

 DESIGN PRACTICES	AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE, AND NOISE CONTROL ELECTROSTATIC PRECIPITATORS	Section XVIII-A6	Page 1 of 37
		December, 2000	

Changes shown by ↗

CONTENTS

Section	Page
SCOPE	3
REFERENCES	3
BACKGROUND	3
SYSTEM COMPONENTS	3
CASING / STRUCTURAL MEMBERS	4
ESP POWER SYSTEM (T-R) AND CONTROLS	5
DISCHARGE ELECTRODES	6
DE SUPPORT SYSTEM / INSULATORS	6
COLLECTION ELECTRODES - "PLATES"	7
ALIGNMENT BETWEEN DES AND CES	8
RAPPING SYSTEM	9
HOPPERS	10
DUST REMOVAL FACILITIES	11
FLUE GAS DUCTING AND GAS FLOW DISTRIBUTION APPLIANCES	12
SAFETY SYSTEMS	13
SPECIAL FEATURES WITH MULTIPLE ESPS	14
PERFORMANCE	14
DESIGN AND / OR EVALUATION PROCEDURE	16
PROCESS / DESIGN BASIS	16
DESIGN AND OPERATING TEMPERATURE	16
DESIGN AND OPERATING PRESSURE	17
FLUE GAS RATE	17
FLUE GAS COMPOSITION	18
INLET SOLIDS LOADING	18
INLET SOLIDS PARTICLE SIZE DISTRIBUTION	18
PARTICLE RESISTIVITY	19
SIZING THE ESP	19
PLATE AREA VIA THE MODIFIED DEUTSCH-ANDERSEN EQUATION	19
ASPECT RATIO	20
SUPERFICIAL VELOCITY	20
ELECTRICAL SECTIONALIZATION	21
SOLIDS HANDLING SYSTEM CAPACITY	22
GUARANTEES	23



Documents

Document Sharing Hub

Section XVIII-A6	Page 2 of 37	<i>AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE AND NOISE CONTROL</i>	ExxonMobil
December, 2000		ELECTROSTATIC PRECIPITATORS	DESIGN PRACTICES

CONTENTS (Cont)

Section	Page
ESP PERFORMANCE TESTING	24
SAMPLING PORTS	24
COMPLIANCE TESTING.....	25
PERFORMANCE / GUARANTEE TESTING	26
NOMENCLATURE	27
Tables	
Table 1 Typical FCCU ESP Process Basis	28
Table 2 "Standard" Particle Size Distribution for FCCU ESP Applications	29
Table 3 "Standard" Resistivity Data for FCCU ESP Applications	29
FIGURES	
Figure 1 Cut-A-Way View of a Typical Single Stage Parallel Plate ESP	30
Figure 2 Common Discharge Electrode (DE) Configurations	31
Figure 3 Typical Discharge Electrode System Insulator Support System.....	32
Figure 4 Typical Penthouse Showing the Purge Air System	33
Figure 5 Typical Collecting Electrode or "Plate"	34
Figure 6 Precipitation Rapping Systems.....	35
Figure 7 Typical Rapping Scheme for Discharge Electrodes	36
Figure 8 Typical ESP Hopper With Ancillary Equipment	37

Revision Memo

12/00	Terminology made consistent with Institute of Clean Air Company's (ICAC) standards. Minor editorial corrections.
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 DESIGN PRACTICES	AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE, AND NOISE CONTROL ELECTROSTATIC PRECIPITATORS	Section XVIII-A6	Page 3 of 37
		December, 2000	

SCOPE

This section discusses the use of dry Electrostatic Precipitators (ESP) for air pollution control applications.

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2. Theodore, Louis, and Buonicore, Anthony J., *Air Pollution Control Equipment: Selection, Design, Operation and Maintenance*, Prentice-Hall, Inc., 1982.
3. McDonald, Jack, and Dean, Allen, *Electrostatic Precipitator Manual*, Noyes Data Corporation, 1982.
4. Bohn, Jaroslav, *Electrostatic Precipitators*, Elsevier Scientific Publishing Company, 1982.
5. United States Environmental Protection Agency Manual - *Operation and Maintenance Manual for Electrostatic Precipitators*, EPA/625/1-85/017, 1985
6. ICAC (Institute of Clean Air Company's) Publication EP-1, *Terminology for Electrostatic Precipitators*, 2000

BACKGROUND

An ESP may be defined in the broadest sense as equipment that utilizes electrical forces to separate suspended particles from gases. This can be done in a wide variety of configurations, but the separation of particles from a gas by electrical precipitation requires three fundamental steps:

- Charging of the particles suspended in the gas stream
- Collection of the charged particles in an electric field
- Removal of the collected particles into an external receptacle

Charging is accomplished by applying a high DC voltage to an electrode system. The presence of a grounded electrode near the charged electrode gives rise to the formation of a corona and a unidirectional electrical field. Particles traveling between the two electrodes acquire a charge from the electrical field and are forced to the collecting electrode by the field. With few exceptions, all commercial precipitators use negative polarity to charge the particles. Even though negative polarity is used, there are some positive ions generated, resulting in particle capture on the discharge electrodes.

- ◆ Particles arriving at the collecting electrode do not have to be captured immediately for successful operation and may actually be collected several times before they are removed. Current flows in the collection process are large enough to describe the operation as electrical in nature. Thus, the term "electrostatic" is one of convention rather than description. Most ESPs that collect dusts are single stage, charging and collecting fields operate simultaneously, and employ parallel collecting plates, but some maybe two staged were charging and collecting occur separately.

Particles remain on the collecting electrode, or plates, until they are dislodged by a mechanical blow, called rapping. They then fall by gravity into a collection system, usually a hopper.

- ◆ ESPs have a long history in refineries. The first generation of Fluid Catalytic Cracking Units (FCCUs), including PCLA #1 (Baton Rouge, 1943) and BWFC #1 (Bayway, 1943), had ESPs installed as a final recovery step of the valuable natural aluminum silicate catalyst. The primary purpose of the early ESPs was catalyst recovery rather than pollution control. As cyclone technology advanced, ESPs were phased out of FCCU designs. However, with the passage of various environmental regulations, ESPs are again being installed. In addition to FCCUs, ESPs have also been installed on Fluid Coking Units, Coke Calciners, and Oil Fired Boilers

SYSTEM COMPONENTS

Figure 1 is a cut-a-way view of a typical single stage parallel plate ESP showing its various components. Each of these components is described in the following sections, along with the specific design requirements.

The discussions, design requirements, specifications, and calculation procedures provided in this section apply specifically to pollution control applications on petroleum refining fluid solids units and more specifically to the Fluid Catalytic Cracking Unit (FCCU). The FCCU application was selected for illustrative purposes because it has been ExxonMobil's major use of ESPs for environmental control. It should be noted, however, that the principles, but not necessarily the exact values, used to design a FCCU ESP can be applied to most environmental ESP applications.

Section XVIII-A6	Page 4 of 37	<i>AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE AND NOISE CONTROL</i>	ExxonMobil
December, 2000		ELECTROSTATIC PRECIPITATORS	DESIGN PRACTICES

SYSTEM COMPONENTS (Cont)

CASING / STRUCTURAL MEMBERS

The purpose of the casing is to confine the gas flow for proper exposure to the electrodes, to avoid excessive heat loss, and to provide structural support for the electrodes and rapping equipment. The casing is normally rectangular, but may be cylindrical for certain specialty ESPs. The casing in most instances is thin carbon steel [about 0.25 in. (6 mm)], but the casing may be lined or constructed of an alloy in specialty services. Insulation is generally required for heat conservation, to prevent condensation of acid gases, and for personnel protection. Access doors for entry into the ESP are installed in the casing, and stairways are attached to the casing. The casing is attached to structural members that support the casing and the ESP internals.

Structural members are built-up trusses, box beams or other shapes. The method employed depends on the ESP supplier. Differential thermal expansion of the structural members can cause the ESP internals to become misaligned (poor performance of the ESP) and thus the ESP must be designed to mitigate this impact. Differential thermal expansion is a function of both the operating temperature of the ESP and length of the major structural members. The operating temperature of the ESP influences the maximum acceptable length of the structural members. Due to the operating temperatures of refinery ESP, current efforts have been aimed at keeping the dimensions of the ESP such that the span is limited to the length of a single member. Misalignment problems seem to increase when multiple members are tied together. The maximum, typical length of most members is 35 ft (10.67 m). Using only a single member is especially important with regard to those members that are perpendicular to the collection electrodes, as experience indicates that these members have the greatest impact on misalignment. Typically for refinery service, it is recommended that the width of the ESP box be less than 35 ft (10.67 m). If a wider (direction perpendicular to the collection electrodes) ESP is required, current practice is to install multiple ESPs, rather than risk differential thermal expansion problems. As experience indicates that the members that are parallel to the gas flow have significantly less impact to differential thermal expansion problems, if required, multiple members [lengths greater than 35 ft (10.67 m)] may be used. Even when the length of structural members of an ESP is limited, other features must be included to minimize the impact of differential thermal expansion. These include providing bearings or sliding pads at the base of the support columns to permit the casing to move without buckling. In addition, it is typical that the support column at the mid-point of the ESP is fixed and all the remaining support columns have sliding pads.

To add rigidity to the ESP box, internal, cross bracing is generally provided by diagonal members across the inlet and outlet of the ESP. They may also be provided between each electrical field.

For FCCU ESP the casing, thermal growth, insulation, and access are addressed in a Duty Specification as follows:

- The precipitator housing shall be fabricated of structural grade carbon steel with a minimum plate thickness of 1/4 in. (6 mm) including a 1/16 in. (1.5 mm) total corrosion allowance. While it is desirable that all columns and stiffeners be external to provide a smooth internal surface for both gas flow and dust removal, the primary concern is that these members be oriented such that their thermal movement/expansion does not interfere with the internal collecting plate/emitting electrode alignment. To achieve this, internal members are permitted, provided they are shaped and designed to minimize interference with either gas flow or dust removal. The columns and stiffeners shall be spaced to avoid misalignment due to wind loads, earthquake loads, rapping forces, ducting reactions, or other external disturbances. Construction shall provide gas-tight integrity. To confirm this, all welds shall be leak-tested. The leak-test method shall be approved by the Owner. All bolted joints shall be gasketed and leak-tested, again by a method approved by the Owner.
- Special consideration shall be given to the support of the electrostatic precipitators so that free thermal growth of the precipitator casing is not inhibited. The precipitator casing should be pinned at one location and free movement of the casing should be provided using guided supports. PTEF pads (or other equivalent devices) under the guided supports may be used to decrease the resistance to free thermal growth. This is important since restrained thermal growth may cause distortion of the precipitator casing resulting in bowing of the precipitator roof thereby affecting spacing between the discharge electrodes and collecting plates. The roof of the precipitator shall be designed so that water permeation of the external insulation is avoided. Water permeation can affect the uniform thermal expansion of the roof under the insulation.
- The precipitator shall be fully insulated, up to its outlet. Specifically, the following shall be insulated: roof (weatherproof, and capable of withstanding personnel traffic, as required for normal maintenance and testing), and inlet transition section, chamber sidewalls, hoppers, and other locations as required for personnel protection at ladders and at testing locations.

ExxonMobil DESIGN PRACTICES	AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE, AND NOISE CONTROL ELECTROSTATIC PRECIPITATORS	Section XVIII-A6	Page 5 of 37
		December, 2000	

SYSTEM COMPONENTS (Cont)

- Insulation shall be as required for personnel protection or to conserve heat. Ladders and platform clips that are welded to breaching and precipitator housings shall be designed to allow for up to 7 in. (178 mm) of insulation. For personnel protection, any precipitator equipment surface over 150°F (66°C) and located in areas considered to be normal access, walkways, work areas, or sampling points must be either guarded or insulated. Insulation, other than that provided for the roof, shall be protected by the Vendor's standard sheathing painted in accordance with the job specifications.
- Quick opening access doors with key interlocks shall be provided for the precipitators at the following locations: downstream side of the inlet slide gate, upstream of the inlet distributor, downstream of the outlet distributor, hoppers (one door for each hopper), precipitator roof (one door for each field), penthouse roof (two doors, one on each end).
- All of the ESP manways shall be equipped with "grab bars", rungs, etc., to ensure safe entrance and egress. In addition, all manway doors shall open so that the full portion of the adjacent walkway/platform is unobstructed.
- The precipitators shall be equipped with external access ladders, walkways, platforms, and railings as needed to provide safe access for operation, maintenance, and/or inspection of the unit.
- Walkways or other access devices on the roof and on other thermally insulated surfaces shall be supported such that they will not restrain the thermal expansion of the precipitator casing. Adequate clearance for thermal displacements should be provided between walkways and attachments to the roof or casing (i.e., rapper, high voltage insulator boxes, etc.).
- Internal walkways shall be installed to permit inspection of otherwise inaccessible sections of the precipitator and cleaning of electrodes and other internal equipment. There shall be two means of egress, at opposite ends, from the precipitator roof.

ESP POWER SYSTEM (T-R) AND CONTROLS

The purpose of the high-voltage equipment in ESPs is to provide the intense electrical fields and corona currents needed for particle charging and collection. This equipment must be stable in operation, provide the proper voltage waveform, protect the equipment against spark over, maintain the proper voltage and current output, and be sturdy. Due to changing process conditions, automatic control of the rectifier output is required.

Each power supply consists of four components: a step-up transformer, a high voltage rectifier, a control element, and a sensor for the control system. Typically, the power supply is called a transformer-rectifier (T-R). The step-up transformer increases the voltage from the line voltage to that required by the ESP. The high voltage rectifier converts the high voltage ac power to dc, to be compatible with the ESP requirements. In most applications, the ESP T-R provides a half-wave dc current. However, due to the fineness of FCCU particles, a full wave form dc current is usually used. The T-R is submerged in a tank filled with a dielectric fluid.

- The automated control system is usually located on the primary or low side of the transformer. Its primary purpose is to maximize the power input (voltage) without sparking occurring. Sparking is the term used when there is an electrical breakdown between the discharge electrode and the collecting plate. During a spark, corona is not generated and the charging of particles does not occur. Modern T-R controls are of the silicon-controlled-rectifier (SCR) which contain multiple feedback loops. The T-R control system is usually located in a small control house in the vicinity of the ESP.
- Virtually every ESP supplier has developed its own proprietary T-R control system. Experience indicates that no supplier has a system significantly superior to any another supplier. Small computers are being added to the control circuit to decrease response times. Generically, the T-R control system attempts to maintain the maximum power input to the ESP in the following fashion. When a spark occurs, the power is cut back to a preset percent of the voltage just prior to the spark. Once the spark has been "quenched," the power is then increased at a specified rate to the point where the previous spark occurred. If, after a preset time, no spark has occurred, the power is increased further. This process goes on continuously. Older control sets required manual setting of various settings. The goal was to set a specific spark rate. The modern controller, with computers, has taken over this function and allows the spark rate to be set directly. An additional feature, in most control systems, will cut the power to almost zero when the sensor indicates massive sparking. Power is then brought up once the spark is quenched. In addition to the control system, the T-R control should have various electrical meters to monitor performance. ESP Vendors are now offering options, which monitor all of the ESP functions and it compatible with most process control systems. This enhances data collection as well as providing an additional diagnostic tool.



Section XVIII-A6	Page 6 of 37	<i>AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE AND NOISE CONTROL</i>	ExxonMobil
December, 2000		ELECTROSTATIC PRECIPITATORS	DESIGN PRACTICES

SYSTEM COMPONENTS (Cont)

For a FCCU ESP Duty Specification, the T-R and T-R controls are specified as follows:

- A minimum of three fields is required in each precipitator. Separate transformer/rectifier sets are required on each field. Each field shall be divided into two bus sections. If more than three (3) fields are supplied, the fields do not have to be subdivided. Bus connections shall be accessible while gas is flowing through the precipitator. The voltage control system shall be the silicon controlled rectifier type with linear reactors. They shall be of the Vendor's most current PLC design, capable of maintaining maximum voltages to the ESP, while maintaining the spark rate to preset limits. Each transformer/rectifier shall be provided with an integral ground switch.
- Each transformer/rectifier (T-R) shall be furnished with a control panel containing a group of meters, relays, indicating lights, and switches as necessary. Meters shall include AC ammeter, AC voltmeter, DC milliammeter, DC kilovoltmeter with its associated resistor in the high voltage circuits, and any other meter required (e.g., spark rate meter) for normal operation. Meter output shall be tied into the current FCCU control system (e.g., TDC 3000) system for monitoring of ESP operation. The supply to each panel shall be xxx volt (three phase, line to line), xx Hz. These T-R control panels and other precipitator motor controls shall be combined in a single weatherproof enclosure located in the immediate area of the precipitator. Ventilation for this enclosure shall be adequate for ambient air temperatures from the minimum up to maximum refinery design ambient temperature. Dust filters shall be provided for ventilation. The electrical classification for this enclosure is the refinery standard.

DISCHARGE ELECTRODES

The heart of the ESP is the discharge electrode (DE). In fact, ESP type is differentiated by the type of DE employed. The three most common DE configurations, as shown in **Figure 2**, are the weighted wire, rigid frame, and rigid mast.

Until the mid-1970s virtually all of the ESPs used the weighted wire DE. The weighted wire DE system is simply a thin wire tensioned by a weight. Additional components required are a method of attaching the wire to the top frame, and a system to maintain the wire in position by weights and guides at the bottom. To facilitate the attachment of the wires to the top frames and weights and to protect the wires from the boundary electrical effects at the attachment points, the ends of the wires are encased in larger diameter shrouds. The weighted wire DE was originally a thin, [1-in. 2.5-mm]] smooth wire. To enhance reliability braided wires have also been employed; to enhance ionization, "barbs" have been added. The weighed wire DE is subject to movement due to both dynamic and electrical forces. This movement reduces ESP performance. In addition, the thin DE is subject to failures due to both mechanical forces and electrical erosion.

As it became evident free hanging wires were unreliable, ESP DE design evolved into the rigid frame design. As the name implies, the DEs are completely encased within a rigid frame. The frame is constructed of either tubular (hollow) or solid shaped members (e.g., square). To further strengthen the frame and to minimize the length of the electrode, the frame is braced with the same framing material every 4 to 6 ft (1.2 to 1.8 m) in both the horizontal and vertical direction. The DEs are installed within the frame sections. However, the DEs are still thin diameter wires, or metal strips (typically 16 Gauge by 1/4 in.) or various geometric shapes (star, barbs, etc.). While the frame minimized/eliminated movement due to dynamic and electrical forces plus reduced some mechanical wear, the actual DEs are still relatively frail and subject to failures.

The latest development in DE design is the rigid mast DE, commonly referred to as an RDE (Rigid Discharge Electrode). The RDE is formed from thin metal sheet (12 or 16 Gauge) that has been formed into a structural shape. In the simplest form it is a tube. Corona is generated by "needle point" studs that are welded every 3 to 6 in. (76 to 152 mm) along opposite faces of the RDE. In some designs, the RDE shape is more complex such as a "C." A further refinement to the RDE has been accomplished shaping the RDE as a hollow "airfoil." Corona discharge is delivered by thin scalloped blades at the leading and trailing edges of the airfoil.

Due to the exceptional reliability of the RDE system, **FCCU ESP Duty Specifications require that:**

- A rigid mast discharge electrode system shall be used.
- The discharge electrodes shall be rigidly attached and supported at both the top and bottom. The discharge electrodes shall be of the scalloped notched or needle design to ensure even corona discharge.
- Stand-off insulators are not permitted.

DE SUPPORT SYSTEM / INSULATORS

The DEs, regardless of type, are connected together by a frame at the top and bottom. These frames are called the high-tension frames. The weight of the entire DE system must be supported, but this support must be such that the charged DE system does not contact other grounded components of the ESP. This is done by means of insulators, typically made of alumina. In addition, the insulators also seal holes in the casing where live components pass through. A typical insulator/support system is shown in **Figure 3**.

 DESIGN PRACTICES	AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE, AND NOISE CONTROL ELECTROSTATIC PRECIPITATORS	Section XVIII-A6	Page 7 of 37
		December, 2000	

SYSTEM COMPONENTS (Cont)

Most ESPs use the bell or crock-type insulator shown in **Figure 3**. This type of insulator is favored due to its load bearing capacity. Alumina is the favored material for insulators due to its strength and resistance to thermal shock. A metal cover prevents process gases and particulates from reaching the exterior of the insulator. The live suspension rod passes through the center of the insulator. However, the live suspension rod acts as a small precipitator and can result in the collection of material on the insulator interior surface. Solids deposition on the interior surface of the insulator can act as a conductive path to reduce the electrical energy available to remove particulates.

Two methods are used to prevent solids buildup on the insulator. A sheath, which is a grounded metal tube beneath the insulator and coaxial with the suspension rod, is installed. In addition to physically preventing the solids from reaching the insulator, it also increases the distance which particles must travel to reach the insulator. The suspension rod/sheath geometry acts as a small precipitator to remove the solids before they reach the insulator. The sheaths are generally rounded/flared to assist in the removal of any material which has been deposited on the sheath and to provide a termination which will not cause sparks to occur. However, by themselves, sheaths are not fully effective in preventing solids deposition on the insulator. Thus, a heated air purge to scour the walls of the insulator is strongly recommended and typically used in most modern ESPs.

It has been found that a superficial velocity of 10 ft/sec (3 m/sec) within the insulator is required to keep solids deposition to acceptable limits. This would require an exceptionally high purge rate. Vendors have compensated by adding directional nozzles to the insulator metal cover plate. These nozzles reduce the quantity of purge air required but they direct the purge air such that the velocity at the surface of the insulator exceeds the minimum requirement. To ensure a reliable supply of purge air, experience indicates that two insulator purge air blowers/fans are required (i.e., one operating and one in standby). Depending on how the insulators are housed, one or two heating elements may be employed.

When the insulators are housed in individual compartments, this is called the "dog-house" insulator compartment arrangement. This arrangement was typically used on older ESPs. While each insulator was protected from the elements, the "dog-house" arrangement had several disadvantages including difficult purge air distribution problems, excessive heat loss, and longer construction times. In the "dog-house" arrangement, all of the heat for the purge air must come from the heater, thus necessitating a heater for each insulator blower/fan. Most modern ESPs use what is called the "penthouse" design to protect the insulators. The penthouse encloses all of the insulators in a single enclosure. This enclosure acts like a large plenum to equally distribute the purge air to all the insulators. The penthouse also reduces construction time due to its simple design. The lower surface area also reduces heat losses. As the floor of the penthouse is not insulated, heat from the process provides most of the heat for the purge air. Thus, only one common heater is required for both purge air insulator blowers/fans. A typical penthouse system is shown in **Figure 4**.

Due to the many advantages of the penthouse design, **FCCU ESP Duty Specifications** require that:

- The discharge electrode support insulators shall be enclosed in a common penthouse. The insulator enclosure shall be furnished with a connection for pressurizing with sufficient heated ambient air to prevent cracking of the insulators and to minimize cleaning.
- Vendor shall supply two roof-mounted blowers with air filters, a common electric heater, and the necessary piping for each precipitator. Operation of the blowers shall be such that any failure/stoppage of the operating blower will automatically commence operation of the spare/standby blower.
- Face velocities on the process side of the insulators shall be maintained at or above 10 ft/sec (3.05 m/sec). Lesser amounts of purge air may be used if the Vendor can demonstrate to the Owner's satisfaction that the insulators will remain free of solids buildup.
- If a grommet is used between the high voltage conductor and the precipitator casing, it shall be designed to allow for differential thermal expansion. An alumina electrical insulating grommet is preferred for this application.
- The discharge electrode support insulators shall be made of alumina. Insulators shall be capable of being cleaned without the cooling of or entry into a precipitator chamber itself during shutdowns.

COLLECTION ELECTRODES - "PLATES"

- ♦ The collection electrodes (CEs) or "plates" are individual grounded surfaces on which the particulate matter is collected. A typical collection electrode or plate is shown in **Figure 5**. In spite of many supplier claims, most plates are simple configurations. The main considerations in the design of the CEs or "plates" are its stiffness and its ability to shield the collected layer of dust to prevent reentrainment. An additional requirement is that the edge of the plate be free of sharp edges or protrusions that can provide localized high field regions, resulting in sparking at low voltages. If the CE segments are welded together, the weld must be smooth to minimize local sparking. A further requirement of the CEs is that the rapping impact should be transmitted uniformly as possible to facilitate uniform dust removal. The CEs must have sufficient strength to prevent damage, especially warpage during rapping. Individual CEs are supported in frames or anvil beams. Typically three to five CEs are supported in each anvil beam. The anvil beams are used to transmit rapping forces to the plates.

Section XVIII-A6	Page 8 of 37	<i>AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE AND NOISE CONTROL</i>	ExxonMobil
December, 2000		ELECTROSTATIC PRECIPITATORS	DESIGN PRACTICES

SYSTEM COMPONENTS (Cont)

Most ESPs use what is called the shielded flat CE. In order to shield the precipitated dust from the gas passing across the CE, baffles are mounted along the CE at specific intervals. Baffle shapes vary from flat strips perpendicular to the gas flow to aerodynamic designs to minimize gas turbulence. These baffles can be welded to the flat CE, but most Vendors form the baffles as part of the CE segment and continuously or spot weld these segments together to achieve the desired CE length. As the CEs are constructed from thin material (typically 18 or 20 Gauge), the baffles also help to strengthen the plate. Segment length varies from 20 to 30 in. (0.51 to 0.76 m) depending on the Vendor and whether the segment is a leading/trailing segment or a middle segment. Thus, depending on the Vendor, length (in the direction of gas flow) of the CEs is limited to multiples of the segments, but typically is the range of 6 to 15 ft (2 to 5 m). On the other hand, the height of the CE can be as high as 50 ft (15.2 m). ExxonMobil experience indicates that tall CEs will readily warp during transport and construction, which results in poor ESP performance. Limiting the maximum allowable CE heights can eliminate this problem. As the CE collects particulates on both faces, the total surface area of the CEs must include the area of both faces.

- ExxonMobil experience indicates that **limiting the height of the CEs in FCCU service to 24 ft (7.32 m) in FCCU service** has eliminated the problem of warpage during transport and erection. Shorter plates are also useful in preventing high voltage frame swinging. Typically, the length of most FCCU ESP CEs is 9 ft (2.74 m).

ALIGNMENT BETWEEN DEs AND CEs

Regardless of the type of ESP, the most critical design parameter is the alignment of the DEs and CEs. If the distance between a specific DE and CE is closer than all the other DEs, there will be a greater chance that sparking (poor ESP performance) will occur at the DE which is closer to the CE. In essence, an ESP is a perfect example of the saying that a chain is no stronger than its weakest link. In an ESP the performance can be set by the closest distance between a DE and CE. Factors which impact on the DE/CE alignment are the construction methods, material handling methods, and thermal movement of the systems as the ESP is brought up to temperature. Based on experiences with coal-fired boilers, suppliers have recognized the impact of differential thermal expansion of alignment. Modern ESP designs now adequately take into account this factor.

Regardless of the type of DE employed, Vendors typically have construction tolerances of 3/8 to 1/2 in. (9.5 to 12.7 mm) with 9 to 10 in. (22.8 to 25.4 cm) CE spacing and 1/2 to 3/4 in. (12.7 to 19 mm) with CE spacing 12 in. (30.5 cm) or greater. In reality, the actual tolerances are probably twice the typical value. This is unacceptable and has lead to "poor" ESP performance. Knowing that alignment is important, ExxonMobil has realigned, **without** any Vendor assistance, an existing weighted wire ESP with 10-in. (25.4-cm) spacing to a tolerance of 1/8-in. (3.2 mm). Based on this accomplishment, the same alignment criteria have been set forth for Vendors. For RDE ESPs the wider DE and the increased CE spacing [12 in. (0.5 cm)] allows the alignment standard to be relaxed to 1/4 in. (6.4 mm). Experience with several RDE ESPs indicates that the suppliers CAN meet this requirement with minimal, additional effort. The net result has been excellent ESP performance for ESPs that have met these criteria.

FCCU ESP Duty Specifications require that:

- Each precipitator shall have collecting electrodes spaced on nominal 12 in. (0.305 m) centers. Collecting/emitting electrode alignment shall be maintained within plus/minus 1/4 in. (6.35 mm).
- The precipitator internals (discharge electrodes, collecting plates, etc.) shall be designed so that over the operating temperature range, the collecting/emitting electrode spacing remains within specified tolerance. Both support systems shall be designed such that they grow (due to the thermal expansion) in the same direction.
- Maintenance of specified tolerances within the operating temperature range may involve presetting the emitting electrode system in the cold position. The amount of preset required depends on the amount of differential thermal expansion between the two support systems.
- The collecting electrodes shall be adequately stiffened and guided to prevent bowing or other thermal distortions that would affect the specified distance between collection plates and discharge electrodes.
- Other conditions including, but not limited to, differential thermal expansion of the precipitator internals and casing and/or operation of various rapping systems shall not disturb the specified alignment.
- Special consideration shall be given to the case in which a cold precipitator is started up with hot flue gas. The specified alignment shall not be disturbed during this situation.
- The Vendor shall offer proof as to the steps/procedures taken with the design to meet the above alignment criteria.

 DESIGN PRACTICES	AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE, AND NOISE CONTROL ELECTROSTATIC PRECIPITATORS	Section XVIII-A6	Page 9 of 37
		December, 2000	

SYSTEM COMPONENTS (Cont)

RAPPING SYSTEM

Once the material has been collected within the ESP, it must be removed from the collection surfaces to maintain optimum electrical conditions in the precipitation zones. The deposited material is dislodged by mechanical impulses or vibrations of the CEs and DEs. This process is known as rapping. The earliest ESPs used manual rapping, that is, operators using sludge hammers on a strike plate. This was readily replaced by mechanical methods. Mechanical rapping systems are generally classified as vibrators, swing hammers, and single impact rappers. These rappers are shown in **Figure 6**. Regardless of the rapping system used, the rapping energy is transmitted to the CE or DE via a rapper rod that is connected to the mounting anvil beam. When used to clean the DE, the rapper rod is provided with an electrical insulation section in order to isolate the high voltage DE from ground, as shown in **Figure 7**. An effective rapping system must be reliable and have the ability to modify the frequency, duration, and intensity of the rap in order to obtain optimum cleaning of the electrode. Note, optimum cleaning of the electrodes does **NOT** mean that the electrodes are completely free of dust. Rather, optimum electrode cleaning means that the dust layer is such that it does not inhibit ESP performance. Finally, to avoid excessive reentrainment of the collected material, rapping sequence should be such that two adjacent rappers (either in the direction of flow or perpendicular to the direction of flow) are not activated sequentially.

Vibrators were one of the first mechanical rapping systems. The vibration can be generated by either electrical or pneumatic means. There are two electric vibrator designs. The most common electromagnetic vibrators consist of a balanced spring-loaded armature suspended between two synchronized electromagnetic coils. When energized, the armature vibrates at line frequency. A less common type consists of an electrical motor equipped with adjustable cam weights mounted on a single shaft or both shafts of a double-ended motor. When operated, the eccentricity positioned cam weights set the entire assembly into vibration. Pneumatic vibrators use a reciprocating piston in a sleeve-type cylinder. This assembly is fastened directly to the end of the rapper rod. With vibrator type rappers, the duration, frequency, and sequence of rapping can be changed but the intensity of rapping cannot be changed. Experience indicates that vibrator type rappers generally do not transmit sufficient energy to adequately clean the electrodes. In addition, the somewhat elaborate electrical components require extensive maintenance and reduce reliability.

The swing hammer, sometimes called drop hammers or “klunk” hammers, rapper system consists of a drive shaft running across the ESP. The shaft rotation carries the swing hammers around the shaft. When the hammer rods swing over the center cam disc and raise the hammer rods, the hammers fall due to gravity, striking an anvil that is attached to the DE or plate. This system is usually used in rigid frame ESPs. The only rapping variable with this system that can be readily changed is frequency. Intensity can only be changed by manually changing out every hammer to a different mass. This can only be done when the ESP is taken out of service. Another disadvantage of this rapping system is that the rappers are located in the process stream. Therefore, they are subject to process stream conditions and cannot be repaired or replaced while the ESP is on stream.

Single impact rappers consist of a plunger which is lifted by energizing a solenoid. On release of the plunger by de-energizing the coil, it falls under the influence of gravity against an anvil that transmits the rap through a rod to the electrodes to be cleaned. The single impact rapper is mounted vertically on top of the ESP. Springs in lieu of gravity can be used to actuate the rapper. Control consists of varying the electrical energy, which changes the magnitude of the impulse or the frequency of rapping. This type of rapper is most amenable to microprocessor control which can readily change intensity, frequency, and sequence.

For a FCCU ESP Duty Specification, rappers are specified as follows:

- The collecting plate and discharge electrode rapping systems shall be completely separate and adjustable. Both the collecting plate and discharge electrode rappers shall be of the electromagnetic type, with the rapping element located external to the ESP box. One weather-tight control cabinet located within the transformer/rectifier control shelter or in a separate shelter on top of the ESP containing repeat cycle timers, variable auto-transformers, and switches necessary to provide continuous sequential rapping is required for the precipitators. These controls shall be of the solid state PLC type.
- Different rapping schedules shall be possible for the discharge electrodes and for each of the collecting electrode fields. It is preferred that each field of collecting plates be rapped in proportion to the estimated amount of solids collected by each field. It is also preferred that the discharge electrodes be rapped, at a minimum, as frequently as the most frequently rapped field of collection electrodes. Rapping schedules shall be such that two adjacent rappers (either in the direction of flow or perpendicular to the direction of flow) are not activated sequentially. The Vendor shall provide his rapping schedule for approval by the Owner during detailed design of the unit. The time interval duration and intensity of rapping shall be variable. A 24-hour timer shall be provided to actuate the rapping cycle as required.

Section XVIII-A6	Page 10 of 37	<i>AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE AND NOISE CONTROL</i>	ExxonMobil
December, 2000		ELECTROSTATIC PRECIPITATORS	DESIGN PRACTICES

SYSTEM COMPONENTS (Cont)

- A maximum number of electric rappers shall be furnished with each chamber such that each field of collecting plates and the discharge electrodes may be rapped as separate units. The number of collecting plates rapped by any one rapper shall be minimized. It is preferred that no more than five percent (5%) of the total collecting electrode plate area be rapped at any one instance. The number of rappers on the emitting electrodes shall be maximized. However, the preferred sequencing of these rappers is such that all rappers attached to a single high voltage discharge frame shall rap simultaneously. The Vendor shall furnish proof of successful operation, defined as two years' operation with minimum operating problems.

HOPPERS

Hoppers are used to collect and store the dry particulate that is removed from the electrodes. A typical hopper is shown in **Figure 8**. Hoppers are either pyramidal or trough shaped. Experience has shown that the pyramidal shaped hopper is more reliable due to the smaller cross-section of its discharge. A hopper can cover several collection fields. However, matching the number of hoppers to the number of collection fields results in greater reliability. The hopper is usually constructed of the same material as the ESP casing. Besides some bracing, the only internal structure to the hopper is the hopper baffle(s). The baffle(s) generally extends below the dust level to provide a seal and to keep the gas from flowing through the hopper. Hopper design must take into account the angle of repose of the solids that are being collected and the storage time that is required. Storage time is generally set by time it might take to repair the solids evacuation system. Experience indicates that the collected material should be removed from the hopper frequently and not allowed to sit in the hoppers for long periods of time. Typically, each hopper should be emptied once a shift (every eight hours).

A key part of hopper design is to keep the collected material dry. If the collected material is allowed to cool, moisture condensation, followed by caking, could occur. Caked material is difficult to remove. If the collected material is not removed, it will build-up and eventually contact the DE. This causes the DE system to "short-out" rendering the ESP inoperable. Keeping the collected material dry is accomplished by heat tracing and insulating the hoppers. Electrical or steam heat tracing is acceptable, provided that sufficient heat is supplied. Due to the abundance of low-pressure steam in a refinery, most refinery ESP hoppers use steam heat tracing. Hopper insulation is similar to that used on the casing, but may have to be increased to conserve heat in the hopper.

If the ESP operates at vacuum conditions, air leakage through the hopper can cause reentrainment of dust from the hoppers. The extension of the hopper baffle close to the discharge point helps to prevent this from occurring. Good seals on the hopper access doors and around the dust removal system are also preventive measures.

Overfilling of the hoppers with dust can be a serious problem leading a "shorted" electrical system, major ESP damage, and/or reentrainment of dust causing a significant reduction in the performance. Due to the importance of detecting high levels in the hoppers, a number of level-detecting systems have been developed. Experience indicates that most of the level detectors are inaccurate or provide false readings, with the exception of nuclear detectors. The nuclear detectors consist of a source and a receptor. When the radiation rays given off by the source do not reach the detector, the level alarm is activated. When nuclear level detectors are employed, additional safety precautions must be taken to ensure that the source is shielded/removed during inspection periods. The low-level detector is only used to determine if the hopper is empty. As it is a detector rather than an alarm, less dependable detectors, such as the capacitance type, can be employed as an alternative.

▶ The hopper should also be equipped with ancillary equipment to assist in the flow of solids from the hopper to the evacuation system. Vibrators installed on the walls of the hopper can assist in the flow of solids. Some Vendors offer aeration systems in the bottom of the hopper. This piece of ancillary equipment should not be used if the collected material is combustible. In addition, these devices are not recommended for any service since even the small quantity of air that is used for aeration can cause considerable reentrainment of the collected solids.

Should a hopper become plugged, two ancillary devices can be essential in returning the hopper to normal operation. A "poke" hole can be used to insert a rod into the hopper to break up the plug. To avoid contact with the energized portions of the ESP, the poke hole should be sloped toward the hopper discharge point. If the ESP is operating under positive pressure, a "stuffing box" is required to prevent blow-back of process gases. Blast connections can be used to provide a one time "fluffing" of the collected material. Air is typically used as the "fluffing" medium but an inert gas (e.g., nitrogen) might be required if the solids are combustible. The blast connections should be used as a last resort in clearing hopper plugs as their use will result in a significant increase in emissions.

 DESIGN PRACTICES	AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE, AND NOISE CONTROL ELECTROSTATIC PRECIPITATORS	Section XVIII-A6	Page 11 of 37 December, 2000
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SYSTEM COMPONENTS (Cont)

For a FCCU ESP Duty Specification, the hopper area is specified as follows:

- A minimum of one (1) dust-collecting hopper shall be provided for each electrical field. The hoppers shall be sized to provide a minimum of “three (3) days” holdup of the collected solids. The Owner shall specify the frequency of dumping; however, it is recommended that at a minimum, the hoppers be emptied once per shift (every 8 hours) to minimize operational problems associated with hopper and/or rotary valve plugging.
- The following data shall be used for hopper design:
 - a. Hopper type: Pyramidal.
 - b. Minimum hopper valley angle: 55°.
 - c. Minimum hopper outlet dimensions: 12 in. ϕ or 12 in. x 12 in. (300 mm ϕ or 300 mm x 300 mm).
 - d. Material of construction: carbon steel with CS-2 allowance.
 - e. Angle of repose of catalyst fines: 55°.
 - f. Loose bulk density of catalyst fines: 33 lb/ft³ (530 kg/m³).
- Each hopper shall be equipped with a high level switch to actuate an alarm (a “small” time delay shall be added to prevent “nuisance” alarms) in the main control room and a low level indicator to be used when emptying a hopper. The high level alarm/indicator shall be of the nuclear type. Additional shielding of the source shall be provided and the electronic portion of these sensors shall be remote from the hot hopper wall. The low level shall also be of the nuclear type. Vibrators along with their sequencing system shall be provided for each precipitator hopper. The hopper vibrator control system shall be adjustable and completely separate from the collector and emitting electrode rapper systems. The hopper shall be provided with a suitable number of poke holes (angled downward) and blast connection(s) (not roddable and terminating in an elbow pointing upwards) to break bridges. The poke holes shall be equipped with full-port gate valves. A single “stuffing box” and “poke hole rod” shall be supplied. The blast connection(s) shall be designed so that they do not project past the projection of the hopper outlet flange. One access way shall be provided on each hopper. The entire hopper shall be insulated, and the lower three-quarters (3/4) of its height shall be steam traced to maintain the collected fines above the flue gas water dew point.

DUST REMOVAL FACILITIES

Equipment located below the exit flange of the ESP hopper is considered to be the dust removal facilities. In general, the dust removal facilities use pneumatic or mechanical (screw conveyors) transport of the solids. Both have been successfully used on ExxonMobil ESPs. Regardless of the system employed, a cut-off type knife gate should be provided at the hopper outlet to isolate the ESP from the dust removal system. The collected solids need to be metered into the transport system. This can be accomplished by either rotary valves or “blow pots.” Virtually all of the ExxonMobil ESPs have used rotary valves, with six blades and open-ended rotors, whose design rpm is based on 100% full pockets with the loose bulk density of the collected material. To prevent condensation and subsequent plugging, both the knife gate and rotary valve are heat traced and insulated. Mechanical dust removal systems are designed in accordance with Design Guide 97 PD 33, but may require heating to prevent condensation in the screw conveyors and their subsequent plugging. Pneumatic transport systems are designed in accordance with [Section VI-A](#). With either system, the solids removal system must be elevated sufficiently above grade to provide adequate access for maintenance of the equipment. Usually, elevating the system at least 3.2 ft (1 m) is sufficient, but refinery practices may dictate a greater elevation. Finally, the solids disposal system must be designed such that fugitive particulate emissions during transport are minimized.

Regardless of the transport system that is employed, the operating sequence is critical to ensure continuous operation. An automatic control system for operation of the precipitator dust handling facilities should be employed. This system should be capable of being manually activated by a single switch. The sequence of operation shall be as follows:

- Activating the transport system and verifying that transport system is operational. When a mechanical system is used, the screw conveyor furthest from the ESP is the first one activated.
- Starting the rotary valve on the inlet field hopper of one precipitator with activation of that hopper's vibrator on a timed basis during the emptying period.
- Continued emptying of the hopper until the low-level indication is reached and then continued operation for a preset period of time before stopping. The preset period of time shall be at least twice the calculated time to completely empty the hopper from the low-level indicator. (**Note:** If the low level indicator is activated at the beginning of this cycle on any hopper, then the rotary valve **must** operate for the preset period of time.)

Section XVIII-A6	Page 12 of 37	<i>AIR POLLUTION CONTROL, INDUSTRIAL HYGIENE AND NOISE CONTROL</i>	ExxonMobil
December, 2000		ELECTROSTATIC PRECIPITATORS	DESIGN PRACTICES

SYSTEM COMPONENTS (Cont)

- Upon completion of the emptying procedure for the inlet field hopper, the same procedure shall be initiated on the next downstream hopper until all the hoppers are emptied. It is **NOT** permissible to empty two hoppers simultaneously. Once all the hoppers on one precipitator have been emptied, the same procedure shall be followed on any other precipitator.
- Upon completion of the emptying procedure for all hoppers, the transport system shall be run for a preset period of time to ensure that there is no catalyst remaining in the transport system.

The precipitator dust handling facilities control system shall have a Programmable Logic Controller (PLC) type control panel located within the transformer-rectifier control shelter. This panel shall show the status of all equipment/features associated with the dust handling facilities and shall provide for a manual override on each component. The transformer-rectifier control shelter shall also house the controls for all ESP motor control valves.

FLUE GAS DUCTING AND GAS FLOW DISTRIBUTION APPLIANCES

The design of the flue gas ducting into and out of the ESP follows standard practices. For optimum performance, a uniform gas split to each ESP in a multiple ESPs configuration and a uniform gas distribution at the inlet and outlet face of each gas passage of each ESP (the area between each CE) is important.

There are many devices/appliances that can be used to ensure uniform gas distribution. These include turning vanes, flow straighteners, flow splitters, and perforated plates of uniform or varying porosity. These devices are described in [Section XIV](#). With multiple ESP applications, additional distribution devices may be required, see SPECIAL FEATURES WITH MULTIPLE ESPs. Due to the low-pressure drop exerted by these devices and the low velocity within the ESP, the correct combination of flow distribution devices can only be determined by a flow model of the ESP system.

The flow model should be provided by the ESP Vendor since most ESP Vendors are experienced and they have flow modeling facilities within their organizations. A flow model should encompass not only the ESP but also all the ducting leading to and from the ESP, even if the ESP Vendor is not providing this ducting. An extended model is required because minor flow distribution appliances upstream of the ESP may eliminate the need for more elaborate flow distribution devices at the ESP inlet. When the ESP Vendor is not providing the ducting to/from the ESP, the ESP Vendor is typically assigned the responsibility to review the ducting design via the flow model study. Any flow distribution appliances that the ESP Vendor deems necessary are then incorporated into the ducting design. Even with existing ESP systems, flow modeling is typically the most cost-effective method for determining the uniformity of the gas flow distribution.

As will be shown in the **PERFORMANCE** section, ESP performance is logarithmic in nature. Thus, an increased velocity in one gas passage (path between two CEs) will decrease the efficiency in that section more than the decreased velocity in another section would have its efficiency increased. Thus, an ESP with non-uniform gas distribution will have significantly poorer performance than an ESP with uniform gas distribution. ExxonMobil experience has shown that poor gas distribution is one of the major causes of properly sized ESPs failing to meet their performance requirements. The typical measure of the uniformity of the gas distribution, obtained from the flow model or actual plant tests, is the root-mean squared (RMS) deviation. In statistical terms, RMS is defined as the standard deviation of the velocities divided by the mean velocity. ExxonMobil experience indicates that a RMS of less than 20% and preferably less than 15% is required for "good" ESP operation. This is about half of the "typical" RMS values (30 to 40%) for most ESPs.

In a FCCU ESP Duty Specification, the flue gas ducting and flow distribution appliances are handled as followed:

- The ESP Vendor shall be responsible for the design and erection of the inlet and outlet, including the stack, precipitator ductwork, starting at the current tie-in point and flue gas distribution headers. This responsibility shall include all structural design including thermal flexibility, expansion joints, turning vanes and distribution baffles, isolation slide gates, and gaskets for gas-tight integrity as required. The ducting shall be designed to minimize loads and reaction forces on the precipitator structures. Flue gas ducting shall be capable of handling the all design throughputs. Should the ductwork be provided by a party other than the ESP Vendor, the ESP Vendor shall review the design to ensure that there is no impact on ESP performance.
- The Vendor's proposal shall include the costs for constructing and testing a three-dimensional model of the flue gas system from the inlet tie-point through the ESP stack exit. The model and testing should be used to ensure proper gas distribution in the Vendor's proposed system. The scale of the model shall be small enough to be accommodated within commercial testing laboratories. Tests shall be conducted with all the design flue gas volumes.