Lesson 4

ESP Design Review

Goal

To familiarize you with the factors to be considered when reviewing ESP design plans for the permit process.

Objectives

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

1. Explain how each of the following dust properties affects ESP performance:
   - Dust type (chemical composition)
   - Size
   - Concentration in gas stream
   - Resistivity
2. Explain how each of the following flue gas properties affects ESP performance:
   - Gas flow rate
   - Temperature
   - Moisture content
   - Chemical properties (dew point, corrosiveness, and combustibility)
3. Identify important design considerations for discharge electrodes, collection electrodes, and hopper and discharge devices
4. Explain how each of the following factors contributes to good ESP design:
   - Electrical sectionalization
   - Specific collection area
   - Aspect ratio
   - Distribution of gas flow
5. Estimate the collection area and the collection efficiency for a given process flow rate and migration velocity
6. Estimate the capital and operating cost of an ESP using tables and figures

Introduction

As discussed in Lessons 2 and 3, finalizing the design of an electrostatic precipitator and its components involves consideration of many factors. Air pollution control agency officers who review ESP design plans should consider these factors during the review process. Some of these factors relate to the properties of the dust and flue gas being filtered, while others apply to the specific ESP design:

- Type of discharge electrode
- Type of collection electrode
- Electrical sectionalization (number of fields and individual power supplied used
- Specific collection area
- Aspect ratio

Construction details, such as shell insulation, inlet location, hopper design, and dust discharge devices are also important.

This lesson reviews the ESP design parameters, along with typical ranges for these variables. It also familiarizes you with cost information for various ESP designs so that you can be aware of cost when reviewing design plans and making recommendations.

Review of Design Variables

The principal design variables are the dust concentration, measured in g/m^3 (lb/ft^3 or gr/ft^3) and the gas flow rate to the ESP, measured in m^3/min (ft^3/min or acfm). The gas volume and dust concentration (loading) are set by the process exhaust gas flow rate. Once these variables are known, the vendor can begin to design the precipitator for the specific application. A thorough review of ESP design plans should consider the factors presented below.

Physical and chemical properties of the dust such as dust type, size of the dust particles, and average and maximum concentrations in the gas stream are important ESP design considerations. The type of dust to be collected in the ESP refers to the chemical characteristics of the dust such as explosiveness. For example, a dry ESP should not be used to collect explosive dust. In this case, it might be a better idea to use a baghouse or scrubber. Particle size is important; small particles are more difficult to collect and become reentrained more easily than larger particles. Additional fields may be required to meet regulatory limits. The dust loading can affect the operating performance. If the dust concentration is too high, the automatic voltage controller may respond by totally suppressing the current in the inlet fields. Suppressed current flow drives the voltage up, which can cause sparking. For this reason, it might be a good idea to install a cyclone or multicyclone to remove larger particles and reduce the dust concentration from the flue gas before it enters the ESP. The facility could install a larger ESP (with more plate area), however, this technique would be more costly.

Resistivity is a function of the chemical composition of the dust, the flue gas temperature and moisture concentration. For fly ash generated from coal-fired boilers, the resistivity depends on the temperature and moisture content of the flue gas and on the sulfur content of the coal burned; the lower the sulfur content, the higher the resistivity, and vice versa. If a boiler burns low-sulfur coal, the ESP must be designed to deal with potential resistivity problems. As previously stated in Lesson 3, high resistivity can be reduced by spraying water, SO_3 or some other conditioning agent into the flue gas before it enters the ESP.

Predicting the **gas flow rate** and **gas stream properties** is essential for proper ESP design. The average and maximum gas flow rates through the ESP, the temperature, moisture content, chemical properties such as dew point, corrosiveness, and combustibility of the gas should be identified prior to final design. If the ESP is going to be installed on an existing source, a stack test should be performed to determine the process gas stream properties. If the ESP is being installed on a new source, data from a similar plant or operation may be used, but the ESP should be designed conservatively (with a large SCA, a high aspect ratio, and high corona power). Once the actual gas stream properties are known, the designers can determine if the precipitator will require extras such as shell insulation for hot-side ESPs, corrosion-proof coatings, and installation of heaters in hoppers or ductwork leading into and out of the unit.

The type of **discharge electrodes** and electrode support are important. Small-diameter wires should be firmly supported at the top and connected to a weight heavy enough (11.4-kg weights for 9.1-m wires) to keep the wires from swaying. The bottom and top of each wire should be covered with shrouds to help minimize sparking and metal erosion at these points. Newer ESPs are generally using rigid-frame or rigid-electrode discharge electrodes.

Collection electrodes—type (either tube or plate), shape of plates, size, and mechanical strength—are then chosen. Plates are usually less than 9 m (30 ft) high for high-efficiency ESPs. For ESPs using wires, the spacing between collection plate electrodes usually ranges from 15 to 30 cm (6 to 12 in.). For ESPs using rigid-frame or rigid electrodes, the spacing is typically 30 to 38 cm (12 to 15 inches). Equal spacing must be maintained between plates throughout the entire precipitator. Stiffeners may be used to help prevent the plates from warping, particularly when hot-side precipitators are used.

Proper **electrical sectionalization** is important to achieve high collection efficiency in the ESP. Electrical sectionalization refers to the division of a precipitator into a number of different fields and cells, each powered by its own T-R set. ESPs should have at least three to four fields to attain a high collection efficiency. In addition, the greater the number of fields the better the chance that the ESP will achieve the designed collection efficiency. There should be approximately one T-R set for every 930 to 2970 m^2 (10,000 to 30,000 ft^2) of collection-plate area.

The **specific collection area (SCA)** is the collection area, in m^2 per 1000 m^3/h (ft^2 per 1000 ft^3/min), of flue gas through the precipitator. The typical range for SCA is between 11 and 45 m^2 per 1000 m^3/h (200 and 800 ft^2 per 1000 acfm). The SCA must be large enough to efficiently collect particles (99.5% collection efficiency), but not so large that the cost of the ESP is too high. If the dust has a high resistivity, vendors will generally design the ESP with a higher SCA [usually greater than 22 m^2 per 1000 m^3/h (400 ft^2 per 1000 acfm)] to help reduce resistivity problems.

Aspect ratio is the ratio of effective length to height of the collector surface. The aspect ratio should be high enough to allow the rapped particles to settle in the hopper before they are carried out of the ESP by the gas flow. The aspect ratio is usually greater than 1.0 for high-efficiency ESPs. Aspect ratios of 1.3 to 1.5 are common, and they are occasionally as high 2.0.

Even **distribution of gas flow** across the entire precipitator unit is critical to ensure collection of the particles. To assure even distribution, gas should enter the ESP through an expansion inlet plenum containing perforated diffuser plates (see Figure 3-7). In addition, the ducts leading into the ESP unit should be straight as shown in Figure 4-1. For ESPs with straight-line inlets, the distance of A should be at least as long as the distance of B in the inlet (Katz 1979). In situations where a straight-line inlet is not possible and a curved inlet must be used (see Figure 4-2), straightening vanes should be installed to keep the flue gas from becoming stratified. The gas velocity through the body of the ESP should be approximately 0.6 to 2.4 m/s (2 to 8 ft/sec). For ESPs having aspect ratios of 1.5, the optimum gas velocity is usually between 1.5 and 1.8 m/s (5 and 6 ft/sec). The outlet of the ESP should also be carefully designed to provide even flow of the gas from the ESP to the stack without excessive pressure buildup. This can be done by using an expansion outlet, as shown in Figure 4-3. Figures 4-1 and 4-2 also have expansion outlets.

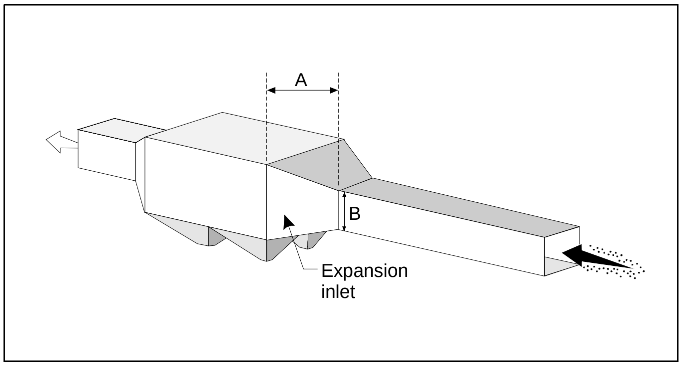


Figure 4-1. Straight-line inlet

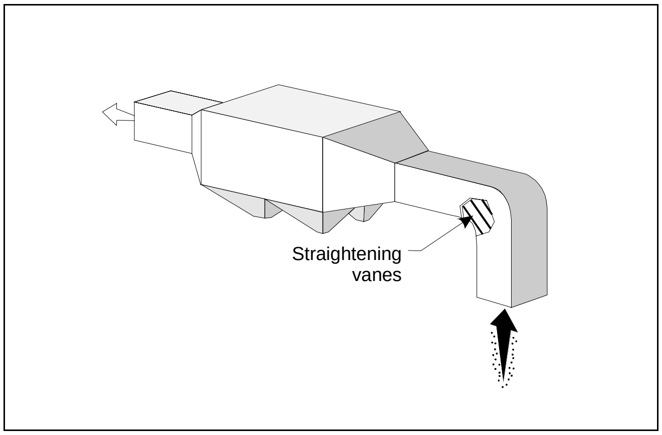


Figure 4-2. Straightening vanes in a curved inlet

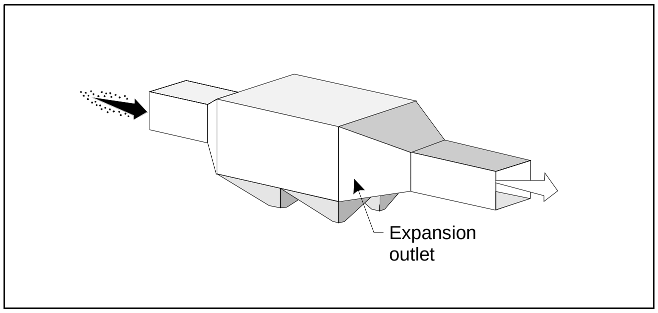


Figure 4-3. ESP with expansion outlet

The **hopper and discharge device** design including geometry, size, dust storage capacity, number, and location are important so that dust is removed on a routine basis. A well-designed dust hopper is sloped (usually 60°) to allow dust to flow freely to discharge devices. It includes access ports and strike plates to help move dust that becomes stuck. Dust should be only temporarily stored in the hopper and removed periodically by the discharge devices to prevent it from backing up into the ESP where it can touch the plates, possibly causing a cell to short out. In addition to the amount of fly ash present, there are a couple of special considerations to keep in mind when ESPs are used on coal-fired boilers. First, the amount of fly ash in the flue gas can vary depending on what type of coal is burned and the ash content of the coal. Coal having a higher ash content will produce more fly ash than coal having lower ash values. Consequently, the discharge device must be designed so that the operator can adjust the frequency of fly ash removal. Second, hoppers need to be insulated to prevent ash from "freezing," or sticking, in the hopper.

Finally, **emission regulations in terms of opacity and dust concentration (grain-loading) requirements** will ultimately play an important role in the final design decisions. Electrostatic precipitators are very efficient; collection efficiency can usually be greater than 99% if the ESP is properly designed and operated.

Typical Ranges of Design Parameters

While reviewing a permit for ESP installation, check whether the design specifications are within the range that is typically used by that industry. The ranges of basic design parameters for fly ash precipitators are given in Table 4-1.

Table 4-1. Typical ranges of design parameters for fly ash precipitators

Parameter	Range (metric units)	Range (English units)
Distance between plates (duct width)	20-30 cm (20-23 cm optimum)	8-12 in. (8-9 in. optimum)
Gas velocity in ESP	1.2-2.4 m/s (1.5-1.8 m/s optimum)	4-8 ft/sec (5-6 ft/sec optimum)
SCA	11-45 m^2/1000 m^3/h (16.5-22.0 m^2/1000 m^3/h optimum)	200-800 ft^2/1000 cfm (300-400 ft^2/1000 cfm optimum)
Aspect ratio (L/H)	1-1.5 (keep plate height less than 9 m for high efficiency)	1-1.5 (keep plate height less than 30 ft for high efficiency)
Particle migration velocity	3.05-15.2 cm/s	0.1-0.5 ft/sec
Number of fields	4-8	4-8
Corona power/flue gas volume	59-295 watts/1000 m^3/h	100-500 watts/1000 cfm
Corona current/ft^2 plate area	107-860 microamps/m^2	10-80 microamps/ft^2
Plate area per electrical (T-R) set	465-7430 m^2/T-R set (930-2790 m^2/T-R set optimum)	5000-80,000 ft^2/T-R set (10,000-30,000 ft^2/T-R set optimum)

Source: White 1977.

Estimating Collection Efficiency and Collection Area

The manufacturer designs and sizes the electrostatic precipitator. However, the operator (or reviewer) needs to check or estimate the collection efficiency and the amount of collection area required for a given process flow rate. You can compute these estimates by using the Deutsch-Anderson or Matts-Ohnfeldt equations (see Lesson 3). These equations are repeated in Table 4-2.

Table 4-2. Equations used to estimate collection efficiency and collection area

Calculation	Deutsch-Anderson	Matts-Ohnfeldt
Collection efficiency	$\eta = 1 - e^{-w(A/Q)}$	$\eta = 1 - e^{-w_k(A/Q)^k}$
Collection area (to meet a required efficiency)	$A = \frac{-Q}{w}[\ln(1-\eta)]$	$A = \left[-\left(\frac{Q}{w_k}\right)^k[\ln(1-\eta)]\right]^{1/k}$
Where:	η = collection efficiency A = collection area w = migration velocity Q = gas flow rate ln = natural logarithm	η = collection efficiency A = collection area w_k = average migration velocity k = constant (usually 0.5) ln = natural logarithm

Example Estimation

The exhaust rate of the gas being processed is given as 1,000,000 ft^3/min. The inlet dust concentration in the gas as it enters the ESP is 8 gr/ft^3. If the emission regulations state that the outlet dust concentration must be less than 0.04 gr/ft^3, how much collection area is required to meet the regulations? Use the Deutsch-Anderson equation for this calculation and assume the migration velocity is 0.3 ft/sec.

1. **From Table 4-2, use this version of the Deutsch-Anderson equation to solve the problem**:

$$A = \frac{-Q}{w}[\ln(1-\eta)]$$

Where: A = collection area, ft^2
Q = gas flow rate, ft^3/sec
w = migration velocity, ft/sec
η = collection efficiency
ln = natural logarithm

In this example,

$$\begin{aligned} Q &= 1{,}000{,}000\ ft^3/min \times 1\ min/60\ sec \\ &= 16{,}667\ ft^3/sec \\ w &= 0.3\ ft/sec \end{aligned}$$

2. **Calculate the collection efficiency, η.**

$$\begin{aligned} \eta &= \frac{dust_{in} - dust_{out}}{dust_{in}} \\ &= \frac{8\ gr/ft^3 - 0.04\ gr/ft^3}{8\ gr/ft^3} \\ &= 0.995 \text{ or } 99.5\% \end{aligned}$$

3. **Calculate the collection area, A, in ft^2.**

$$\begin{aligned} A &= \frac{-16{,}667\ ft^3/sec}{0.3\ ft/sec}[\ln(1-0.995)] \\ &= (-55{,}557\ ft^2) \times [-5.2983] \\ &= 294{,}358\ ft^2 \end{aligned}$$

Estimating Capital and Operating Costs

This section contains generalized cost data for ESP systems described throughout this guidebook. These data should be used only as an estimate to determine system cost. The total capital investment (TCI) includes costs for the ESP structure, the internals, rappers, power supply, and auxiliary equipment, and the usual direct and indirect costs associated with installing or erecting new structures. These costs, given in second-quarter 1987 dollars, are described in the following subsections.

ESP Equipment Cost

Most of the following cost discussion is taken from the EPA *OAQPS Cost Control Manual* (1990). Costs for rigid-electrode, wire and plate, and flat-plate ESPs can be estimated using Figure 4-4. Costs for two-stage precipitators are given later.

Figure 4-4 represents two cost curves (the two in the middle) along with their respective equations (outer lines with arrows). Each curve requires two equations for calculating cost: one for total plate areas between 10,000 and 50,000 ft^2 and another for total plate areas between 50,000 and 1,000,000 ft^2. The lower curve shows the cost for the basic unit without the standard options. It represents the flange-to-flange, field-erected price for a rigid-electrode design. The upper curve includes all of the standard options (listed in Table 4-3) that are normally used in a modern system. All units (both curves) include the ESP casing, pyramidal hoppers, rigid electrodes and internal collection plates, transformer-rectifier (T-R) sets and microprocessor controls, rappers, and stub supports (legs) for 4-foot clearance below the hopper discharges. The costs are based on a number of actual quotes that have been fitted to lines using the “least squares” method. Don’t be surprised if you obtain quotes that differ from these curves by as much as ±25%. (Significant savings can be obtained by solicitating multiple quotes.) The equations should not be used to extrapolate costs for total plates areas below 10,000 or above 1,000,000 ft^2. The standard options included in the upper curve add approximately 45% to the basic cost of the flange-to-flange hardware. Insulation costs are for 3 inches of field-installed glass fiber encased in a metal skin and applied on the outside of all areas in contact with the exhaust gas stream. Calculate insulation for ductwork, fan casings, and stacks separately. To obtain more accurate results, solve the equations for the lines instead of reading the values from the graph.

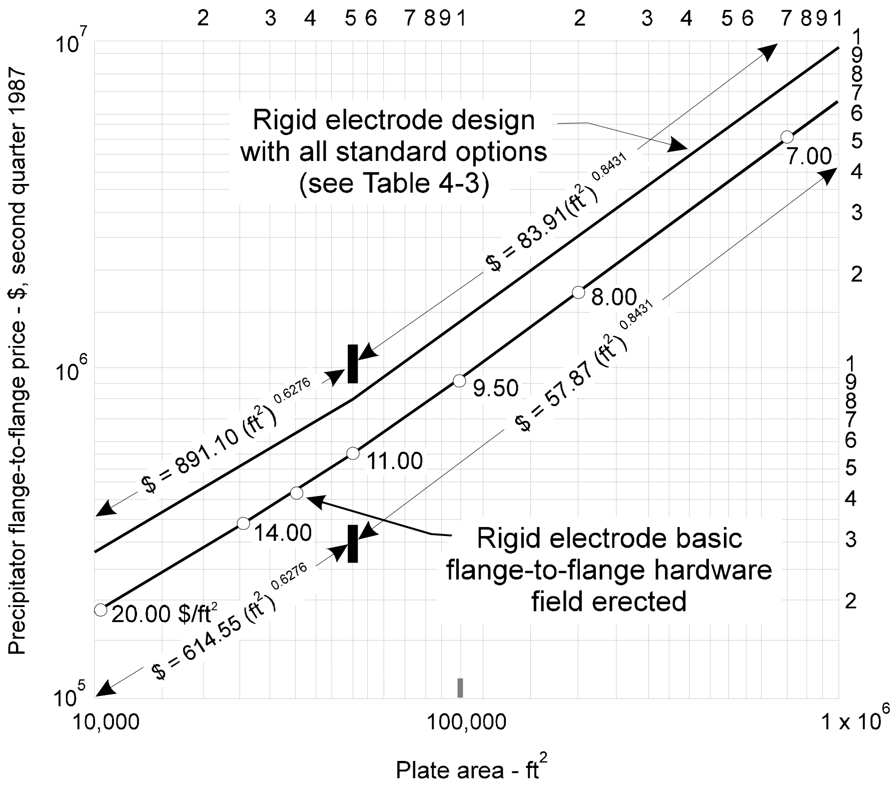


Figure 4-4. Dry-type rigid electrode ESP flange-to-flange purchase price versus plate area

Table 4-3. Standard options for basic equipment

Item	Cost Adder, %
1. Inlet and outlet nozzles and diffuser plates	8 to 10
2. Hopper auxiliaries/heaters, level detectors	8 to 10
3. Weather enclosure and stair access	8 to 10
4. Structural supports	5
5. Insulation	8 to 10
Total options 1 to 5	1.37 to 1.45 × base

Impact of Alternative Electrode Designs

All three designs—rigid electrode, weighted wire, and rigid frame—can be employed in most applications. Any cost differential between designs will depend on the combination of vendor experience and site-specific factors that dictate equipment size factors. The rigid-frame design will cost up to 25% more than the wire and plate design if the plate height is restricted to that used in wire/plate designs. Several vendors can now provide rigid-frame ESPs with taller plates, and thus the cost differential can approach zero.

The weighted wire design uses narrower plate spacings and more internal discharge electrodes. This design is being used less; therefore, its cost is increasing and currently is approximately the same as that for the rigid electrode ESP. Below about 15,000 ft^2 of plate area, ESPs are not normally field-erected (erected at the installation site), and the costs will probably be higher than values extrapolated from Figure 4-4.

Impact of Materials of Construction: Metal Thickness and Stainless Steel

Corrosive or other adverse operating conditions may require specifications of thicker metal sections in the precipitator. Metal thickness can be moderately increased with minimal cost increases. For example, collection plates are typically constructed of 18-gauge mild steel. Most ESP manufacturers can increase the section thickness by 25% without significant design changes or increases in manufacturing costs of more than a few percent.

Changes in the type of material can increase the purchase cost of the ESP significantly. Using type 304 stainless steel instead of 18-gauge mild steel for collection plates and precipitator walls can increase costs 30-50%. Using even more expensive materials for all elements of the ESP can increase costs up to several hundred percent. Based on the carbon steel 18-gauge cost, the approximate factors given below can be used for other materials.

Table 4-4. ESP costs using various materials

Factor	Material
1.0	Carbon Steel, 18-gauge
1.3	Stainless Steel, 304
1.7	Stainless Steel, 316
1.9	Carpenter 20 CB-3
2.3	Monel-400
3.2	Nickel-200
4.5	Titanium

Source: U.S. EPA 1991.

Recent Trends

Most of today's market (1987) is in the 50,000 to 200,000 ft^2 plate area size range. ESP selling prices have increased very little over the past 10 years because of more effective designs, increased competition from European suppliers, and a shrinking utility market.

Design improvements have allowed wider plate spacings that reduce the number of internal components and higher plates and masts that provide additional plate area at a low cost. Microprocessor controls and energy management systems have lowered operating costs.

Few, if any, hot-side ESPs (those used upstream from an air preheater on a combustion source) are being specified for purchase. Recognition that low-sodium coals tend to build resistive ash layers on the collection plates, thus reducing ESP efficiency, has almost eliminated sales of hot-side units. Of the 150 existing units, about 75 are candidates for conversion to cold-side units (using resistivity conditioning agents) over the next 10 years (U.S. EPA 1990).

Specific industry application has little impact on either ESP design or cost, with the following three exceptions: paper mills, sulfuric acid manufacturing plants, and coke by-product plants. Because paper mills have dust that can be sticky and difficult to remove, paper mill ESPs use drag conveyer hoppers. These hoppers increase the cost by approximately 10 percent of the base flange-to-flange equipment cost. For emissions control in sulfuric acid plants and coke by-product ovens, wet ESPs are used. In sulfuric acid manufacture, wet ESPs are used to collect acid mist. These precipitators usually are small and use lead for all interior surfaces; hence, they normally cost \$65 to \$95/ft^2 of collecting area installed (mid-1987 dollars) and up to \$120/ft^2 in special situations. Using Figure 4-4, the standard cost for a rigid-frame ESP ranges from \$7 to \$14/ft^2 of collecting area. In addition, a wet circular ESP is typically used to control emissions from a coke oven off-gas detarring operation. These precipitators are made from high-alloy stainless steels and typically cost \$90 to \$120/ft^2 installed. Because of the small number of sales, small size of units sold, and dependency of site-specific factors, more definitive costs are not available.

Retrofit Cost Factor

Retrofit installations increase the cost of an ESP because of the frequent need to remove something to make way for the new ESP. Also, the ducting usually is much more expensive as a retrofit application because the ducting path is often constrained by existing structures, additional supports are required, and the confined areas make erection more labor intensive and lengthy. Costs are site-specific; however, for estimating purposes, a retrofit multiplier of 1.3 to 1.5 applied to the total capital investment can be used. The multiplier should be selected within this range based on the relative difficulty of the installation.

A special case is the conversion of a hot-side to a cold-side ESP for coal-fired boiler applications. The magnitude of the conversion is very site-specific, but most projects will contain the following elements:

- Relocating the air preheater and the ducting to it
- Resizing the ESP inlet and outlet duct to the new air volume and rerouting it
- Upgrading the ID (induced draft) fan size or motor to accommodate the higher static pressure and horsepower requirements
- Adding or modifying foundations for fan and duct supports
- Assessing the required SCA and either increasing the collecting area or installing an SO_3 gas-conditioning system
- Adding hopper heaters
- Upgrading the analog electrical controls to microprocessor-type controls
- Increasing the number of collecting plate rappers and perhaps the location of rappers

In some installations, it may be cost-effective to gut the existing collector totally, utilize only the existing casing and hoppers, and upgrade the ESP using modern internal components. The cost of conversion is a multimillion dollar project typically running at least 25 to 35 percent of the total capital investment of a new unit.

Costs for Two-Stage Precipitators

Purchase costs for modular, two-stage precipitators should be considered separately from large-scale, single-stage ESPs (see Figure 4-5). To be consistent with industry practice, costs are given as a function of flow rate through the system. The lower cost curve is for a two-cell unit without a precooler, installed cell washer, and a fan. The upper curve is for an engineered package system with the following components: inlet diffuser plenum, prefilter, cooling coils with coating, coil plenums with access, water-flow controls, triple-pass configuration, system exhaust fan with accessories, outlet plenum, and in-place foam cleaning system with semiautomatic control and programmable controller. All equipment is fully assembled mechanically and electrically, and it is mounted on a steel structural skid.

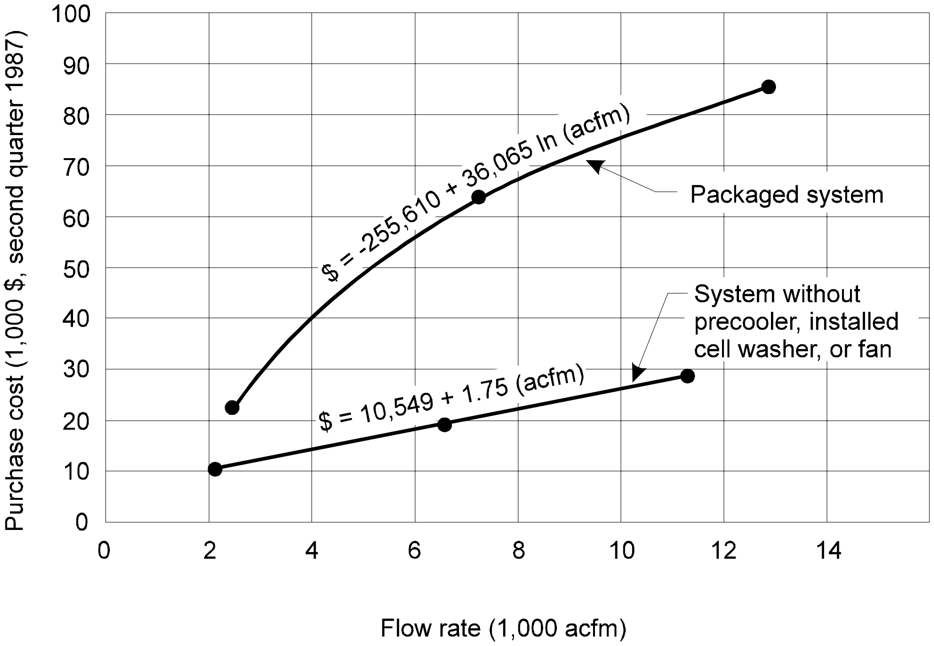


Figure 4-5. Purchase costs for two-stage, two-cell precipitators

Total Purchase Cost

The total purchase cost of an ESP system is the sum of the costs of the ESP, options, auxiliary equipment, instruments and controls, taxes, and freight. The last three items generally are taken as percentages of the estimated total cost of the first three items. Typical values are 10% for instruments and controls, 3% for taxes, and 5% for freight.

Costs of standard and other options can vary from 0% to more than 150% of ESP base cost, depending on site and application requirements. Other factors that can increase ESP costs are given in Table 4-5.

Table 4-5. Items that increase ESP costs

Item	Factor or Total Cost	Applied to
Rigid-frame electrode with restricted plate height	1.0-1.25	ESP base cost
Type 304 stainless-steel collector plates and precipitator walls	1.3-1.5	ESP base cost
All-stainless construction	2-3	ESP base cost
ESP with drag conveyor hoppers (paper mill)	1.1	ESP base cost
Retrofit installations	1.3-1.5	ESP base cost
Wet ESP		
Sulfuric acid mist	\$65-\$95/ft^2	-
Sulfuric acid mist (special installation)	Up to \$120/ft^2	-
Coke oven off-gas	\$90-\$120/ft^2	-

Source: U.S. EPA 1990.

Total Capital Investment

Total capital investment (TCI) is estimated from a series of factors applied to the purchased equipment cost (PEC) to obtain direct and indirect costs for installation. The TCI is the sum of the direct costs (equipment and installation) and indirect costs. The required factors are given in Table 4-6. Because ESPs can vary from small units attached to existing buildings to large, separate structures, specific factors for site preparation or for buildings are not given. However, costs for buildings and materials may be obtained from references such as *Means Square Foot Costs 1987*. Land, working capital, and off-site facilities are excluded from the table because they are required only for very large installations. However, they can be estimated on an as-needed basis.

Note that the factors given in Table 4-6 are for average installation conditions, and for example, include no unusual problems with site earthwork, access, shipping, or interfering structures. Considerable variation may be seen with other-than-average installation circumstances. For two-stage precipitators purchased as packaged systems, several of the costs in Table 4-6 would be greatly reduced or eliminated. These include instruments and controls, foundations and supports, erection and handling, painting, and model studies. An installation factor of 0.25 of the PEC (instead of 0.67 PEC) would be more nearly appropriate for the two-stage ESPs.

Table 4-6. Capital cost factors for ESPs

Cost Item	Factor
Direct Costs	
Purchased equipment costs	
ESP + auxiliary equipment	As estimated, EC
Instruments	0.10 EC
Sales taxes	0.03 EC
Freight	0.05 EC
Purchased equipment cost, PEC	PEC = 1.18 EC
Direct installation costs	
Foundation and supports	0.04 PEC
Handling and erection	0.50 PEC
Electrical	0.08 PEC
Piping	0.01 PEC
Insulation for ductwork[1]	0.02 PEC
Painting	0.02 PEC
Direct installation costs	0.67 PEC
Site preparation	As required, SP
Buildings	As required, Bldg.
Total Direct Costs DC	1.67 PEC + SP + Bldg.
Indirect Costs (installation)	
Engineering	0.20 PEC
Construction and field expense	0.20 PEC
Contractor fees	0.10 PEC
Start-up fee	0.01 PEC
Performance test	0.01 PEC
Model study	0.02 PEC
Contingencies	0.03 PEC
Total Indirect Costs IC	0.57 PEC
Total Capital Cost = DC + IC	2.24 PEC + SP + Bldg.

[1] If ductwork dimensions have been established, cost may be estimated based on \$10 to \$12/ft^2 of surface for field application.

Source: U.S. EPA 1990.

Example

A basic, flat-plate, rigid-electrode ESP, requiring a plate area of 40,800 ft^2, is proposed. The manufacturer recommends using 304 stainless steel for the discharge electrodes and collection plates due to the corrosive nature of the flue gas. Assume that the auxiliary equipment costs \$10,000.

Using Figure 4-4 and Tables 4-4 and 4-6, estimate the following:

1. Equipment cost (EC)
2. Purchased equipment cost (PEC)
3. Total capital cost of purchasing and installing the ESP

1. **Estimate the equipment cost**. Because the ESP is a basic, rigid-frame ESP without the standard options, the lower line from Figure 4-4 is used to obtain the capital cost. Using a collection area of 40,800 ft^2, a cost of $470,000 can be read from Figure 4-4. But this cost figure assumes that the ESP discharge electrodes and collection plates are made out of carbon steel material. As stated in Table 4-4, the cost factor for 304 stainless steel is 1.3. The equipment cost is:

$470,000 × 1.3	=	$611,000
Auxiliary equipment cost	=	<u>$10,000</u>
Equipment cost (EC)	=	$621,000

2. **Estimate the purchased equipment cost (PEC) using the cost factors in Table 4-6** (some calculations are rounded).

Equipment cost (EC)	=	$621,000
Instrumentation (0.10 × 621,000)	=	$62,100
Sales Tax (0.03 × 621,000)	=	$18,600
Freight (0.05 × 621,000)	=	<u>$31,100</u>
Purchased equipment cost (PEC)	=	<u>$732,800</u>

3. **Estimate the total capital cost**. Knowing the PEC and using the cost factors in Table 4-6, you can estimate the remaining direct and indirect costs, which make up the total capital cost. A summary of these costs are provided in Table 4-7.

Table 4-7. Example case capital costs

Cost Item	Factor	Cost(s)
Direct Costs		
Purchased equipment costs		
ESP + auxiliary equipment	As estimated, EC	$621,000
Instruments	0.10 EC	62,100
Sales taxes	0.03 EC	18,600
Freight	0.05 EC	31,100
Purchased equipment cost, PEC	PEC = 1.18 EC	$732,800
Direct installation costs		
Foundation and supports	0.04 PEC	$29,300
Handling and erection	0.50 PEC	367,000
Electrical	0.08 PEC	58,600
Piping	0.01 PEC	7,330
Insulation for ductwork[1]	0.02 PEC	14,700
Painting	0.02 PEC	14,700
Direct installation costs	0.67 PEC	$491,630
Site preparation	As required, SP	
Buildings	As required, Bldg.	
Total Direct Cost, DC	1.67 PEC + SP + Bldg.	$1,224,430
Indirect Costs (installation)		
Engineering	0.20 PEC	$147,000
Construction and field expense	0.20 PEC	147,000
Contractor fees	0.10 PEC	73,300
Start-up fee	0.01 PEC	7,330
Performance test	0.01 PEC	7,330
Model study	0.02 PEC	14,700
Contingencies	0.03 PEC	22,000
Total Indirect Cost, IC	0.57 PEC	$418,660
Total Capital Cost = DC + IC	2.24 PEC + SP + Bldg.	$1,643,090

[1] If ductwork dimensions have been established, cost may be estimated based on $10 to $12/ft^2 of surface for field application.

Summary

Some key factors that affect the design of an ESP include the following:

- Type of discharge electrode
- Type of collection electrode
- Electrical sectionalization
- Specific collection area
- Aspect ratio

We also covered how to estimate the cost of ESPs. These estimates can be used as budgetary estimates by facilities planning to install an ESP or by agency engineers for reviewing permit applications.

Review Exercise

1. Two important process variables to consider when designing an ESP are the gas ____________________ ____________________ and the dust ____________________.

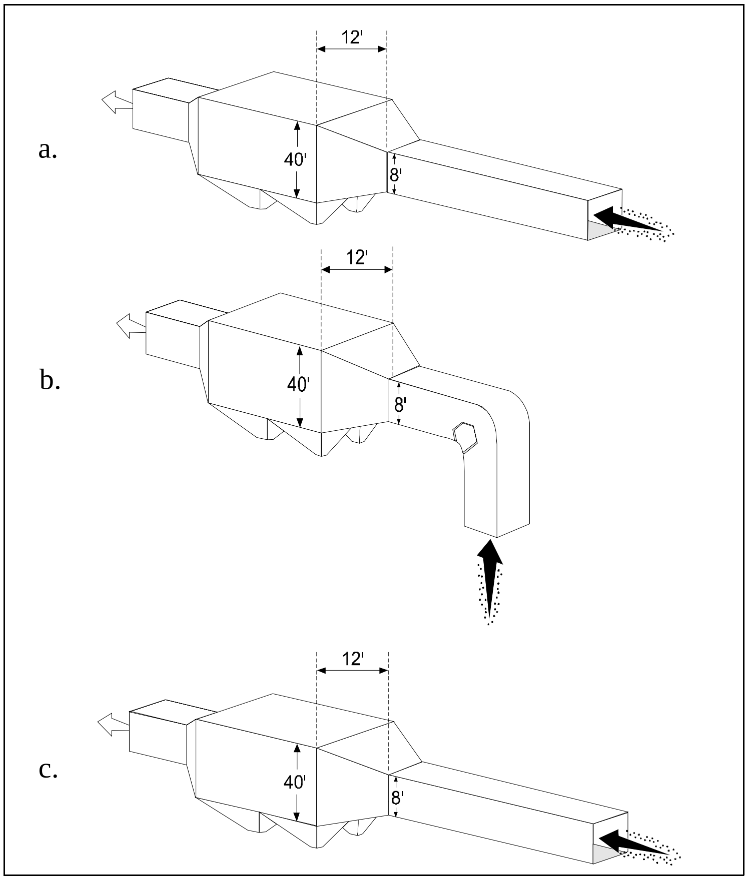
2. In an ESP, the amount of dust coming into the ESP is important. If the dust loading is very high it will:

   a. Suppress the current in the inlet field and cause the controller to drive up the voltage
   b. Increase the current in the inlet field and cause the controller to decrease the voltage
   c. Cause an increase in the dust resistivity
   d. Have no effect on the ESP performance

3. If coal burned in a boiler has a low sulfur content, the resulting dust will usually have ____________________ resistivity.

   a. High
   b. Low

4. Which of the drawings below shows a good design of an inlet into the ESP?



5. True or False? Dust can be stored in hoppers for any length of time without causing problems.

6. An ESP has a collection area of 750,000 ft^2 and filters fly ash from flue gas flowing at 1,500,000 ft^3/min. The migration velocity of the dust is 0.25 ft/sec. Estimate the collection efficiency of the ESP using the Deutsch-Anderson equation.

$$\eta = 1 - e^{-w(A/Q)}$$

7. The design plan states that an ESP will filter fly ash from flue gas that has a dust loading of 2 gr/ft^3 and a flow rate of 2,000,000 acfm (ft^3/min). The dust migration velocity is 0.3 ft/sec. If the regulations state that the emissions must be less than 0.02 gr/ft^3, what is the total collection area needed for the ESP design? Use the Deutsch-Anderson equation.

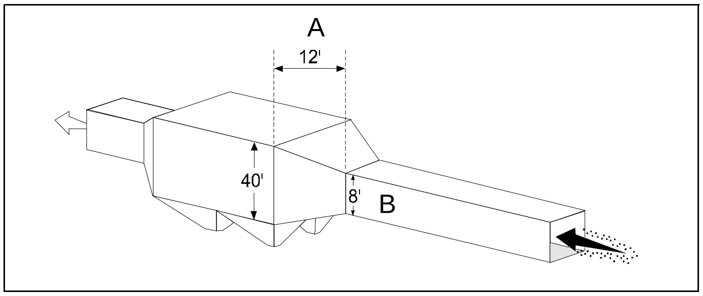
Review Exercise Answers

1. **Flow rate**
   Concentration
   Two important process variables to consider when designing an ESP are gas flow rate and dust concentration.

2. **a. Suppress the current in the field and cause the controller to drive up the voltage**
   In an ESP, the amount of dust coming into the ESP is important. If the dust loading is very high it will suppress the current in the inlet field and cause the controller to drive up the voltage.

3. **a. High**
   If coal burned in a boiler has a low sulfur content, the resulting dust will usually have high resistivity.

4. **c.**



The figure in option "c" shows the best inlet design because it has a straight-on inlet and an inlet plenum with a distance of A as long as (or longer than) B. Option "b" is fine if there are straightening vanes in the duct.

5. **False**
   Dust can NOT be stored in hoppers for any length of time without causing problems. Dust should be stored temporarily in the hopper and removed periodically by the discharge device to prevent the dust from backing up into the ESP.

6. **99.94%**
   Solution:
   Calculate the collection efficiency using the Deutsch-Anderson equation:

$$\eta = 1 - e^{-w(A/Q)}$$

Where: w = 0.25 ft/sec × 60 sec/min = 15 ft/min
A = 750,000 ft^2
Q = 1,500,000 $\text{ft}^3\text{/min}$

$$\begin{aligned}\eta &= 1 - e^{-15\,\text{ft/min}(750{,}000\ \text{ft}^2/1{,}500{,}000\ \text{ft}^3/\text{min})}\\ &= 1 - 0.00055\\ &= 0.9994 \text{ or } 99.94\%\end{aligned}$$

7. **512,000 ft^2**

   Solution:

   1. Using equation 4-1, calculate the collection efficiency required to meet emissions regulations.

$$\eta = \frac{2\text{gr}/\text{ft}^3 - 0.02\text{gr}/\text{ft}^3}{2\text{gr}/\text{ft}^3}$$

$$= 0.99 \text{ or } 99\%$$

   2. Calculate the total collection area needed, using the following form of the Deutsch-Anderson equation:

$$A = \frac{-Q}{w}[\ln(1-\eta)]$$

Where: w = 0.3 ft/sec × 60 sec/min = 18 ft/min
Q = 2,000,000 ft^3/min
η = 0.99

$$A = \frac{-2{,}000{,}000\ \text{ft}^3/\text{min}}{18\ \text{ft}/\text{min}}[\ln(1-0.99)]$$

$$= 512{,}000\ \text{ft}^2$$

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