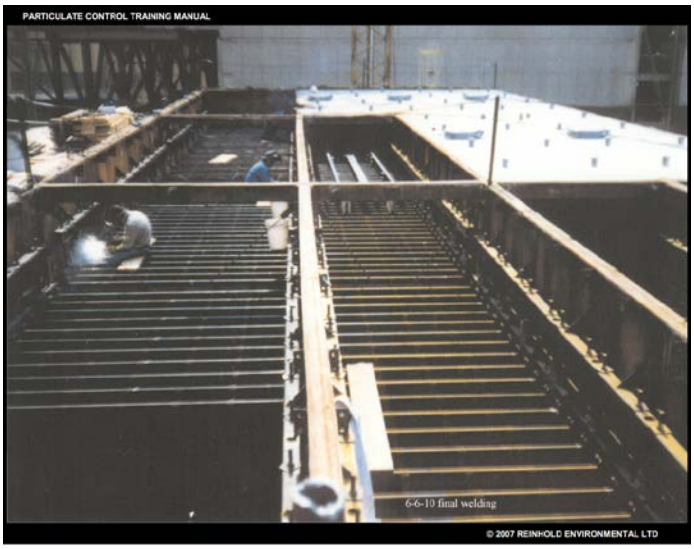
Pictured:

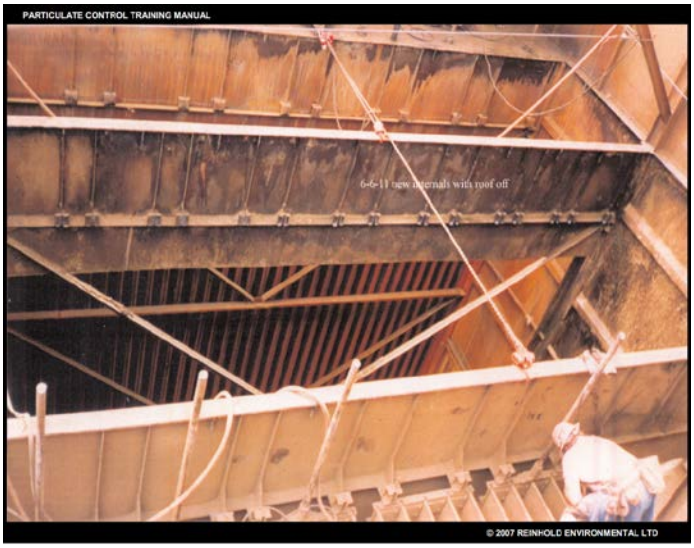
Final Welding of Plates to Supports with Hot Roof Removed



Final Welding of Plates to Supports with Hot Roof Removed

Pictured:

Installing All New Internals with Both Hot and Cold Roofs Removed



Installing All New Internals with Both Hot and Cold Roofs Removed

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Pictured:

Installing New Internals through Slots in Side Frames with Hot and Cold Roofs and Supporting Columns in place.

Installing New Internals through Slots in Side Frames with Hot and Cold Roofs and Supporting Columns in Place

Pictured:

RDE Discharge Electrode Frame Resting on the Tops of the Collecting Plates before the Installation of the Hot Roof and the Raising of the Frame to its Final Position.

RDE Discharge Electrode Frame Resting on the Tops of the Collecting Plates

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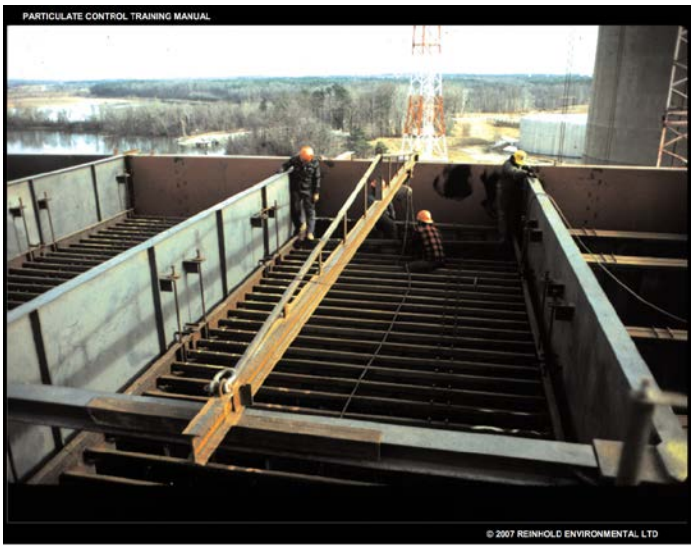
Pictured:

The Collecting Electrodes Support Tension Bolts to the Left



The Collecting Electrodes Support Tension Bolts to the Left

Pictured:

Bottom or Lower Frame for the RDE Discharge Electrodes

Bottom or Lower Frame for the RDE Discharge Electrodes

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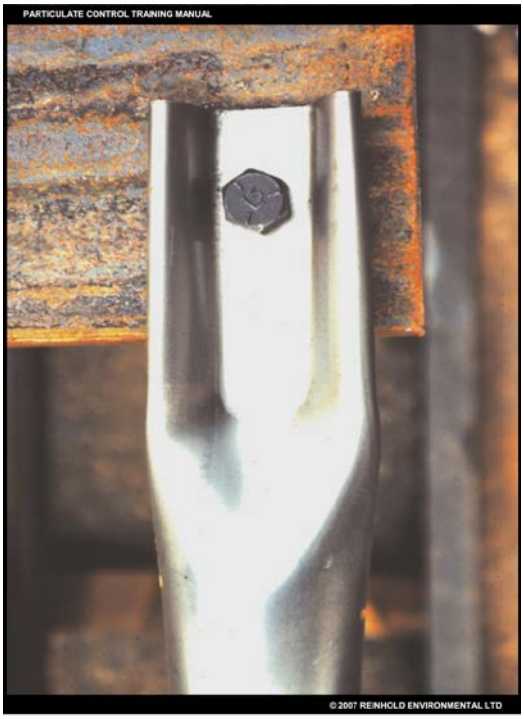
Pictured:

Vertical Collecting Electrode Bundles, Stored in the Precipitator and Waiting to be Installed in Proper Position and Fastened to Support.

Vertical Collecting Electrode Bundles Waiting to be Positioned, Installed and Fastened

Pictured:

Detail of Fastening an RDE to Its Support Frame



Detail of Fastening an RDE to Its Support Frame

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Pictured:

Roof Access Door. Note Key Interlock and Chain.

Roof Access Door; Note Key Interlock and Chain

Pictured:

Side Access Door on Precipitator, Not a Removable Heat Insulation Panel

Side Access Door on Precipitator;
Not a Removable Heat Insulation Panel

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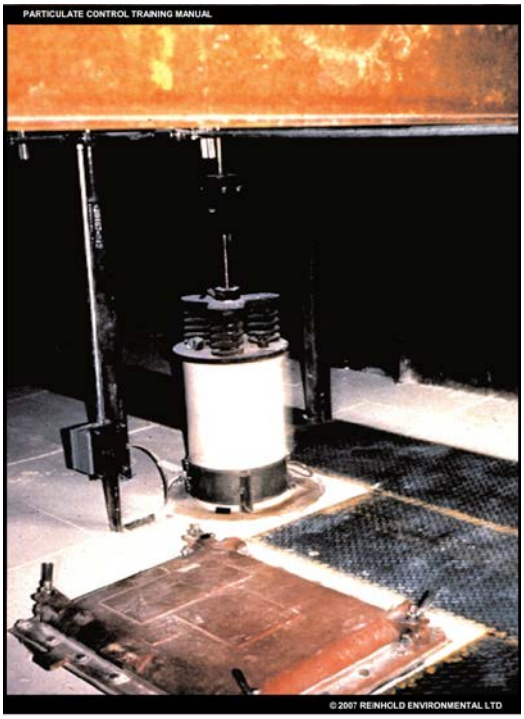
Pictured:

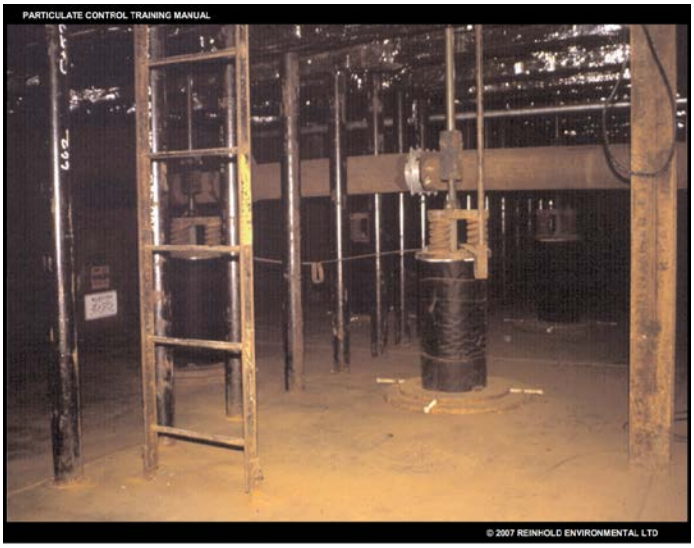
Inside of the Insulator Housing, Hot Roof, Support Insulator and Access Doors through the Hot Roof



Inside of the Insulator Housing, Hot Roof, Support Insulator and Access Doors through the Hot Roof

Pictured:

Inside Top Insulator Housing. Note Hot Roof, Collecting Electrode Rapper Bars, HT Rapper Bars, Support Insulator and Access Ladder from Cold Roof.



Inside Top Insulator Housing

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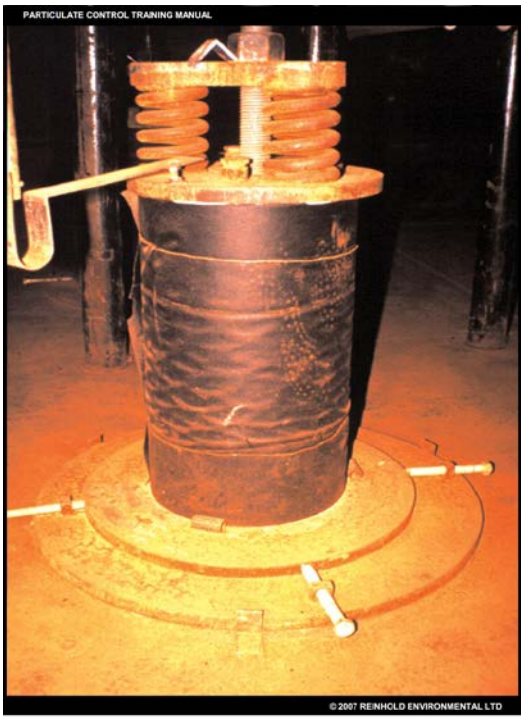
Pictured:

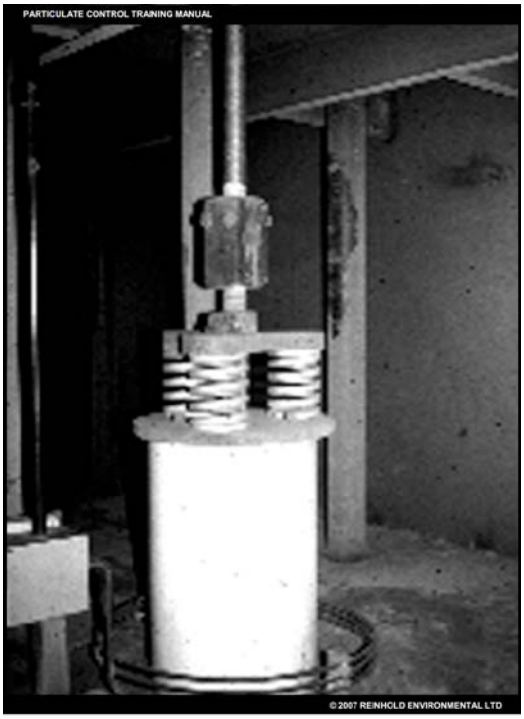
Support Insulator in Top Housing with Integral Heat Insulation.



Support Insulator in Top Housing with Integral Heat Insulation

Pictured:

Support Insulator in Top Housing. Note Electric Strip Heaters at Bottom of Insulator.



Support Insulator in Top Housing

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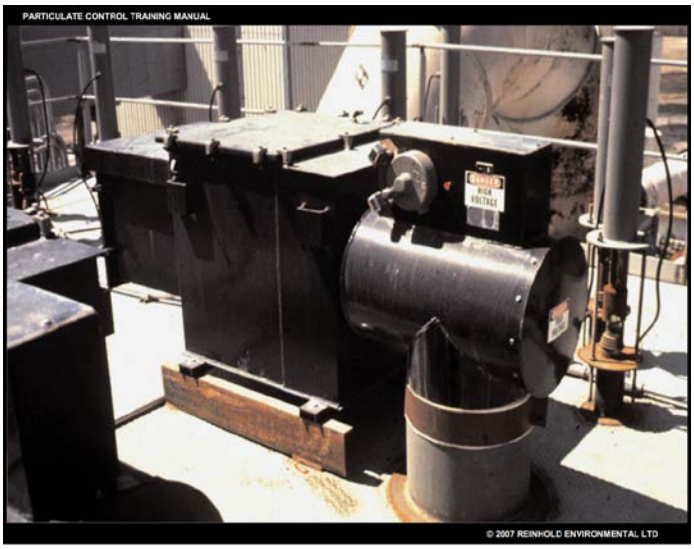
Pictured:

Transformer Rectifier Control Unit with the Access Door Open Showing the Power Components and Wiring as well as the Automatic Control and Instruments.

Transformer Rectifier Control Unit

Pictured:

High Voltage Transformer Rectifier Assembly with Bus Duct Connected. Note the High Voltage Bus Duct Covering the Side Mounted High Voltage Output.



High Voltage Transformer Rectifier Assembly with Bus Duct Connected

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Pictured:

Protector Tube (Volute) where High Voltage Hanger Pipe Penetrates Hot Roof.

Protector Tube (Volute) Where High Voltage Hanger Pipe Penetrates Hot Roof

Pictured:

Individual collecting Electrode Rappers on Cold Roof

Individual collecting Electrode Rappers on Cold Roof

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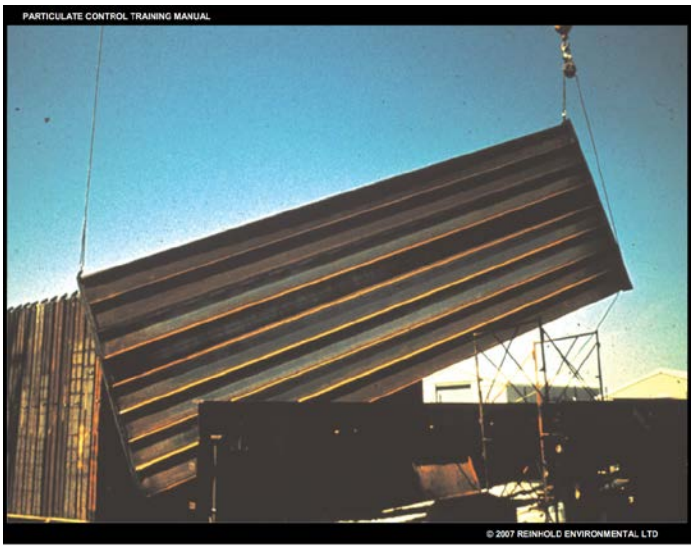
Pictured:

Collecting Electrode Impact Rappers on the Cold Roof of the Insulator Housing

Collecting Electrode Impact Rappers on the Cold Roof of the Insulator Housing

Pictured:

Lifting of Collecting Electrode Assemblies in Vertical Bundles to Prevent Handling Problems with Individual Plates in the Wind.



Lifting of Collecting Electrode Assemblies in Vertical Bundles

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Pictured:

Method of Handling and Storing Assembled Collecting Electrodes in Bundles to Prevent Distortion of Individual Assemblies.

Method of Handling and Storing Assembled Collecting Electrodes in Bundles

Pictured:

Detail of Fastening the Collecting Electrode Rapper Bar to Two Collecting Electrodes. Looking down note the RDEs between the collecting electrodes.

Detail of Fastening the Collecting Electrode Rapper Bar to Two Collecting Electrodes

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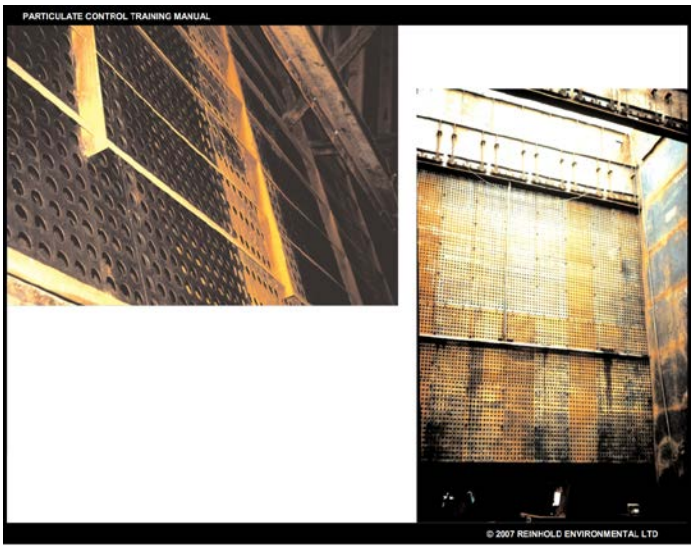
Pictured:

Method of Assembly of the Roll Formed Collecting Electrode Strips into an Interlocked Collecting Electrode Module. Note the Tadpole Support on Top.

Method of Assembly of the Roll Formed Collecting Electrode Strips into an Interlocked Collecting Electrode Module

Pictured:

Inlet Perforated Distribution Plate Installation



Inlet Perforated Distribution Plate Insulation

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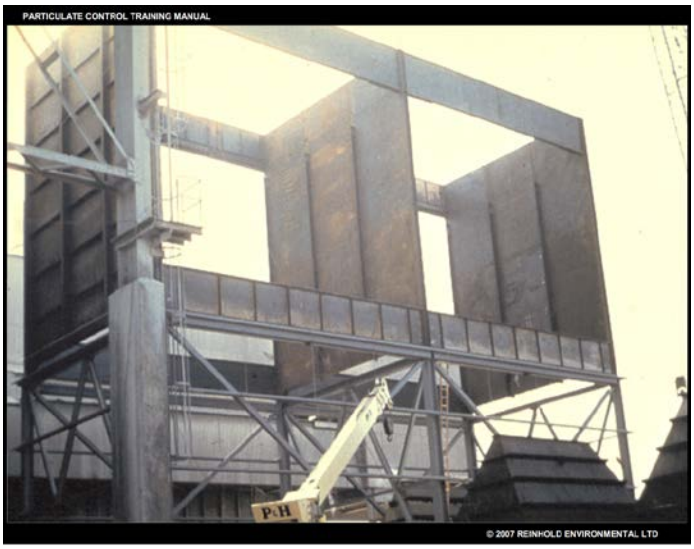
Pictured:

Fabrication and Assembly in a Horizontal Position of a Precipitator Casing Vertical Side Frame

Fabrication and Assembly in a Horizontal Position of a Precipitator Casing Vertical Side Frame

Pictured:

Start of the Erection of a New Two Chamber Precipitator. The two side frames and the partition frame seperating the two chambers have been erected and tied together with the top and bottom inlet and outlet end frames. The casing is ready for the installation of the collecting and discharge electrodes through the roof opening.



Start of the Erection of a New Two Chamber Precipitator

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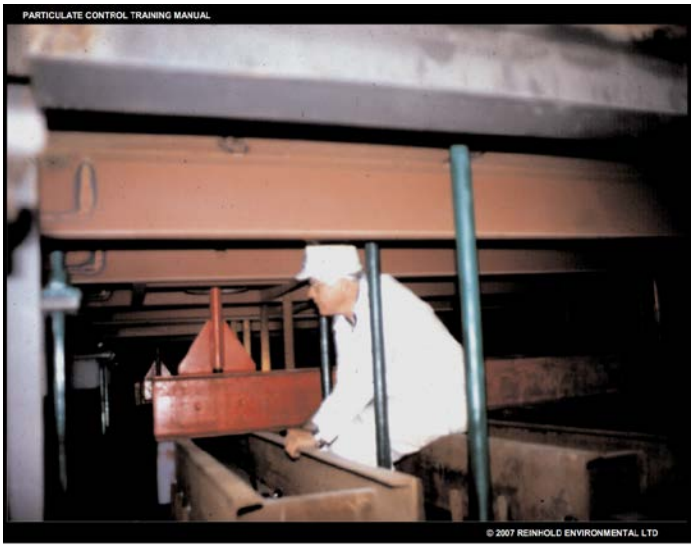
Pictured:

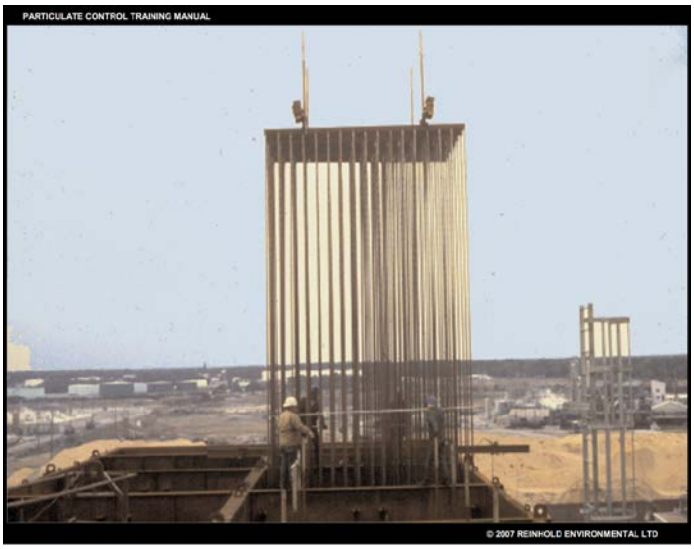
Final Positioning of a Weighted Wire Discharge Electrode Frame Below the Hot Roof



Final Positioning of a Weighted Wire Discharge Electrode Frame Below the Hot Roof

Pictured:

Lifting of an Assembled High Voltage Discharge Electrode System and its Installation through the Roof. The RDE Discharge Electrodes have Previously been Assembled to the Upper High Voltage Frame.



Lifting of an Assembled High Voltage Discharge Electrode System and Its Installation through the Roof

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CHAPTER 14 - TROUBLESHOOTING - STRUCTURAL PROBLEMS

This chapter shows pictures of various problems relating to ESP Structural Problems and suggested solutions.

Problem:

Eroded pipe strut in flue due to high velocity area.

Solution:

Repair and reinforce strut. Try to eliminate high velocity area.

Eroded Pipe Strut in Flue Due to High Velocity Area

Pictured:

Exterior of Duct with Holes and Cracked Welds.

Exterior of Duct with Holes and Cracked Welds

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Problem:

Corrosion of sneak baffle and roof beams due to heat sink and standing water on roof.

Solution:

After repair, improve insulation details and lagging to prevent heat sink and water saturation of heat insulation.

Corrosion of Sneak Baffle and Roof Beams Due to Heat Sink and Standing Water on Roof

Problem:

Corroded roof beams, sneak baffles and plates due to cold purge air. Temporary repairs in place to prevent collapse.

Solution:

Fix purge air heating system after permanent repair.

Corroded Roof Beams, Sneak Baffles and Plates Due to Cold Purge Air

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Problem:

Corroded roof beams under support insulator, letting roof come down tilting insulators.

Solution:

After repair use proper quantity of heated purge air.

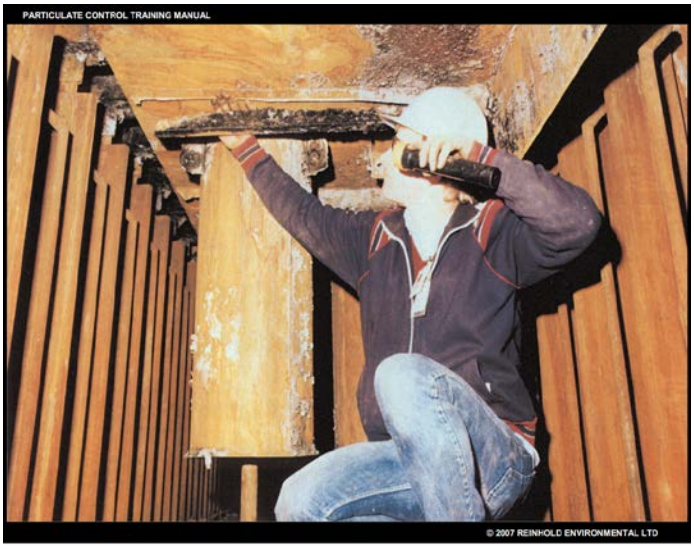
Corroded Roof Beams under Support Insulator, Letting Roof Come Down Tilting Insulators

Problem:

Roof beam corrosion due to cold purge air in insulator compartment.

Solution:

Fix heater after structural repair. Monitor heater conditions with ammeters in heater circuit.



Roof Beam Corrosion Due to Cold Purge Air in Insulator Compartment

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Problem:

Leaks in seam weld of flue.

Solution:

Clean and reweld. Inspect all seams for leaks.

Leaks in Seam Weld of Flue

Problem:

Corroded corona shield or volute due to cold purge air.

Solution:

Replace corona shield. Supply sufficient heated purge air and make sure heaters are working.

Corroded Corona Shield or Volute Due to Cold Purge Air

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Problem:

Leak in seam weld where roof frame joins end frame.

Solution:

Clean and reweld.

Leak in Seam Weld Where Roof Frame Joins End Frame

Pictured:

Extreme Cold Air/Moisture in-leakage has Caused Plate to Peel and Separate.

Extreme Cold Air/Moisture In-leakage Has Caused Plate to Peel and Separate

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CHAPTER 15 - TROUBLESHOOTING - HOPPERS

This chapter shows pictures of various problems relating to Hoppers and suggested solutions.

Problem:

Split Seam weld in Hopper.

Solution:

Clean and reweld. Check all seam welds.

Split Seam Weld in Hopper

Problem:

Door in Hopper Baffle Left Open Causing Hopper Scouring

Solution:

Check to make sure all interior doors are closed before closing outer doors.

Door in Hopper Baffle Left Open Causing Hopper Scouring

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Problem:

Missing Hopper Insulation Causing Cold Spots, Corrosion and Hopper Plugging

Solution:

Maintain integrity of all heat insulation.

Missing Hopper Insulation Causing Cold Spots, Corrosion and Hopper Plugging

Problem:

Full Hopper Up Over Wire Weights and into Plates Grounding Field.

Solution:

Keep hoppers empty. Make sure hoppers are discharging and install hopper level indicators.

Full Hopper Up Over Wire Weights and Into Plates Grounding Field.

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Pictured:

Plugged Precipitator Hopper with Rathole in Center. Impossible to empty, but shows as empty on ash handling system recorder.

Plugged Precipitator Hopper with Rathole in Center

Pictured:

Oil Leak in Top Cover Gasket of Transformer Rectifier

Oil Leak in Top Cover Gasket of Transformer Rectifier

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Pictured:

Burned Support Insulator and Upper HT Frame with close clearance to insulator compartment wall.

Burned Support Insulator and Upper HT Frame

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CHAPTER 16 - TROUBLESHOOTING - CLEANING SYSTEMS (RAPPERS)

This chapter shows pictures of various problems relating to Cleaning Systems (Rappers) and suggested solutions.

Pictured:

Check for Broken welds in Area of Rapper Bar Anvil and Anvil Beam

Check for Broken Welds in Area of Rapper Bar Anvil and Anvil Beam

Pictured:

Check Lower Hammers for Wear, Misalignment, Damage to Plates, pins pulling out, missing pieces, etc.

Check Lower Hammers for Wear, Misalignment, Damage to Plates, Pins Pulling Out, Missing Pieces, etc.

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Pictured:

Check Rapper Connection to Anvil and Anvil Connection to Plates for broken welds and missing or broken bolts.

Check Rapper Connection to Anvil and Anvil Connection to Plates for Broken Welds and Missing or Broken Bolts

Pictured:

Repaired Broken weld from Rapper Bar to Anvil. Gussets added to increase strength.

Repaired Broken Weld from Rapper Bar to Anvil

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Problem:

Broken Plate Rapper in Lodge Cottrell Precipitator Due to Failure of Wrist Pin

Solution:

Replace missing hammer and wrist pin. Make sure wrist pin is secured.

Broken Plate Rapper in Lodge Cottrell Precipitator Due to Failure of Wrist Pin

Problem:

Non-functioning plate Rapping System Due to Broken Sprocket Chain (Lodge Cottrell Precipitator)

Solution:

Hand clean plates if built up with dust, replace sprocket chain and lubricate.

Non-functioning Plate Rapping System Due to Broken Sprocket Chain (Lodge Cottrell Precipitator)

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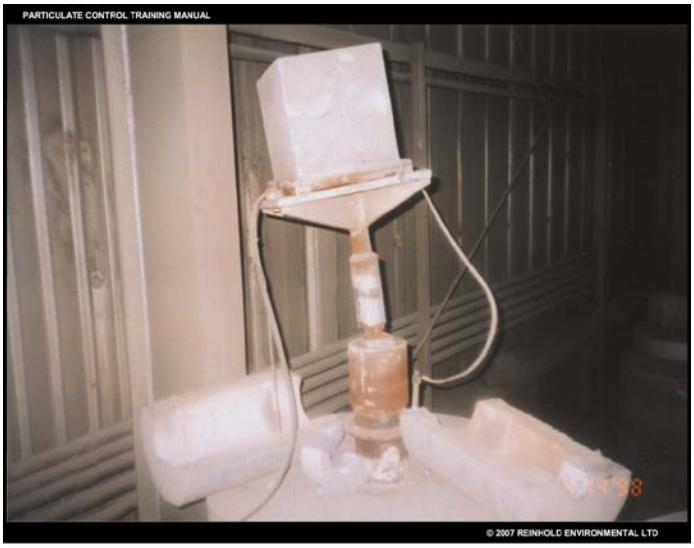
Problem:

HT Vibrator Tilted Due to Broken Vibrator Isolation Ceramic Shaft

Solution:

Replace broken isolator with double tapered alumina shaft. Replace clamps with tapered sockets.



HT Vibrator Tilted Due to Broken Vibrator Isolation Ceramic Shaft

Pictured:

Welds Broken Loose on High Voltage Rapper Beam. Welds had been run in too cold with an NUG welder. Welds were ground out and rewelded with stick welding.

Welds Broken Loose on High Voltage Rapper Beam

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Problem:

Electric Vibrator Discharge Electrode Rappers Require Constant Adjustment of pole face clearance or rapper loses power.

Solution:

Replace with electromagnetic gravity impact rappers.

Electric Vibrator Discharge Electrode Rappers Require Constant Adjustment

Problem:

Spring Opposed Magnetic Impulse Rapper (ML Rapper) with Broken Springs

Solution:

Change to magnetic impulse gravity impact rappers (no springs)

Spring Opposed Magnetic Impulse Rapper (ML Rapper) with Broken Springs

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Problem:

Magnetic Gravity Impulse Rapper Out of Plumb causing wear on inside of plastic tube and possible coil failure.

Solution:

Carefully plumb rappers.

Magnetic Gravity Inpulse Rapper Out of Plumb

Problem:

Collecting Electrode Drop Rod Rapper Leaking Flue Gas into Sealed Tube causing drop rod to seize in tube and wear on lifting cam.

Solution:

Carefully inspect and repair or replace as required.

Collecting Electrode Drop Rod Rapper Leaking Flue Gas into Sealed Tube

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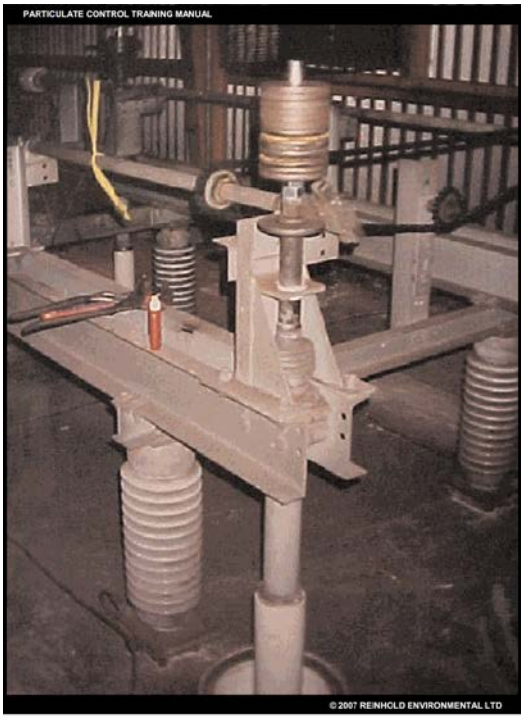
Problem:

Discharge electrode Drop Rod Rapper with Cam Wear

Solution:

Inspect and replace as required.



Discharge Electrode Drop Rod Rapper with Cam Wear

Problem:

Tumbling Hammer Collecting electrode Rappers with (1) misalignment of hammer and anvil and (2) wear and failure of wrist pin or wrist pin retainer.

Solution:

Inspect, realign and replace as required.

Tumbling Hammer Collecting Electrode Rappers with (1) Misalignment, and (2) Wear and Failure

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Pictured:

Replacement of Electric Vibrators with Impact Rapper to reduce maintenance and improve rapping effectiveness. Use of tapered shafts instead of welded or bolted connections greatly improves reliability.

Replacement of Electric Vibrators with Impact Rapper

Problem:

Rapper Bar Has Broken Free of the Anvil Beam or the Anvil Beam Has Shifted

Solution:

Inspect these connections and positions at every opportunity. Repair and realign as required.

Rapper Bar Has Broken Free of the Anvil Beam or the Anvil Beam Has Shifted

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Problem:

Mounting Flange Failed Due to Corrosion caused by a heat sink at the casing penetration.

Solution:

Inspect and maintain integrity of heat insulation and lagging at all casing penetrations.

Mounting Flange Failed Due to Corrosion Caused by a Heat Sink at the Casing Penetration

Problem:

Collecting Electrode Failure Beginning on Opzel Plate next to rapper bar (see cracks and holes)

Solution:

Repair and reinforce. Inspect all collecting electrodes in areas of rapper bars.

Collecting Electrode Failure Beginning on Opzel Plate Next to Wrapper Bar

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Problem:

Misaligned Rapper Tumbling Hammer and Anvil. Off center rapper will bend the plate.

Solution:

Realign.

Misaligned Rapper Tumbling Hammer and Anvil

Problem:

Misaligned Plate Rapper Shaft contacting side of sleeve, dampening rapping.

Solution:

Realign to eliminate interference.

Misaligned Plate Rapper Shaft Contacting Side of Sleeve

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Problem:

Broken HT Rapper Connection from Isolating Insulator to Rapper Bar disabling HT rapping on this DE frame.

Solution:

Replace using, if possible, taper end insulator and tapered sockets.

HT Rapper Connection from Isolating Insulator to Rapper Bar

Problem:

Detached High Tension Rapper Anvil

Solution:

Weld and bolt anvil back in place.

Detached High Tension Rapper Anvil

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Problem:

Sonic Horns for Rapping Discharge Wires or RDEs and perforated distribution plate must be properly aimed.

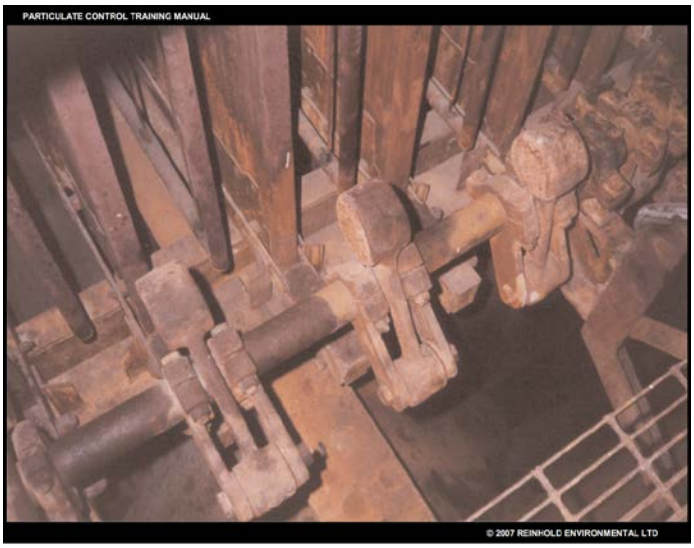
Solution:

Trial and error aiming and evaluation over time.

Sonic Horns for Rapping Discharge Wires or RDEs and Perforated Distribution Plate

Pictured:

Tumbling Hammer Rappers. Corrosion can cause sticking of hammers if not designed, manufactured or installed properly.



Tumbling Hammer Rappers

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CHAPTER 17 - TROUBLESHOOTING - DISCHARGE ELECTRODES

This chapter shows pictures of various problems relating to ESP Discharge Electrodes and suggested solutions.

Smooth Discharge Electrode Buildup Top to Bottom

Problem:

Smooth Discharge Electrode Buildup Top to Bottom. Very destructive to performance as it chokes off corona discharge.

Solution:

Check to insure that there are sufficient rappers and they are working properly. Increase rapper frequency and intensity.

Very Heavy Uniform Smooth Discharge Electrode Buildups

Problem:

Very Heavy Uniform Smooth Discharge Electrode Buildups

Solution:

Must be washed or sand/grain blasted. Check sufficiency of rapper design. Increase frequency and intensity.

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Problem:

Round Weighted Wires Functionally Clean at Left and with Some Buildups at Right.

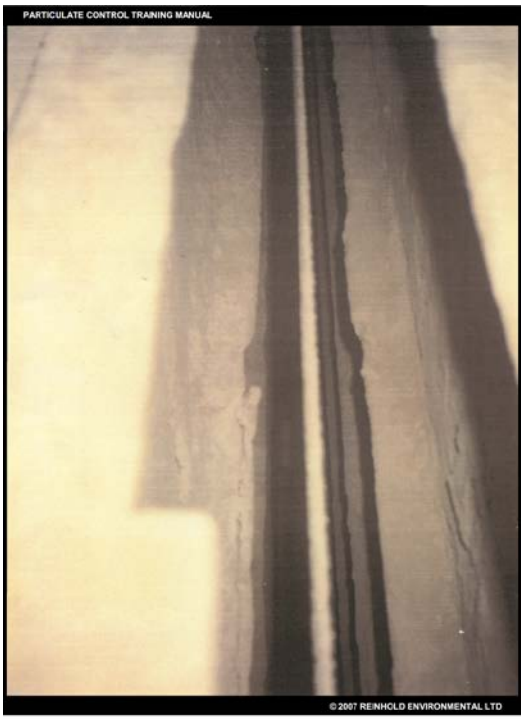
Solution:

Hand rap donuts off.

Round Weighted Wires Functionally Clean at Left and with Some Buildups at Right

Pictured:

Smooth Buildup on Round Wire



Smooth Buildup on Round Wire

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Problem:

Badly Fouled Round Wire Discharge Electrodes, rapper not functioning.

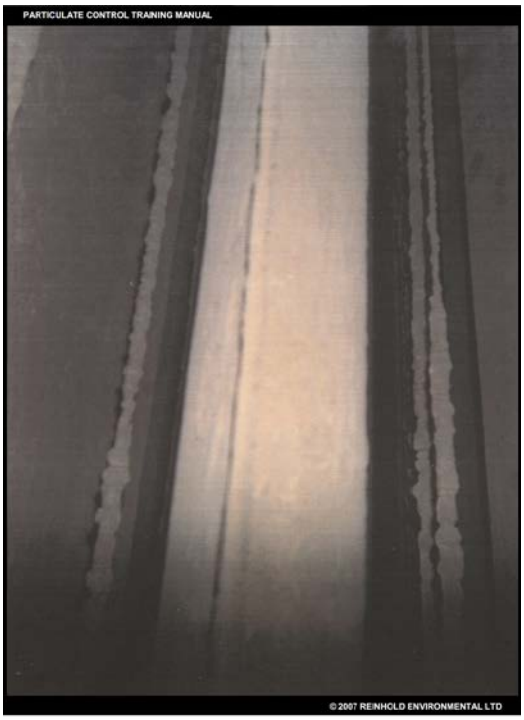
Solution:

Wash or sand/grain blast to clean and repair rapper.

Badly Fouled Round Wire Discharge Electrodes, Rapper Not Functioning

Pictured:

Heavy Buildup on Round Wire.



Heavy Buildup on Round Wire - 1

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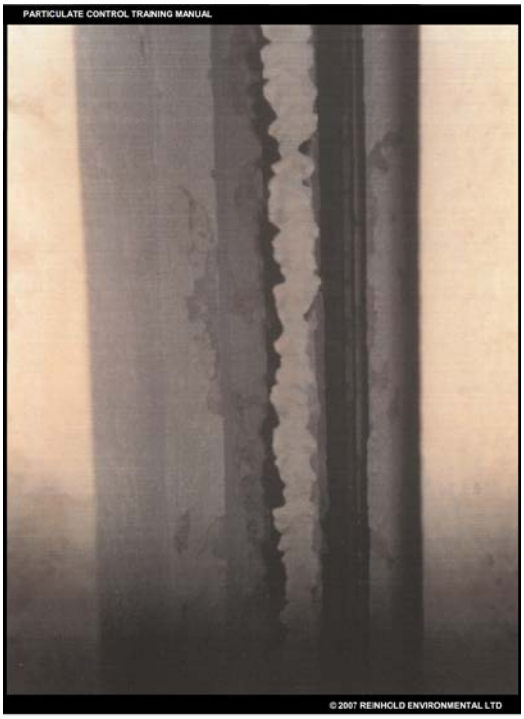
Pictured:

Heavy Buildup on Round Wire 2



Heavy Buildup on Round Wire - 2

Pictured:

Heavy Buildup on Round Wires 3

Heavy Buildup on Round Wires - 3

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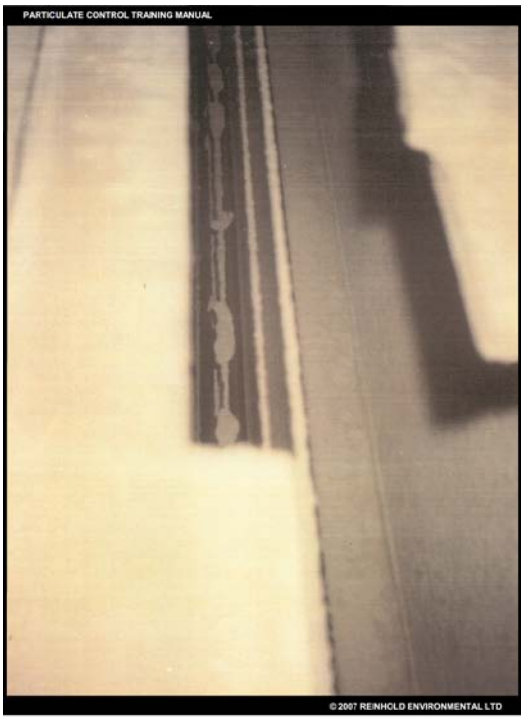
Problem:

Moderately Heavy Discharge Electrode Buildups on Round Wires in foreground and donuts in background.

Solution:

Hand rap or clean off donuts. Increase rapping frequency and intensity.



Moderately Heavy Discharge Electrode Buildups on Round Wires

Pictured:

Clean Pipe and Spike RDE Discharge Electrodes

Clean Pipe and Spike RDE Discharge Electrodes

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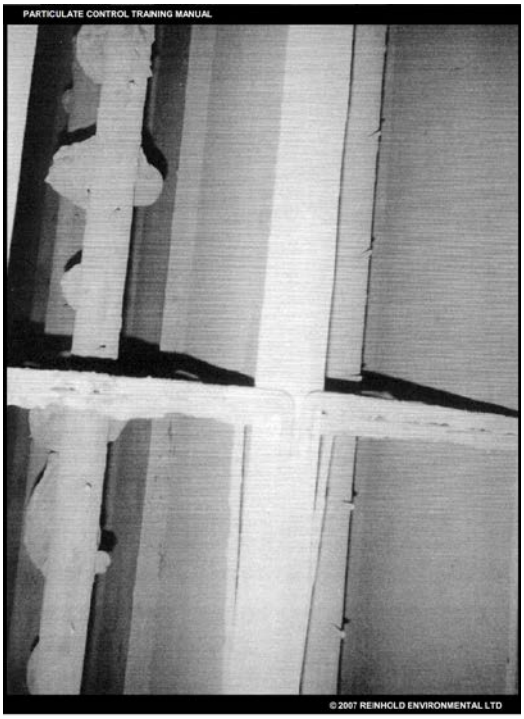
Pictured:

Dust Buildup on Pipe and Spike Discharge Electrode



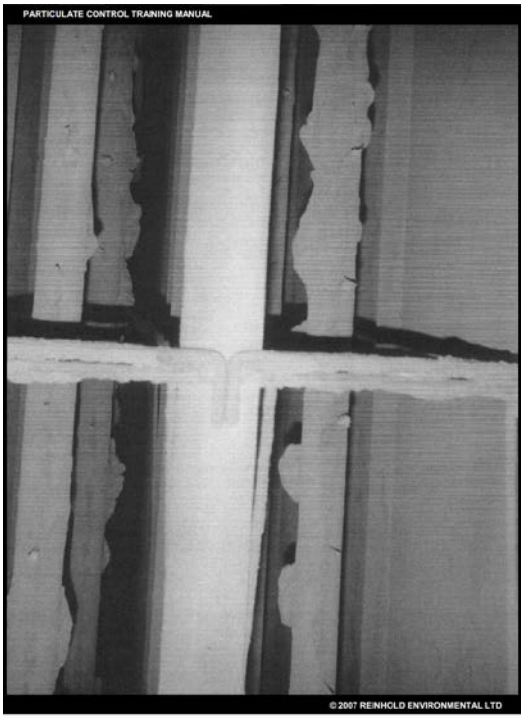
Dust Buildup on Pipe and Spike Discharge Electrode

Problem:

Pipe and Spike RDE Badly Fouled Due to Inoperable HT Rapper

Solution:

Fix rapper.



Pipe and Spike RDE Badly Fouled Due to Inoperable HT Rapper

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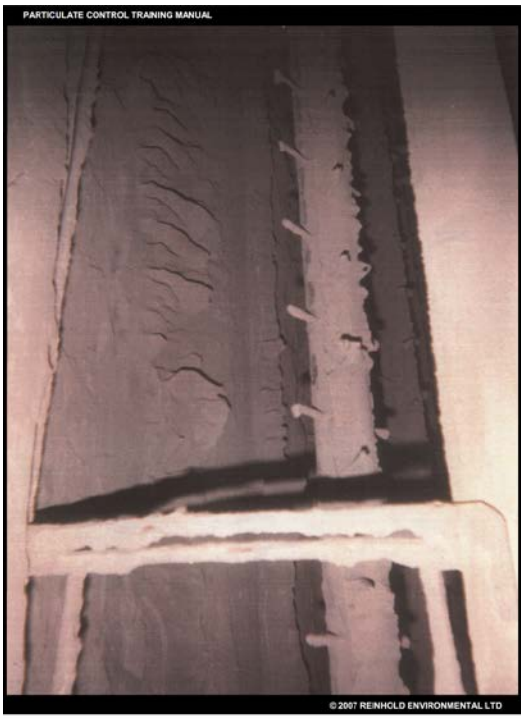
Pictured:

Dust Buildup on Pipe and Spike Discharge Electrode 2 (note spacer plate)



Dust Buildup on Pipe and Spike Discharge Electrode - 2

Problem:

Badly Fouled RDEs. Rapper Was Not Functioning.

Solution:

Hand clean and fix rapper.

Badly Fouled RDEs; Rapper Was Not Functioning

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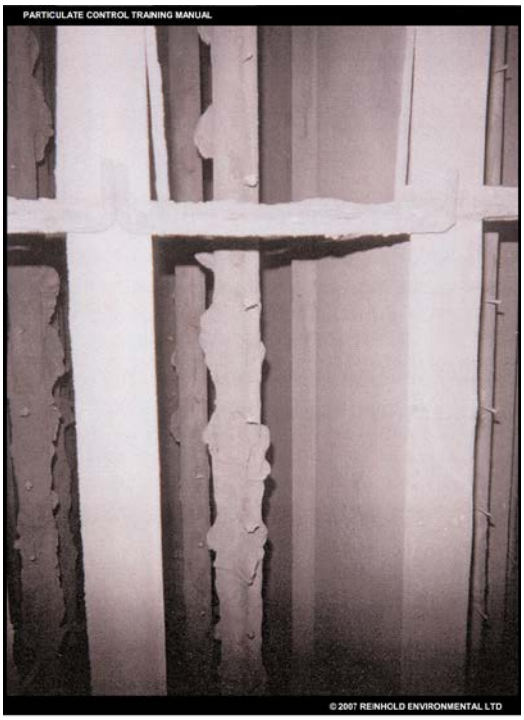
Problem:

Pipe and Spike RDEs Badly Fouled Due to Rapper Failure

Solution:

Restore rappers to service.



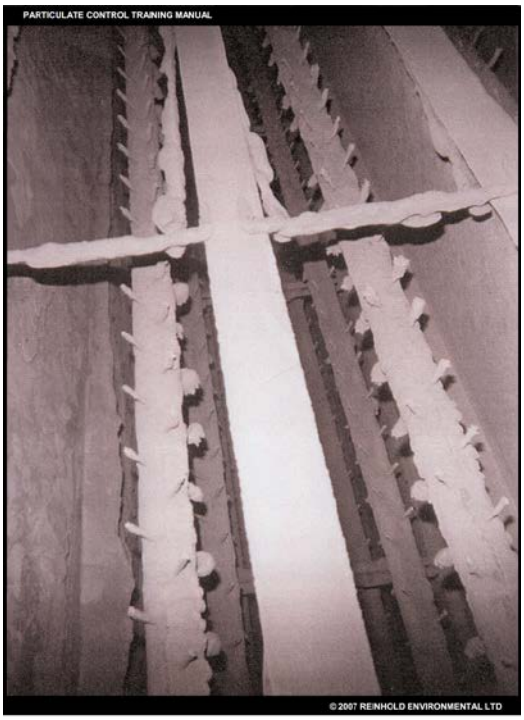
Pipe and Spike RDEs Badly Fouled Due to Rapper Failure

Problem:

Pipe and Spike RDEs Slightly Fouled

Solution:

Increase HT rapper frequency.



Pipe and Spike RDEs Slightly Fouled

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Problem:

Moderately Fouled Barbed Discharge Electrode with Bellied Plate

Solution:

Improve rapping. Straighten plate and make sure no compressive forces are applied to plate from differential expansion.

Moderately Fouled Barbed Discharge Electrode with Bellied Plate

Problem:

Badly Fouled Barbed Wire Discharge Electrode

Solution:

Substantially increase rapping frequency and intensity.

Badly Fouled Barbed Wire Discharge Electrode

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Pictured:

Functionally Clean Spiral Wires

Functionally Clean Spiral Wires

Pictured:

Discharge Electrode Tumbling Hammer Rapper Drive showing couplings and bearing on HT frame.

Discharge Electrode Tumbling Hammer Rapper Drive

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Pictured:

Double Wire Weights are Prone to Slack Wires and Close Clearances

Double Wire Weights are Prone to Slack Wires and Close Clearances

Problem:

Measuring device shows Discharge Electrode - Collecting Electrode Misalignment of 6" to one side and 3" to the other.

Solution:

Fix alignment.

Discharge Electrode - Collecting Electrode Misalignment

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Problem:

Bent Wires, Bent Collecting Plate and a Mixture of Barbed Wires and smooth wires in the same field.

Solution:

Remove wires, straighten plates and replace wires with all of the same kind.

Bent Wires, Bent Collecting Plate and a Mixture of Barbed Wires and Smooth Wires in the Same Field

Pictured:

Rigid frame Collecting Electrode with Collecting Electrodes Removed

Rigid Frame Collecting Electrode with Collecting Electrodes Removed

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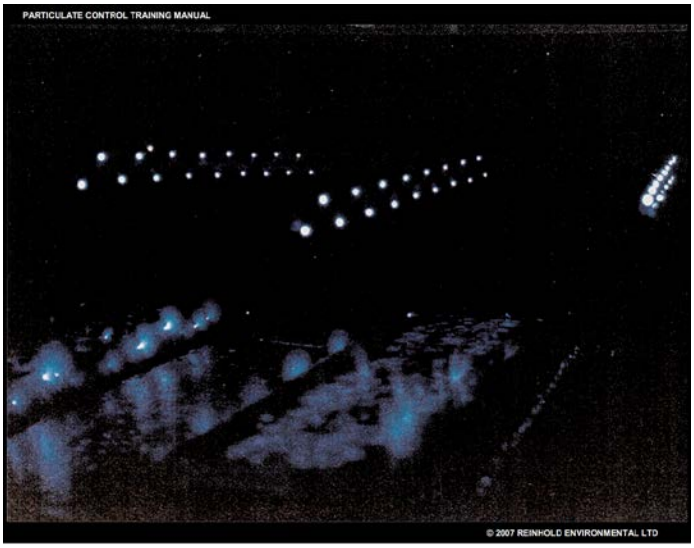
Pictured:

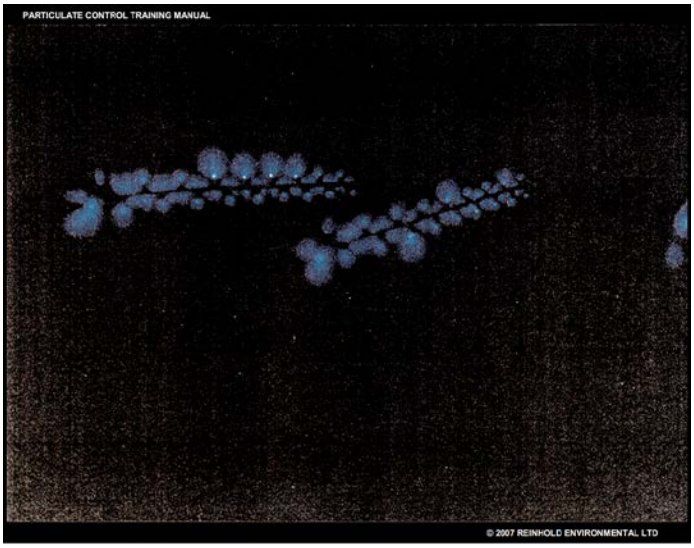
Back Corona, Note Glow on Plate



Back Corona (Note Glow on Plate)

Pictured:

Normal Corona from a Spiral Wire



Normal Corona from a Spiral Wire

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Pictured:

Builtup Dirty Discharge Electrodes and Dirty Collecting Plates

Builtup Dirty Discharge Electrodes and Dirty Collecting Plates

Problem:

Major Carbon Monoxide in Precipitator which burned for about six hours and Destroyed Plate and Discharge Electrode Support causing collapse of internals.

Solution:

Completely rebuild saving only support steel.

Major Carbon Monoxide in Precipitator which Destroyed Plate and Discharge Electrode Support

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ABBREVIATIONS

AEGI - Amine Enhanced Gas Injection

AGR - Advanced Gas Reburning

AH-SCR - Air Heater Selective Catalytic Reduction

BACT - Best Available Control Technology

BOOS - Burners Out of Service

Btu - British thermal unit

CAAA90 - Clean Air Act Amendments of 1990

$CaCO_3$ - Calcium Carbonate (limestone)

CaO - Calcium Oxide (lime)

Cascade - SNCR/SCR Hybrid

$CaSO_3$ - Calcium Sulfite

$CaSO_4$ - Calcium Sulfate

$CaSO_4 \bullet 2H_2O$ - Gypsum

CCOFA - Closed-Coupled Overfire Air

CEM - Continuous Emissions Monitor

CFD - Computational Fluid Dynamics

CKM - Chemical Kinetic Model

CO - Carbon Monoxide

CO_2 - Carbon Dioxide

$CO(NH)_2$ - Urea

CR - Coal Reburning

CTR - Combustion Controls

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DOE - Department of Energy

EPA - Environmental Protection Agency

EPRI - Electric Power Research Institute

ESP - Electrostatic Precipitator

FCC - Fixed Charge on Capital

FEGT - Furnace Exit Gas Temperature

FF - Fabric Filter

FGD - Flue gas Desulfurization

FLGR - Fuel Lean Gas Reburn

GR - Gas Reburn

H_2O - Water

H_2SO_3 - Sulfurous Acid

HSR - Hybrid Selective Reduction

IPPs - Independent Power Producers

kW - Kilowatt

kWh - Kilowatt hour

LAER - Lowest Achievable Emission Rate

L/G - Liquid to gas ratio

LNB - Low NOx Burners

LNCB - Low NOx Cell Burners

LNCFS - Low NOx Concentric Firing System

LOI - Loss of Ignition

MMBtu - Million Btu

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MWe - Megawatt of Electrical Generation (generator gross output)

N_2 - Nitrogen

NGR - Natural Gas Reburn

NH_3 - Ammonia

NO - Nitric Oxide

NOx - Nitrogen Oxides (NO + NO_2)

NOxOUT® - SNCR Technology designed by Fuel-Tech N.V.

NSPS - New Source Performance Standards

NSR - New Source Review

NUG - Non-Utility Generator

O&M - Operation & Maintenance

OEM - Original Equipment Manufacturer

OFA - Over Fire Air

OLF - Operating Costs Levelization Factor

PJFF - Pulse Jet Fabric Filter

ppm - Parts per million

PRB - Powder River Basin Coal

RACT - Reasonably Available Control Technology

RAFF - Reverse Air Fabric Filter

RDE - Rigid Discharge Electrode

RF - Rigid Frame

SCR - Selective Catalytic Reduction

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SNCR - Selective Non-Catalytic Reduction

SOFA - Separated Overfire Air

SO_2 - Sulfur Dioxide

SO_3 - Sulfur Trioxide

SOx - Sulfur Oxides

TiO_2 - Titanium Dioxide

V_2O_3 - Vanadium Pentoxide

WO_3 - Tungsten Trioxide

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GLOSSARY

Abrasion - Flex: Fabric weakness created by repeated fiber bending.

Abrasion Resistance: Ability of a fiber or fabric to withstand surface wear.

Abrasion - Surface: Fabric wear on the surface created by particulate erosion, rubbing or scuffing.

ACFM: Actual cubic feet of gas per minute. The volume of the gas flowing per minute at the operating temperature, pressure and composition. *Note - in the metric system, the corresponding value may be expressed in actual cubic meters per hour, ACM (H).

Acid Deposition: The process by which acidic particles, gases, and precipitation leave the atmosphere. More commonly referred to as acid rain, acid deposition has two components: wet and dry deposition.

Acid dew point: The temperature at which combustion gases are saturated with sulfuric acid.

Acid rain: The result of sulfur dioxide (SO_2) and nitrogen oxides (NOx) reacting in the atmosphere with water and returning to earth as rain, fog, or snow. Broadly used to include both wet and dry deposition.

Adsorb: To take up and hold (a gas, liquid, or dissolved substance) in a thin layer of molecules on the surface of a solid substance. **A/E:** Architect / Engineer

Air Heater: A heat exchanger, which transfers heat otherwise wasted from the flue gases to the incoming furnace air. It may be regenerative (Ljungstrom or Rothemuhle) or direct (tubular) air heaters may also be heated with fuel (direct fired) or steam.

Air, Standard: Dry air at 70°F and 29.92 in Hg pressure. Equivalent to 0.075 lb/ft3

Air-To-Cloth (A/C) Ratio: The ratio between ACFM, flowing through a filter, and the square feet of filter area available. This can also be thought of as the velocity of the gas passing through the filter area in feet per minute (FPM). The typical A/C ratios for various types of cleaning systems are:

- Cleaning System A/C Ratio*
- Shaker 2.5 - 3.0 to 1
- Reverse Air 2.0 - 2.5 to 1
- Pulse-Jet 5 - 6 to 1
- Plenum Pulse 3.5 - 4 to 1

* NOTE: The term usually used in the metric system is filtration velocity instead of air-to-cloth ratio, defined as the relation between the cubic meters per min of air flowing through a filter and the square meters of filter area available. The typical filtration velocities are:

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- Cleaning System Filtration Velocity
- Shaker 0.76 - 0.91 m3/m2/min
- Reverse Air 0.61 - 0.76 m3/m2 min
- Pulse-Jet 1.52 - 1.83 m3/m2/min
- Plenum Pulse 1.07 - 1.22 m3/m2/min

Alignment: Refers to how well optimum clearances are maintained between the high voltage discharge electrode system and the grounded collecting plate surfaces. Uniform corona current distribution, maximum use of installed plate area, highest possible operating voltages and best precipitator performance occur when proper discharge electrodes are everywhere centered within collecting plate gas passages or ducts. Reasonable maximum tolerances are considered +1/4 (± 6 mm) off center for discharge electrodes and +1/4" (± 6 mm) from flat for collecting plate surfaces. Clearance from corona source to vertical projecting plate baffles or edges should be a least 0.75 duct width. The sharper the edge or projection on the collecting surface anode, the greater the clearance to discharge corona. Good alignment depends upon good and reliable overall system mechanical integrity without thermal distortions. High voltage discharge elements and frame must be held plumb with respect to vertical collecting plate surfaces. Uneven foundation settling cannot be tolerated.

Allowance: A tradeable permit to emit a specific amount of a pollutant. For example, under the Acid Rain Program, one allowance permits the emissions of one ton of sulfur dioxide (SO_2).

Anemometer: A device for measuring small air velocities. See hot-wire anemometer and rotating vane anemometer.

Anode: Positive electrical terminal of high voltage power supply; this is the collecting plate surface, which is maintained at ground potential. Precipitator (ESP) sparking starts at the anode.

Anti-Sneak Baffles: A gas distribution device in which, internal baffle elements within the precipitator prevent the gas from bypassing the active field or causing hopper re-entrainment.

Anti-Sway Insulator: Ceramic insulators used to prevent the bottom guide frame for the discharge wire tensioning weights from swinging and causing periodic misalignment of discharge electrodes resulting in premature sparking, poor precipitator performance. Two types in common use with two-point, high-tension (HT) frame support design: (1) vertical shaft 36" long supported off hopper walls; (2) horizontally mounted ceramic, positioning bars between bottom guide frame and precipitator outer steel shell. In some cases, teflon is used instead of ceramics.

AR: Aspect ratio; ratio of ESP total collecting plate length to plate height.

Arc: A relatively long, large discharge of high voltage, which is not immediately self-extinguishing.

Aspect Ratio: The length of a precipitator divided by its height. The aspect ratio normally ranges from approximately 0.5 to 1.5 and affects the amount rapping re-entrainment contributes to the

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outlet burden.

ASTM: American Society for Testing Material

Automatic Power Supply Control: The automatic regulation of high voltage power for changes in precipitator operating conditions using feedback signal(s).

Auxiliary Control Equipment: The electrical components required to protect, monitor and control the operation of precipitator rappers, heaters and other associated equipment.

AVC: Automatic Voltage Control is an electrical or electro mechanical system to regulate the precipitator voltage requirements because of changes in operating conditions.

Back Corona: A localized corona discharge, which occurs when the gas within a high resistivity dust on the collecting surface breaks down and becomes ionized. Back corona starts at a critical bulk dust resistivity, e.g. = 1.0E+10 ohm cm. In the incipient early stages it causes ESP sparking at reduced voltages and current densities; severe back corona (5.0E+11 - 5.0E+12 ohm) causes heavy positive ion back current, greatly reduces particle charge and destroys ESP ,bprocess.

BACT: Best Available Control Technology

Baffle: A device, usually consisting of a plate or series of plates, which evenly distributes airflow and dust within a dust collector to protect filter bags from direct abrasion by dust.

Baghouse: An air filtration structure utilizing filter fabrics for the purpose of removing solid particulate from direct abrasion by dust.

Balanced draft: The condition where the absolute pressure in the boiler furnace is exactly equal to the absolute atmospheric pressure outside the furnace or is slightly negative.

Batch cleaned: Usually refers to that process used in heat-cleaning glass cloth in roll form by exposing it to 500°F - 600°F temperatures for prolonged periods to burn off the starches.

BDAT: Best Demonstrated Available or Achievable Technology

Bleedthrough: Particulate migration through the interstices of a woven filter bag fabric or through the needled fibers of a felt bag.

Blinding: Fabric blockage by dust, fume or liquid not being discharged by the cleaning mechanism, resulting in reduced gas flow or increased pressure drop across the media.

Blowpipe: Pipe connected to the pneumatic pulsing system with holes to distribute cleaning air to bag rows in pulse-jet units.

Bridging: The blockage of a hopper by the formation of an arch or "bridge" of compacted dust

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over the hopper exit.

Bulked yarn: Filament yarn that has been processed by high-pressure air passing through the yarn and relaxing it into gentle loops, bends, etc.

Bursting Strength: General: A material's ability to resist rupture by pressure. Specific: Force required to rupture a fabric by distending it with the force applied at right angles to the fabric plane under specified conditions. Usually expressed in pounds per square inch. (kg/cm2)

Bus: A conductor enclosed within a grounded duct.

Bus Section: The smallest size high voltage assembly of discharge electrodes and minimum collecting plate area that can be independently energized by one electrical set; or one electrical output.

Cake: The dust formation developed on the surface of the filter medium during the filtration process.

Calendaring: High pressure pressing of the fabric; pushes the surface fibers down onto the body of the filter medium.

Can Velocity: In a dust collector with the filter elements suspended from the tubesheet, can velocity is the upward air stream speed passing between the filters calculated at the horizontal cross-sectional plane of the collector housing at the bottom of the filters. Example:

- Air volume: 18,850 ACFM (8.9 m3/hr)
- Total cross-sectional area of collector: 15 ft x 8 ft = 120 ft2 (4.57 m x 2.43 m = 11 m2)
- Total area of filter bottoms: 20 x 12 = 240 filters; 28.27 in2/filter (0.018 m2/filter) = 47 ft2 total (4.37 m2 total)
- Open area between filters: 120 ft2 (11.2 m2) - 47 ft2 (4.37 m2) = 73 ft2 (6.64 m2)
- Can velocity: 18,850 ACFM ÷ 73 ft2 (6.78 m2) = 258 FPM (1.31 m/sec)

Cathode: This is the negative polarity, high voltage DISCHARGE ELECTRODE of a precipitator. It is the cathode that suffers metal erosion due to ESP repetitive sparkover - a common cause of localized wire thinning, draw-out due to weight tension, and ultimate breakage with sharp points.

Cell: A separate section of a precipitator which is energized by one TR set and which is located transverse to the gas flow. (a 4-cell precipitator would contain 4 parallel

electrically separated high voltage systems in each field) **Cell (in width):** A cell is an arrangement of a bus sections parallel to gas flow. Note: Number of cells wide times number of fields deep equals the total number of bus sections.

Cell Plate (Tubesheet): A steel plate to which the open end of the filter bags are connected.

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Separates the clear air and dirty air plenums of the baghouse.

CFM (Cubic Feet Per Minute): The cubic feet of air being moved through the system per minute. Must be expressed as actual (ACFM) Standard (SCFM) wet or dry (SCFM W or SCFM D)

Chamber: A gas-tight longitudinal subdivision of a precipitator. A precipitator with a single gas-tight dividing wall is referred to as a two-chamber precipitator. Note: very wide precipitator chambers are frequently equipped with non-gas-tight load bearing walls for structural considerations. These precipitators are by definition single chamber precipitators.

Chamber: A parallel sub-division of a large precipitator, which is sealed off from other chambers by a solid steel wall. Each chamber contains its own set of individual sections comprising CELLS and FIELDS.

Char: The carbonaceous material in dust - usually incompletely burned fuel which has larger particles than the rest of the dust.

Chemical Conditioner: A chemical used to lower the resistivity of dust to reduce or eliminate back-ionization.

Clean Air Plenum: The baghouse area through which clean filtered gases are directed after filtration, located on the clean side of the bags above the tubesheet.

Cloth: In general, a pliant fabric that is woven, knitted, felted or therwise formed from any textile fiber, wire, or other suitable material.

Cloth weight: usually expressed in oz/yd2 or oz/ft2. However, cotton sateen is often specified at a certain number of linear yd/lb of a designated width.

Coating: Immersing the filter medium in a solution to provide the fibers with a coating that will lubricate and thereby reduce self-abrasion; in the case of woven-glass bags, the most common coatings have been Teflon and silcone graphite

Cold side ESP: An ESP, which is installed downstream of the air heaters.

Cold spot: A point where a continuous metallic heat transfer circuit through the insulation creates an uninsulated area, resulting in an area that is colder than the surrounding area.

Collecting Surface: Describes the reinforced sheet metal, usually 20, 18 or 16 ga (0.90, 1.25 or 1.65 mm), collector plate or plates that form the gas passages of precipitator parallel ducts. The electrically charged dust particles are deposited or collected on said surfaces by means of powerful electric forces applied directly to the particles, per se.

Collection Efficiency: A measure of dust collector's ability to remove particulate from the inlet gas expressed in percent. % Efficiency = (Dust in - Dust out)/Dust in x100.

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Collection Electrode (CE): The electrode (usually grounded) on which the particulate is deposited in an electrostatic precipitator. Also called collecting plate.

Collection Surfaces: The individual elements, which make up the collecting system and provide the total surface area of the precipitator for the deposition of dust particles.

Collection Surface Area: The total flat projected area of collecting surface exposed to the active electrical field (effective length) x (effective height) x (2) x (number of gas passages).

Collection Surface Rapper: A device, which imparts vibration or shock to the collecting surface to dislodge the deposited particles.

Compressed Air: Pressurized air generated by a compressor used to clean filter bags in a pulse-jet baghouse. Measured in psi (pounds per square inch). (Kg/cm2)

Concentration: Amount of dust in the gas. Usually expressed in terms of grains/ft3, lb/1000 lb of gas, ppm, mg/m3, or lb/million Btu.

Conductivity: The reciprocal of resistivity - the units are Mho-meters (Mho = Ohm, spelled backwards).

Conical Hopper: A hopper shaped like an inverted cone.

Control Damper: A device installed in a duct to regulate the gas flow by degree of closure. Examples: Butterfly or Multi-Louver.

Control Equipment: High voltage power supply control equipment generally consists of: electrical components required to protect, monitor and regulate the power supplied to the precipitator high voltage system.

Control Unit: Usually in an air conditioned room containing modern solid-state thyristor components for silicon-controlled-rectifier (SCR) electric power controls, microprocessor-mini computer type automatic voltage controls, instrumentation, protective devices, fault indicators, programmable inputs, various input and output signals capabilities, manual control switch, main line 1 or 3 ph, 50 Hz or 60 Hz circuit breakers, etc.

Corona: A gaseous discharge found near an ESP discharge electrode resulting in a faint glow caused by ionization of gas molecules due to the electric field.

Corona Power (KW): The product of secondary current and secondary voltage. Power density or specific power is generally expressed in terms of: 1) Watts DC per square foot (square meter) of collecting surface. Or 2) Watts DC per 1000 ACFM or watts per 1000 AMCH of gas flow.

Coronizing: A heat cleaning process for fiberglass fabric to burn off the starches (used in

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processing) usually at temperatures of 1000°F (537.7°C) for a short duration before the finish is applied. Same as scouring.

Crimp: Waves contained in a yarn.

Curing: In finishing fabrics, the process by which resins or plastics are set in or on textile materials, usually by heating.

Current Density or Specific Current: The amount of secondary current per unit of ESP collecting surface.

Denier: A weight-per-unit-length measure of any linear material. The size of yarns used in woven fabrics including scrims is defined or designated by denier.

Dew point: The temperature of a gas at which condensation occurs. May be water dew point or acid dew point.

Diaphragm Valve: A compressed air valve operated by a pilot solenoid valve used to clean the filters in pulsejet or plenum pulse collectors.

Differential Pressure (ΔP): The change in pressure or the pressure drop across a component or device located within the airstream; the difference between static pressures measured at the inlet and outlet of a component, compartment or device (i.e., between the dirty and clean sides of filter bags and tubesheet).

Dimensional stability: Ability of the fabric to retain its size in hot or moist atmosphere.

Discharge Electrode (DE): The part, which is installed in the high voltage system to perform the function of ionizing the gas and creating the electric field. Typical configurations are: rigid frame, weighted wire, rigid discharge electrode.

Discharge Electrode Rapper: The device for imparting vibration or shock to the discharge electrodes in order to dislodge dust accumulation.

Drag: Normalized value for pressure drop wherein pressure drop is normalized by dividing by the gas velocity. This property allows comparison of one dust/filter medium to another on a common basis and at various parts of the filtration cycle.

Duct: A gas passage or space between two parallel collecting plate surfaces. Duct widths now typically vary from 9 to about 16 inches (229-400 mm). An electrostatic precipitator forms an electrical capacitor between the DE assemblies and the grounded collecting plates on each side thereof in each duct. Effective capacitance of typical ESP is Cp ≅ 30 - 40 picofarad/m2 plate area (9-10" ducts, wire DE).

Dustcake: Dust layer on filtration surface. A certain amount of porous dustcake is necessary for

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filtration purposes unless the fabric is a surface filtration type (BHA-TEX or spun bonded fabric).

Dust (or Mist) Concentration: The weight of dust or mist contained in a unit of gas, e.g., pounds per thousand pounds of gas, grains per actual cubic foot of gas, or grains per standard dry cubic foot (the temperature and pressure of the gas must be specified if given as volume). Metric equivalents are grams or milligrams/Kg of gas or milligrams/m3 of gas.

Dust Loading: The amount of solid particulate suspended in an air (gas) stream, usually expressed in terms of grains per cubic foot, grams per cubic meter or pounds per thousand pounds of gas.

Effective Cross-Sectional Area: Effective width times effective height.

Effective Height: The total height of collecting surface measured top to bottom.

Effective Length: The total length of collecting surface measured direction of gas flow.

Effective Migration Velocity: This parameter, defined by the Deutsch-Anderson relationship, is related to the average speed with which dust particles in an electrostatic precipitator move towards the collecting electrode. Values are generally stated in terms of ft/min. or cm/sec.

Effective Width: Total number of gas passages multiplied by spacing dimension of the collecting surfaces.

Electrical Set: May refer to the complete high voltage power supply energizing a precipitator section, or to the TRANSFORMER-RECTIFIER SET, per se, which is a major part of said power supply. The other principal parts of the complete ESP power supply include the special LINEAR REACTOR connected in series with the transformer primary circuit, and the CONTROL UNIT.

End: same as warp thread

End count: Same as warp count

EPA: Environmental protection Agency.

ESP: Abbreviation short form of ELECTROSTATIC PRECIPITATOR or ELECTRO FILTER.

Evaporative Gas Cooling: Water is sprayed into a hot gas stream. Energy is absorbed by the water as it is transformed from a liquid to gas, thus reducing the temperature of the gas stream. This technology is used to condition a gas stream to optimize the efficiency and reliability of air pollution control equipment. Also called adiabatic gas cooling.

Extensibility: Stretching characteristics of fabric under specified conditions.

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Fabric: A collective term applied to cloth no matter how constructed and regardless of the kind of fiber used. In the commonest sense, it refers to a woven cloth.

Fan: A device for moving air and dust through the system. If the fan is on the dusty side of the collector pushing the dust-laden air through the collector, it is called a positive system. If the fan is on the clean airside of the collector pulling the air through the collector, it is called a negative system. (Most collectors are negative systems)

Felt (Needled): A fabric produced by using barbed needles to interlock carded fibers.

Felted bag: Type of bag frequently used on pulse-jet dust collectors. Features a thick mat of fibers supported by a woven backing or scrim.

Fiber: A slender, elongated structure of synthetic material. A group of fibers that form a single substance, such as flax.

Field (In depth): An arrangement of bus sections perpendicular to gas flow energized by one or more high voltage power supplies.

Fill: crosswise threads woven by loom. Yarn running from selvage to selvage at right angles to the warps in woven fabrics.

Fill count: Number of fill threads per inch of cloth.

Fill Yarn: An individual yarn, which interlaces with the warp yarn at right angles in a woven fabric. Also known as a pick or filling pick. These run around the circumference of the bag.

Filter cake: the accumulation of dust on a bag. Often assists in the filtration process.

Filter Drag: The ratio of differential pressure across the filters (differential pressure, inches or mm W.C. to velocity through the filters (air-to-cloth ratio, MPM meter/minute)

Filter Media: The permeable barrier employed in the filtration process; the fabric on which the filter cake is supported.

Filtration: A process by which particles are separated from a fluid stream by use of a permeable barrier.

Flange-to-flange: The APC equipment from inlet flange to outlet flange.

Float: The position of a yarn that passes over two or more yarns passing in the opposite direction.

Fly ash: Dust from a furnace; the term distinguishes the ash that is entrained in the gas from bottom ash which drops to a grate or pan at the bottom of the furnace.

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Gas Distribution Devices: Internal elements in the transition or ductwork to produce the desired velocity contour at the inlet and outlet face of the precipitator. (See Gas Distribution)

Gas Distribution Plate Rapper: A rapper used to prevent dust buildup on gas distribution devices.

Gas Passage: A duct formed by two adjacent rows of collecting surfaces.

Gas sneakage: Bypassing of dust laden gas around ESP electrified regions, such as through hoppers and above the collecting plates.

Gas-to-cloth ratio: Gas volumetric flow rate/cloth area...the amount of process gas entering the fabric filter dust collector divided by the amount of cloth area filtering the dust from the air. Normally the gas flow is given in CFM and the cloth in square feet.

Glazing: High-pressure pressing of the filter medium at elevated temperatures; fuses surface fibers to the body of the filter medium.

Grab tensile: The tensile strength, in lb/in, of a textile sample cut 4 in. by 6 in. and pulled in two lengthwise by two 1 in. sq. clamp jaws set 3 in. apart and pulled at a constant specified speed.

Grain: A dust weight unit commonly used in air pollution control equal to 1/7000 lb.

Grain Loading: The amount of particulate by weight in a given volume of air (Grains/ft3); 1 lb (0.454 Kg) = 7000 grains.

Greige (Grey, Greige, Gray):s: Cloth, regardless of color, that has been woven in a loom, but has received no dry or wet finishing operations. Unfinished woven fabric.

Header: A pressurized pipe that contains the compressed air supply for a pulse type baghouse.

Heat Set Finish: Heat finishing treatment that will stabilize many man-made fibers so that there will be minimal change in shape or size.

High Voltage Bus: A conductor enclosed within a grounded duct.

High Voltage Conductor: A conductor, which carries the high voltage from the transformer-rectifier to the precipitator high voltage system.

High Voltage Power Supply: The supply unit, which produces the high voltage required for precipitation, consisting of a transformer-rectifier and controls.

High Voltage System: All parts of the precipitator, which are maintained at a high electrical potential.

High Voltage System Support Insulator: A device, which physically supports and electrically isolates

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the high voltage system from the grounded structure.

Hopper: The vessel at the bottom of a precipitator where dust falls as it is rapped from the electrodes.

Hopper Capacity: The total capacity of a hopper measured from a point some distance below the high voltage system or plates, whichever is lower.

Hot side ESP: An ESP, which is installed upstream of the air heater.

Hot-Wire Anemometer: A device that measures gas flow by its cooling effect on a heated element. Air velocities of centimeters per second can be measured by this method.

Hydrophilic fibers: Fibers that do not readily absorb water.

Impedance Device: A linear inductor or current-limiting reactor required to work with SCR-type controllers. A transformer with a specially designed high impedance core and coils. Saturable core reactor. Resistors.

Impingement: the physical contact of dust laden gas flow against a filter media. Typically referring to an abrasive wear caused by this impact.

Inch of Water: A unit of pressure equal to the pressure exerted by a column of liquid water one inch high at standard conditions(70°F or 21°C @ sea level); 27.7 inches of water (703 mm w.c.) = 1 psi (69 mbar); usually expressed as inches water gauge (w.g.) or inches water column (w.c.)

Inlet dust loading: A measure of the particulate matter entering an ESP expressed in grains of particulate matter per actual cubic foot of flue gas.

Inside Collection: Particles are collected on the inside surface of the bag (most reverse air and most shaker baghouses).

In-situ resistivity: Particle resistivity as determined by a probe inserted into the flue gas stream.

Insulator Compartment: An enclosure for the insulator(s) which supports the high voltage system (may contain one or more insulators).

Interfacing: Openings between the interlacings of the warp and filling yarns in a fabric.

Interstices: The opening between the interlacings of the warp and filling yarns, i.e. the voids in the fabric through which air/gas passes.

Isokinetic Sampling: A sampling of the flue gases drawn from the mainstream of the gas into the sampling apparatus with no change of velocity.

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Linear Reactor: A vital element for assuring reliable, stable electric energization at optimum current densities and highest ESP performance capability. It is an iron-core, convection-cooled inductance whose value is chosen according to rated power supply DC current output. The reactor has several important functions:

1) Essential series circuit impedance in the primary of the HV transformer acting as a ballast for stability with sparking load and limiting peak power supply current flow during ESP sparking to safe values.

2) ESP current waveform control adjustment capability to match power supply ratings to load demands for the best ESP performance and to prevent premature sparking.

3) Proper inductance values for TR Set ESP current conduction times ≅ 70-86% maximum time between current pulses of 8.333 milliseconds (FW energization) provides for fast voltage and current recovery following a spark.

4) Slow down otherwise very steep rate of rise of currents when main SCRs are turned on and off 120 times a second, and protect silicon diodes in HV rectifier from damage by securing a nearly half sine wave shape for the ESP current pulses.

It is not the installed TR Set capacity that does the job; it is only the actual voltages and currents drawn under optimum conditions of electrode geometry, electrode alignment, and TR Set match to load that counts. In cases where high power TR Sets are running at only 10-50% of rated current capacity that major gains in useful electrical energy and ESP performance can often be realized by using an appropriately larger size reactor inductance to match a revised TR Set rating more closely to the ESP current needs at hand. The larger inductance is chosen to increase the ESP current conduction time to the optimum range ≅ 70-86% instead of the original short conduction time of perhaps 25-55%. The broader current pulses result in significant increases in average DC precipitator currents and voltages, reduce premature sparking due to narrow current pulses and peaky voltage waveforms which limit useful current unnecessarily. Achieving the best possible electrical energization quality pays off handsomely in high ESP performance. In cases where proper operating currents are unknown, or to accommodate possible shifts in coal quality, etc., from time to time, it is convenient to use tapped linear reactors to cover a range from say one-half to full load in three taps.

Loom finish: Same as greige cloth.

Magnehelic Gauge: An instrument used to measure the differential pressure drop between two points in a system.

Manometer: A U-shaped tube filled with a specific liquid. The difference in height between the liquid in each leg of the tube is the differential pressure between the two points being monitored. Used to monitor differential pressure.

Manual Power Supply Control: The manual regulation of high voltage power based on precipitator

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operating conditions observed by plant operators.

Micron: A unit of length, 1/25,000 of an inch (1/1000 of one millimeter) here used as a measurement of the largest diameter of a particle; 74 microns are equal to a 200 mesh opening.

Migration Velocity: A parameter in the Deutsch-Anderson equation used to determine the required size of an electrostatic precipitator to meet specified design conditions. Values are generally stated in terms of ft/min or cm/sec. See also "effective migration velocity".

Mit Flex Endurance Test: A test whereby a filter media specimen is rapidly flexed in an arc under a specified load until fabric rupture occurs. Test conditions are usually: 270°arc, 180 cycles/minute, 4 lb load, ½ inch width specimen.

Modacrylic: A synthetic polymerized fiber that contains less than 85% acrylonitrile.

Mullen Burst Test: Evaluation of the rupture strength of paper or cloth using a hydraulic diaphragm. Expressed as the pressure per square inch that will burst a two inch diameter test specimen.

Multifilament: Yarn composed of several filaments, which are continuous strands of fiber of indefinite length.

NAAQS: National Ambient Air Quality Standards (USA Clean Air Act)

Napping: A scraping of the filter-medium surface that raises the surface fibers. The rupturing of the filling yarns to produce a fleecy surface on woven fabrics.

Needled felt: A felt constructed by the use of barbed needles moving up and down, pushing and pulling the fibers to form an interlocking of adjacent fibers.

Negative Pressure Baghouse: A system where fan is located after the baghouse on the clean air side, pulling air through the system.

Nonwoven felt: felt made either by needling, by matting of fibers, or by compressing with a bonding agent for permanency.

NSPS: New Source Performance Standards.

Null Period: The period during the cleaning sequence in which neither cleaning nor on-line filtering is occurring, causing a static environment to allow dust to drop into hopper or discharge area.

Opacity: The visual density of stack emissions, usually expressed in percent.

OSHA: Occupational Safety and Health Act. (USA)

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Outside Collection: Systems that are designed to collect dust on the outside of the filter. (Pulse-jet/plenum pulse baghouses and some reverse air and shaker baghouses.)

Particle resistivity: The electrical resistance (inverse of conductivity) of fly ash particles expressed in units of ohm-cm.

Particle size: The diameter in μm (micrometers) of a particular piece of particulate matter.

Particulate matter: Solid or liquid particles entrained in a gas stream.

Penthouse: An enclosure over the precipitator, which contains the high voltage insulators.

Permeability: A measure of fabric porosity or openness, expressed in cubic feet of air per minute per square foot of fabric at a 0.5 in. w.c. (13 mm w.c.) pressure differential.

pH: A value indicating the acidity or alkalinity of a material. A pH of 7.0 is neutral; less than 7.0 is acidic; and more than 7.0 is alkaline or basic.

Photohelic Gauge: An instrument used to measure differential pressure that has adjustable set points for starting and stopping the filter cleaning in order to maintain the desired range of operating differential pressure.

Plain weave: A weave in which each warp yarn passes alternately over each filling yarn.

Pitot Tube: A common instrument used for velocity determination in ducts leading to and from air pollution control devices.

Plenum: An enclosure typically fabricated of stiffened sheet metal; casing; housing (See clean air plenum).

Ply: Two or more yarns joined together by twisting

PM: Particulate Matter

Poppet Valve: A valve utilized to isolate compartments and/or allow for reverse airflow through individual compartments. Typically constructed of a flat wafer plate assembled on the end of the shaft of an air cylinder, which drives the wafer (poppet) into position against a seat or ring, which causes the seal.

Porosity: Sometimes erroneously used as a synonym for permeability. Originally a designation for the amount of air in a fabric, i.e. blankets.

Positive Pressure System: A system with a fan located prior to the collector on the dirty side, pushing air through the system.

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PPB/PPM: Parts Per Billion/Parts Per Million

Precipitator Current: The rectified or unidirectional average current to the precipitator.

Precipitator Gas Velocity: A figure obtained by dividing the volume rate of gas flow through the precipitator by the effective cross-sectional area of the precipitator. Gas velocity is generally expressed in terms of ft./sec. And is computed as follows:

Velocity = Gas volume (ACFM) divided by Effective cross-section area (ft2) or actual meters cubed divided by sq. meters (Effective cross-section is construed to be the effective field height x width of gas passage x number of passages.)

Precoat: Material added to the air stream on initial process startup to aid in establishing an initial dustcake on the filter bags.

Pressed felt: A type of felt manufactured by pressing fibers into a scrim.

Pressure Drop: A measure of the resistance the gas stream encounters as it flows through a collection system. May refer to pressure differential across the tubesheet, across the entire collector or the pressure drop across the entire system. Commonly referred to as Delta P (ΔP); see differential pressure.

Primary Current: The current in the transformer primary.

Primary Voltage: The voltage across the primary of the transformer.

PSD: Prevention of Significant Deterioration (USA Clean Air Act)

PSI: Pounds per square inch; a unit of pressure; 1 psi equals 27.7 in. (70.35 cm) water gauge or 2.04 in. (5.18 cm) mercury (Hg).

Pulse Cycle: On a pulse-jet baghouse, the interval of time between one pulsing of a row of bags and the next pulsing of the same row.

Pulse Duration (On-time): The length of time a pulse lasts, generally described as the length of time the electrical signal holds the solenoid pilot valve open. However, due to mechanical losses, the time the diaphragm is open will vary.

Pulse Interval (Off-time): Elapsed time between pulses in a pulse-jet collector.

Pulse Jet: Generic name given to all pulsing collectors.

Pyramid Hopper: A hopper shaped like an inverted pyramid.

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Radiant Cooling: A method of reducing exhaust gas stream temperature, which involves the use of long uninsulated ducts that allow the gas stream to cool as heat radiates from the duct walls.

Rapper Insulator: A device to electrically isolate discharge electrode rappers yet mechanically transmit forces necessary to create vibration or shock in the high voltage system.

Rappers (Both CE and DE): May be vibrator or impact (shock) type, the latter preferred. Function is to remove collected dust from collecting plate electrodes and from discharge electrodes. Individual electric type, single impact rappers. The function is to accelerate the metal electrodes away from the deposited material.

Rapping Intensity: Acceleration in multiples of acceleration due to gravity measured at various points on collecting or discharge electrodes. Measured forces should be specified as longitudinal or transverse.

Rapping Re-entrainment: Dust, which has been rapped from the electrodes and is carried back into the gas stream. This process can substantially lower the collecting efficiency of a precipitator.

Re-entrainment: The phenomenon whereby dust, which has been removed from a filter is returned to the air stream. It occurs when dust is cleaned from a filter and then caught again by an upward moving air stream, which re-deposits it on a filter.

Resistance: In airflow, caused by friction of the air against any surface or by changing the momentum of the gas.

Resistivity: The electrical resistance that a meter cube of a substance (usually of packed dust) has when measured between opposite faces of the cube. The units are ohm-meters (or ohm-centimeters - a resistivity of 1 cm is equivalent to a resistivity of 100).

Reverse-air Baghouse: A unit employing reverse flow flushing air to clean the dust from the bags.

Rings: metal bands sewn in the bag at various intervals to prevent bag from total collapse while cleaning.

Rotary Airlock Valve: A material handling valve that transfers material in pockets formed by vanes mounted on a turning shaft similar to a paddle wheel. This star wheel shaped shaft rotates in close fitting housing that provides a dust-tight seal while still transferring material through the valve.

Rotating Vane Anemometer: A windmill-like device, small enough to be held in the hand, for measuring air speed and direction.

Safety Ground Device: A device for physically grounding the high voltage system prior to personnel entering the precipitator. The most common type consists of a conductor, one end of which is grounded to the casing, the other end attached to the high voltage system using an

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insulated operating lever or handle.

Saturable rectifier: A variable impedance device to regulate the current at the transformer primary.

SCA: Specific collecting area, given by the square feet of collecting area per 1000 acfm of flue gas.

SCFM: Standard cubic feet per minute. The volume of dry gas flow per minute at standard temperature and pressure conditions (70°F or 21°C @ sea level). Other standards such as 32°F and 29.92 inches of mercury (chemical engineers) and 60°F, 30 inches of mercury saturated (American Gas Assn.) may be used. Always specify which standard.

Scouring (ESP): The process in which collected dust is removed from the collecting electrodes by the gas flow. Usually associated with a region of high velocity.

Scouring (FF): Process of removing the starches and lubricants, which were applied to fabric to protect it during weaving. Fabrics that have been scoured are generally softer and better withstand clean action. Same as coronizing.

SCR: Silicon controlled rectifier.

Scrim: An open mesh, plain-weave cloth used as the base in some felted fabrics.

Secondary Current: The current in the transformer/rectifier secondary is the main energy source.

Secondary Voltage: The voltage as indicated by AC voltmeter across the secondary of the transformer.

Seeding: The application of a relatively coarse, dry dust to a bag before startup to provide an initial filter cake for immediate high efficiency and to protect bags from blinding. Also called precoating.

Selvage: The binding on the lengthwise edge of a woven fabric.

Shaker baghouse: A unit wherein cleaning is accomplished by shaking the bags.

Silicon Controlled Rectifier (SCR): A semi-conductor, electronic switch for voltage regulation; two are used in an inverse parallel arrangement for each half cycle, positive and negative. Also called thyristor.

Silicone finish: A treatment with silicone to provide a slick finish for improved dust release.

Sine Wave: A waveform consisting of a positive and negative half cycle, each one lasting 8.33 milliseconds. Based on U.S. power generation at a 60 hertz cycle or European at 50 hertz.

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Singeing (Singed Finish): The process of burning off or melting fibers protruding from fabric surface by passing it over a flame or heated copper plates. Singeing gives the fabric a smoother surface, which aids in dustcake release, particularly in applications where moisture is a problem.

SIP: State Implementation Plan (UUSA Clean Air Act)

Sizing: A protective coating applied to yarn to ensure safe handling.

Slip: The proportion of dust escaping from the precipitator outlet. Slip may be expressed as a decimal fraction, or a percentage. It is usually estimated by dividing the outlet dust burden by the inlet dust burden. Also used to quantify conditioning materials such as sulfur trioxide and ammonia leaving the precipitator.

Slippage: The movement of yarns in a fabric due to insufficient interfacings.

Sneakage: The process in which dust-laden gas escapes through the treatment zone, either through the top, bottom or around the sides. Each percent of gas sneakage reduces the attainable precipitator collecting efficiency by almost one percent.

Solenoid Valve: Often times referred to as a "pilot valve", it is an electromechanical plunger energized to either a "normally closed" or "normally open" position to allow for relief of air pressure. In a baghouse, the solenoid valve is normally used to activate a compressed air device.

Space-Charge: The charge present (as dust particles, gas ions, and free electrons) in the space between the electrodes. Space-charge modifies the local electric field in an electrostatic precipitator in a way analogous to spacecharge modifying the field inside a thermionic diode. The space-charge strengthens the field near the collecting electrode (anode) and weakens the field near the discharge electrode (cathode).

Spark: A short, self-extinguishing discharge from the high voltage system to the grounded system. Sparks effectively cause the gas stream to act as a conductor.

Specific Collecting Area (SCA): A figure obtained by dividing total effective collecting surface of the precipitator by gas volume expressed in thousands of actual cubic feet per minute. In the metric system it is expressed as square meters per thousand actual cubic meters per hour.

Specific Corona Power: The quotient of the total corona power of all precipitator bus sections divided by the total gas volume handled by the precipitator, multiplied by 1000. Units are expressed as watts/1000 acfm.

Specific Resistance Coefficient of the Filter Cake: An indicator of how rapidly pressure drop increases during filtration.

Spray Tower Cooler (Conditioning Tower): A tower or cylinder into which a hot gas stream enters and water is sprayed. As the water evaporates, the gas stream is cooled to the desired exit

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temperature by adiabatic cooling.

Spun fabric: fabric woven from staple spun fiber; same as staple.

Spunbonded: A non-woven fabric formed by producing, laying and self-bonding a web of filamentous material in one continuous set of processing steps. Usually made of polyester, polyamides or olefins.

Staple fiber: Short fiber cut to specific length in synthetics, 1.5 in., 2 in., 2.25 in., etc. Also, natural fibers of a length characteristic of fiber, animal fibers being the longest.

Sweepage: Sweepage is the process by which gases passing beneath the electrodes of a precipitator pick up dust from the hoppers and carry it out of the precipitator. Sweepage can severely limit precipitator efficiency and is usually controlled by means of baffles.

Tensile Strength: The force required to pull apart the fabric; this is designated by the measure of resistance to a testing machine (in pounds) that a fabric provides before the material breaks. The test strip width depends on the type of fabric.

Tenter frame: A machine for drying cloth under tension (Tentering: also called framing).

Texturized Yarn: Filament glass yarn that has been processed by high pressure air passing through the yarn to open of the yarn bundle, providing more surface area.

Thread count: The number of warp and filling yarns in a fabric.

Throw: A process of doubling or twisting fibers into a yarn of the desired size and twist.

T/R (TR): Transformer rectifier.

TR Set: Consisting of an oil or liquid insulation filled tank containing the high voltage transformer, a silicon diode, full-wave (FW) bridge rectifier assembly and usually a high voltage resistance divider calibrated for indicating the ESP operating voltage on an external kilovolt (KV) meter. On top of the tank is the high voltage output bushing, which is connected via pipe and guard to the HT frame of a typical ESP section. The TR Sets are located on the ESP roof. A nameplate on the tank specifies all connections and ratings. A tank with two HV bushings is equipped for HW (half-wave) energization - rarely used in modern ESPs.

Transformer/Rectifier: A unit comprising a transformer for stepping up normal service voltages to voltages in the kilovolt range, and a rectifier operating at high voltage to convert AC to unidirectional current (DC).

Treatment Time: A figure, in seconds, obtained by dividing the effective length in feet of a precipitator by the precipitator gas velocity figure calculated above. The length of time it takes process gas to move through the treatment zone.

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TRI: Toxic Release Inventory

Tubesheet (Cell Plate): The steel plate with holes to which the open ends of bags and cages are connected; separates the clean air and dirty air sections of the baghouse.

Turning Vanes: A gas distribution device in which vanes in ductwork or transition guide the gas and dust flow to minimize pressure drop and control the velocity and dust concentration contours.

Turnkey: Complete APC system including all dust pickups, ducting, dust discharge auxiliaries and all equipment, which is part of the dust collection system.

Twill weave: Warp yarns floating over or under at least two consecutive picks from lower left to upper right, with the points of intersection moving one yarn outward and upward or downward on succeeding picks, causing diagonal lines in the cloth.

Twist: The number of complete spiral turns in a yarn, in a right or left direction, i.e., "Z" or "S", respectively.

U-Tube Manometer: (see Manometer)

Upper Weather Enclosure: A non-gas-tight enclosure on the roof of the precipitator to shelter equipment (T/R sets, rappers, purge air fans, etc.) and maintenance personnel.

Venturi: A cone-shaped device located at the top of each filter in pulse-jet collectors into which compressed air is blown. A negative pressure at the top of venturi is created to help pull additional volumes of air down into the filter element during pulsing.

VOC: Volatile Organic Compounds

Voltage: The average DC voltage between the high voltage system and grounded side of the precipitator.

Warp: The yarn running lengthwise (machine direction) in a woven fabric.

Warp count: Number of warp threads per inch of width.

Water Gauge (W.G.): See "Inch of Water."

Weather enclosure: A non-gas tight enclosure on the roof of the precipitator to shelter equipment and maintenance personnel.

Weave: The pattern of weaving, i.e. plain twill, satin, etc.

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Weft: Same as filling.

Weight (fabric): The nominal weight per square yard of fabric. There is always a manufacturing tolerance on either side of this average weight, which may range from 3% to 8% depending on the product. Example: A 16 oz. (453.6 g) polyester felt has a weight tolerance ± 1 oz. (28.5g).

Woof: Same as filling.

Wovens: Filter media fabrics constructed solely by weaving or interlacing yarns more or less at right angles into a uniform structure.

Yarn: A term for an assemblage of fibers or filaments forming a strand, which can be woven or otherwise formed into a textile material.

Yarn Size (Denier or Count): A relative measure of fineness or coarseness of yarn. The higher the denier of a filament year, the coarser (heavier) the yarn is. Count is the number of yarns in a weave pattern per lineal inch.

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