EPA/452/B-02-001

Section 2

Generic Equipment and Devices

EPA/452/B-02-001

Chapter 4

Monitors

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October 2000

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4.1 Introduction

Emissions monitoring is an increasingly important part of air pollution control. Air pollution legislation often takes the form of emissions limits or guidelines which an industrial process must meet. Monitoring demonstrates compliance with regulatory or permit limits. In addition, monitoring provides information regarding gaseous pollutants and particulate matter released into the atmosphere that can be used for compiling emissions inventory data, permitting new and existing facilities, and performing audits. Industrial facilities can use emissions monitoring to assess and monitor process control and efficiency, to determine pollution control device efficiency, and to monitor health and safety within the plant. Participation in emissions trading programs generally requires emissions monitoring.

The term monitor refers to a wide variety of instrumentation used to measure the concentration of both gaseous compounds, particulate matter and physical properties such as opacity in a waste gas stream. There are many different types of monitors commercially available for emissions monitoring. Monitors generally require additional equipment for sample collection, calibration of instruments, and data acquisition and processing. Monitors must be able to provide accurate reproducible data.

The 1990 Clean Air Act required enhanced and periodic monitoring for specific pollutants at various stationary sources. These requirements were codified in the Compliance Assurance Monitoring (CAM) Rule. Emissions units with air pollution control equipment at sources regulated under Title V are required to have CAM. CAM requires a modification to the Title V permit to include a program to establish monitoring adequate to demonstrate compliance with applicable regulations. Title V recordkeeping and reporting requirements apply to CAM affected units. States have flexibility in establishing adequate CAM approaches.

Under the CAM Rule, there are two viable monitoring options for monitoring source compliance with permits or regulations. The first option is **continuous emissions monitoring** (CEM), which is a direct measurement of pollutant concentration from a duct or stack on a continuous or periodic basis. The second option is **parametric monitoring**, which involves indirect measurement of emissions by monitoring key parameters related to the operating status of air pollution control equipment or process equipment. Parametric monitoring requires demonstration that the process or control parameters being monitored correlate to measured pollutant emission levels.

CEM is required for large sources or sources that have monitoring requirements under New Source Review (NSR), New Source Performance Standard (NSPS), National Emissions Standards for Hazardous Air Pollutants (NESHAPS), or other State requirements. CEM is required under some of the EPA regulations for either continual compliance determinations or determination of exceedances of the standards. [1] Parametric monitoring is more frequently used at small emission sources. As a result of the CAM Rule, parametric monitoring is becoming increasingly important. Use of parametric monitoring can provide more flexible and less expensive options for demonstrating compliance for regulated sources.

Selecting the proper monitoring equipment or parametric method involves more than basic cost and performance comparisons. Operational conditions vary from facility to facility for a given source category, making the choice of monitoring equipment unique to each installation. The choice of monitoring system depends on the following [Clarke, 1998] considerations:

- physical/chemical properties of the pollutant and waste gas stream,
- regulatory or permitting limits and any associated reporting requirements,
- location and method of collecting, processing, and disposing of samples,
- calibration and accuracy requirements,
- quality assurance and quality control requirements,
- maintenance requirements, and
- facility safety and management.

This chapter describes cost estimation methods for monitoring equipment used to determine compliance status under the Clean Air Act.

4.2 Continuous Emissions Monitoring Systems

A continuous emission monitoring system(s) (CEMS) is an integrated system that demonstrates source compliance by collecting samples directly from the duct or stack discharging pollutants to the atmosphere. A CEMS consists of all the equipment necessary for the determination of a gas or particulate matter concentration or emission rate. This includes three basic components:

- the sampling and conditioning system,
- the gas analyzers and/or monitors, and
- data acquisition system (DAS) and controller system.

A CEMS can be designed to monitor a single pollutant or multiple pollutants and waste gas stream parameters. Gaseous compounds, particulate matter, opacity, and volumetric flow rate are typically monitored by CEMS. Figure 4.1 depicts a typical CEMS layout for multiple parameter monitoring.

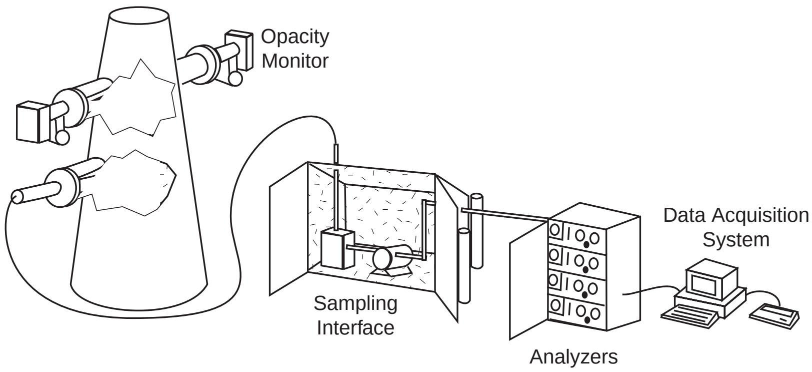

Figure 4.1: Typical CEMS for Multiple Parameter Monitoring

Proper placement of sampling ports in the waste gas stream and proper equipment selection for the components are all critical for the collection of accurate and reproducible information from a CEMS. For this reason, the design of a CEMS is usually based on vendor experience and, therefore, vendor-specific. Most systems are provided on a "turn key" basis where the vendor supplies, installs, and and tests all necessary equipment [18].

EPA has published standard methods for installing, operating and testing CEMS. EPA rules specify the reference methods that are used to substantiate the accuracy and precision of the CEMS. The EPA also maintains performance specifications used for evaluating the acceptability of the CEMS after installation. Finally, the rules provide quality assurance and control procedures to evaluate the quality of data produced by CEMS once in operation [18]. The data produced under these standard or reference methods are direct and enforceable measurements of emissions.

4.2.1 Sampling Systems

CEMS are divided into two major categories, extractive and in situ. **In situ** CEMS typically have monitors and/or analzyers located directly in the stack or duct. **Extractive** CEMS capture a sample from the duct or stack, condition the sample by removing impurities and water, and transport the sample to an analyzer in a remote, environmentally protected area. Some monitoring system designs may employ both types of systems. The two systems are discussed in greater detail in the next sections.

All sampling systems need programmable logic controllers (PLCs) to link the sampling equipment to both monitors and DAS. PLCs are generally modular in design and used widely throughout industry. Typical functions of PLCs are:

- Logic timing
- Counting
- Data transfer
- Triggering automatic functions
- Providing analog to digital signal conversion
- Registering alarms
- Data logging
- Perform mathematical calculations or calibration functions

In CEMS applications, PCLs manage sampling and calibration by controlling solenoid valves that send either waste gas or calibration gas to the monitor. This information is also sent to the DAS to prevent calibration data from inadvertently being used as sample data. PLCs typically control functions such as zero and span checks, alarms for excess emissions or system malfunctions and interfacing with the DAS.

4.2.1.1 Extractive CEMS

In an extractive CEMS, the system extracts a sample at a specified site in the waste gas stream and then transports it to a monitor in an environmentally protected area. This type of system protects the monitoring instrumentation from the high temperatures, high velocities, high pressures, particulate matter, corrosive substances, and water vapor in the waste gas stream.

A sample is transported from the sampling probe location to the analyzer or monitor. In general, the sample requires some form of conditioning prior to analysis. Conditioning can include, filtering of particulate mater, removal of water vapor, cooling of the sample, and dilution of the sample. Extractive systems are generally classified based on the type of conditioning: hot-wet, cool-dry, or dilution. **Hot-wet systems** maintain the sample at high temperature and do not remove water vapor. **Cool-dry systems** lower the sample temperature and remove water vapor. **Dilution systems** sample at low flow rates or dilute the sample prior to analysis which results in lower water vapor and particulate matter content. Conditioning may be performed at the port or at the analyzer. Depending on the type of system, extractive CEMS sampling and conditioning equipment can include sampling probe/port, sampling transfer lines, line heaters, a pump, a filter, a condenser or dryer, and chillers. The choice of sampling system type is application-specific [18.] Figure 4.2 shows a typical extractive system with a cool-dry sampling system.

Extractive analyzers are typically less expensive and easier to maintain and repair than in situ analyzers. This is primarily due to their location in an environmentally controlled room at ground level, rather than at the source. Due to their location they do not require additional environmental protection. In addition, the analyzers are easily accessible to technicians for maintenance and repair. Having an environmentally controlled room also allows the calibration gasses and systems to be located in the same area, which simplifies calibrations.

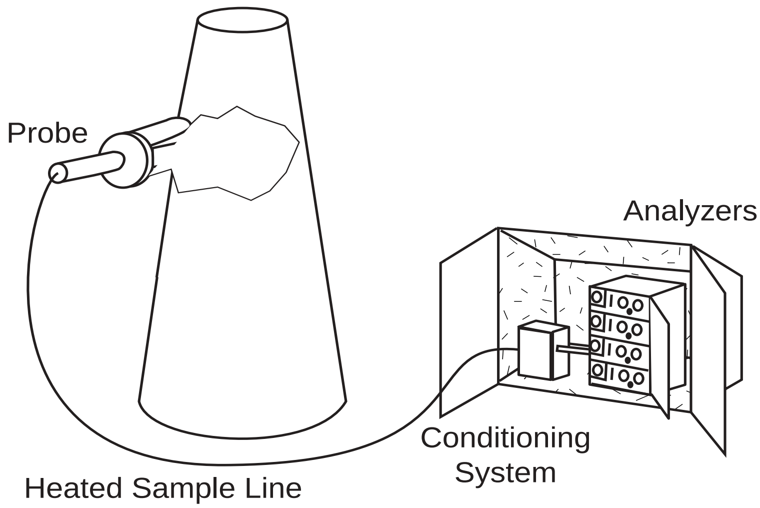

Figure 4.2: Example of an Extractive CEMS with Cool-Dry Sample

However, the advantages of extractive CEMS can be offset by the requirements of the sampling system. Initial costs of sampling systems can be quite high, and sampling and conditioning equipment requires routine maintenance. Other sample handling problems include:

ï Probes and lines clogging with contamination,
ï Heated lines failing in cold climates causing water to freeze and block lines,
ï Probe filter causing loss of pollutant as it passes through the probe media (scrubing),
ï Dilution probe causing temperature, pressure, gas density effects, and water droplet evaporation when dilution air is added to the sample gas,
ï Water entrainment,
ï Leaks in the tubing or elsewhere in the system,
ï Adsorption of pollutant to the wall, filter, tubing or other components, and
ï Absorption of pollutant to the water which is removed by a conditioning systems.

Other important factors in selection and design of monitoring systems include:

- Regulatory requirements;
- Data availability (% time monitor supplies data)
- Volume of waste gas must which must be collected and conditioned [18].

There are a number of commercially available CEMS monitors and gas analyzers available, including several multi-pollutant analyzers. This manual provides costs for the following types of extractive CEMS given in Table 4.1:

Table 4.1: Pollutant Monitoring Capability for Commercially Available Extractive CEMS

Gaseous Compound Analyzers	Monitors
NO_x	Opacity
SO_2	PM
$COCO_2$	Flow Rate
O_2	
THC	
HCl	

4.2.1.2 In Situ CEMS

In situ CEMS are systems where the analyzer is physically located in the stack or duct. The effluent gas is measured in situ as it flows through a sampling location placed in the stack or duct. Two types of in situ measurements are possible: point (in-stack) and path (cross-stack). **Point** measurements take place at the precise point where the sampling cell is located. **Path** measurements are taken across a given path in the emissions stream. Most path measurements are taken by sending a signal across the stack and reflecting it back to a detector near the source of the signal. The emissions crossing that path are then averaged over a given period of time. Figure 4.3 depicts a typical in situ CEMS.

In situ monitors require durable construction and are generally enclosed in sturdy, sealed cabinets to protect them from extreme temperatures, moisture and corrosive gases. As a result, in situ monitors are generally more expensive than comparable extractive monitors.

The primary advantage of in situ monitors is the location of the monitor in close proximity to the sampling probe, which minimizes the loss of contaminate from leaks, absorption, and adsorption, and also eliminates the need for a complex and costly sampling and conditioning system.

Although in situ analyzers were developed to avoid maintenance and availability problems associated with the sampling systems used in extractive monitoring, some problems remain. Service, maintenance and replacement of in situ analyzers is more difficult than with extractive units due to their locations. Because the concentration of pollutants (especially particulate matter) in a stack is not uniform, placement of the in situ analyzer (like placement of the extractive analyzer's probe) is a critical consideration. The sampling probe can become contaminated or plugged. Although the problem of gas sample transportation to the monitor has been eliminated by in situ placement, the need to take calibration gas to the in situ analyzer has taken its place.

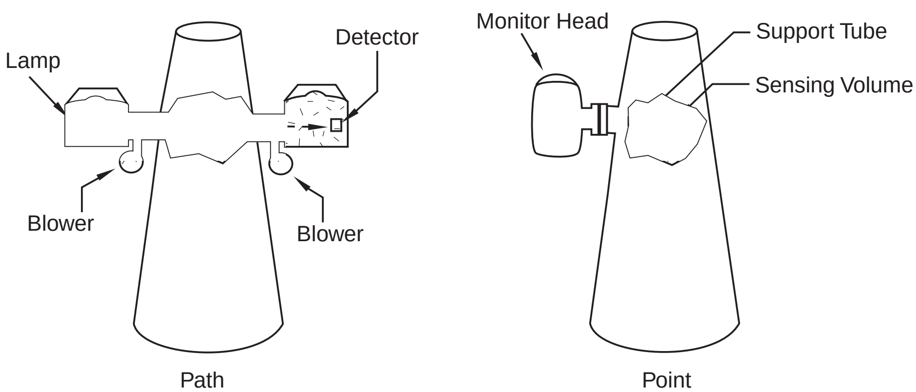

Figure 4.3: Example of an In Situ CEMS with Path and Point Sampling

There are a number of commercially available CEMS monitors and gas analyzers available, including several multi-pollutant analyzers. This manual provides costs for the following types of in situ CEMS given in Table 4.2:

4.2.2 Monitors and Gas Analyzers

A monitor is a device that senses or measures a physical/chemical property of a given substance such as light absorption. The sensor or measuring device generates an electrical output signal. Strip charts and/or computer data acquisition systems record the output signal, which correlates to a pollutant concentration or other parameter (e.g. flow rate) through an equation, graph, or more complicated mathematical relationship. CEMS convert results into units of the applicable emission standard and provide a record (typically a printed chart and/or an electronic data file). Many integrated systems also include a calibration system for gas analyzers that automatically performs and records the required calibrations on a periodic basis (e.g., daily).

Table 4.2: Pollutant Monitoring Capability for Commercially Available In Situ CEMS

Gaseous Analyzers Compound	Monitors
SO_2	Opacity
CO	PM
O_2	Flow Rate
SO_2/NO_x	
$SO_2/NO_x/O_2$	
CO/CO_2	

Older generation gas analyzers produced only a relative measurement (e.g., percent of full scale) that needed to be compared against the calibration gases before the stack concentration could be calculated. Many current generation analyzers can control and integrate calculation data allowing them to read actual stack concentrations on the front of the instrument. These analyzers may also perform data acquisition functions and communicate directly with computers that produce reports. The configurations and installation requirements vary widely between different analyzers and applications.

Critical factors in selecting the type of analyzer or monitor for a particular application include gas concentration, stack and ambient temperatures and the presence of contaminants that could damage or interfere with the sampling or analyzer systems. Other issues such as data availability requirements may influence analyzer selection or drive the need for two analyzers with one in a backup capacity. These issues impact equipment selection and can substantially impact capital, operating, and maintenance costs. As manufactures overcome past limitations, monitors and gas analyzers are becoming more versatile. The selection of a monitor and the cost analysis should be performed on a site-specific basis.

A technical discussion on the types of monitors and gas analyzers that are commercially available for extractive and in situ systems is beyond the scope of this document. Reference [18] provides a detailed technical discussion of gas analyzers and monitors for various types of CEMS and the pollutants and parameters that can be monitored. Table 4.3 and Table 4.4 summarize the various types of monitors that are currently available for extractive and in situ systems including both point and path type monitors. A discussion on selected monitors is provided below.

Fourier Transformation Infared Spectroscopy

Fourier Transformation Infrared Spectroscopy (FTIR) detects compounds based on the absorption of infrared light at critical wavelengths. The amount of absorption is dependant on the molecular bonds present in the waste gas compounds. This absorption creates a unique "fingerprint", or chemical signature, that can be analyzed to determine the compounds present and their concentrations. Current FTIR CEMs can accurately monitor up to six gaseous compounds (SO_2, NO_x, CO, HCl, CO_2, and O_2), various hazardous air pollutants, and volatile organic compounds simultaneously. Figure 4.4 illustrates a simplified schematic of an FTIR Analyzer. [4]

Current FTIR systems are primarily extractive sampling instruments and have similar installation requirements to extractive CEMS. Although FTIR instruments tend to be more expensive than other analyzers, the ability to monitor multiple pollutants with one instrument improves its cost effectiveness. As FTIR CEMS are a relatively new technology, there is little information on their long-term performance. Due to the precision of the instrument, maintenance requirements are high. Maintenance of a FTIR CEMS requires the following:

Table 4.3: Extractive CEMS Gas Analyzers [18]

Absorption Spectroscopic Methods (Infrared/Ultraviolet)	**Luminescence Methods**	**Electro Analysis Methods**	**Paramagnetic Methods**
Spectrophotometry	Fluorescence	Polargraphy	Thermomagnetic
Differential Absorption	Chemiluminescen	Potentiometry	Magnetodynamic
Gas Filter Correlation	Flame Photomete	Electrocatalysis	Magnetopuematic
Fouier Transform Infrared		Amperomatic	
		Conductimetric	

Table 4.4: In-Situ CEMS Gas Analyzers [18]

Gas Analyzers		**PM Monitors**	
Point	**Path**	**Point**	**Path**
Second Derivative	Differential Absorption	Light Back Scattering Absorption	
Polargraphy	Gas Filter Correlation	Ion Charge	Light Scattering and Absorption
Potentiometry		Nuclear Radiation	
Electrocatalysis			Attenuation

- Technical maintenance personnel
- High priced parts
- Lengthy calibration
- Short frequency

<u>Opacity Monitor</u>

Opacity monitors are in situ path devices based on the principle of transmissometry; the measurement of the transmission of light through a fluid. A light source of known frequency is generated by one of the following devices: LED, incandescent light, or laser. The opacity monitor then detects the decrease in light transmission across the stack due to particulate matter. Light absorption and scattering due to particulate matter in the gas stream is detected at a specified optical wavelength that minimizes absorption by other material in the stack gas. Interference caused by high levels of NO_2 and water droplets can reduce accuracy. An opacity monitor consists of a light source for generating the light, a transmissometer for accurately measuring the transmission of light, an internal reference system for calibration, and a data acquisition system for data collection. [3]

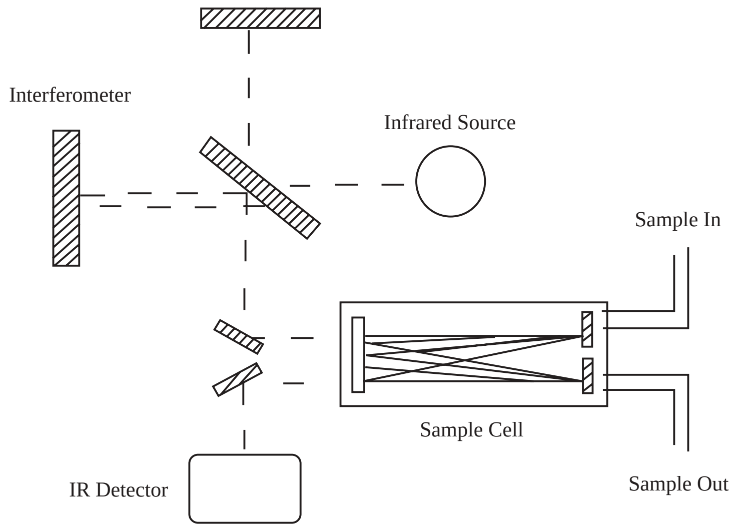

Figure 4.4: Simplified Schematic of an FTIR Analyzer [4]

Particulate Matter Monitor

The standard EPA reference methods for measuring PM are based on flowing a measured volume of waste gas across a particle filter and capturing the PM. The filter is weighed before and after exposure to determine the weight of PM in the measured volume of air. This technique is known as gravimetric measurent.

Particulate matter (PM) monitors are a relatively new technology, and, therefore, make use of newer techniques. Typical approaches include light scattering measurement, transmissometry (see opacity monitors), and other optical and electrostatic techniques. The method that comes closest to the gravimetric method is beta attenuation, where a strip of filter media is exposed to a known volume of the gas stream. The filter media then goes through a beta ray source and detector that measures the attenuation (absorbtion) of the beta source by the PM on the filter. This method is subject to variation due to high beta attenuation of heavy metal in the PM.

CEMS cannot replicate the EPA method, and, therefore, rely on surrogate measures of PM concentration, such as the optical or electrostatic characteristics of the PM in their path. For processes where the PM and other stack characteristics are constant, a calibrated instrument can provide reasonable accuracy. In application such as hazardous waste incinerators, where the gas stream can vary substantially, the potential for inaccuracy increases.

PM monitoring is an advancing technology, and changes in techniques and instrumentation are likely to occur quickly. These changes result in changes in instrument costs. Although a general cost has been provided for PM monitors, this cost is less reliable than the costs of better established technologies such as extractive gas monitors. If more reliable cost inforation is required, a cost estimate should be obtained from a vendor.

4.2.3 Data Acquisition System

Data acquisition systems (DAS) consist of a computer, monitor, printer and software that interface with the monitoring system and provide reports, data storage, and screen displays. Analyzers produce an output signal in volts or milliamps that represents a fraction of the full scale reading established using calibration gases. This output signal typically goes to a strip chart recorder that uses colored pens and paper graph charts to record the analyzers readings. This reading must be interpreted based on the calibration value; for example, if a calibration gas of 10 ppm produced a signal of 10 volts, then a reading of 4 volts corresponds to a concentration of 4 ppm. While many CEMs still include strip chart recorders as back-up systems, most CEMs rely on DAS for data processing and management.

DAS typically include analog to digital conversion boards that take the voltage or milliamperage signal from the analyzer and convert it into digital information that can be understood by a computer. Newer generation monitors have the ability to include calibration information and directly report concentrations; they are also capable of storing data and communication directly to computers with digital information. The computer can also provide controlling functions for the monitors such as performing calibrations, if not provided by a PLC system.

Reporting requirements can have a significant effect on the design of a DAS, and the reporting frequency and averaging time for the monitoring results can impact capacity and cost. However, the growing power of personal computers has improved the functionality and lessened the upper-end costs for DAS, (Table 4.16 in Appendix A shows a range of cost between $16,000 and $20,000). Proprietary software typically comes from the DAS vendor. This software manages data and produces quality assured reports for use by plant personnel and regulatory authorities. Examples of DAS computer program functions include [7]:

ï Allowing the operator to interface with the CEMS;
ï Averaging data, calculating emissions estimates, and creating reports;
ï Providing electronic and hard copies of logs and reports;
ï Interfacing with other computer systems.

4.3 Parametric Monitoring

Parametric monitoring differs from CEMS in that emissions are not monitored directly. Parametric monitoring is the monitoring of key, emissions-correlated easurables (such as pressure). Operating parameters are monitored by thermocouples, differential pressure gauges, or other instrumentation. For example, a thermal treatment device designed to control VOCs demonstrates compliance with a VOC destruction efficiency of greater that 90% as long as a temperature of 1800 °F is maintained by the device. This correlation of temperature to emissions reduction is established thorough periodic monitoring (e.g., annual compliance testing). Parametric monitoring allows the use of temperature monitoring in place of VOC monitoring for this device once the correlation of temperature to VOC destruction has been established.

The use of parametric monitoring can provide more flexible and less expensive options than CEMS for demonstrating compliance of regulated sources. EPA's view of the use of parametric monitoring is expressed in the May 1, 1998 "EPA Draft Final Periodic Monitoring Guidance" document.

Parametric monitoring provides a reasonable assurance of compliance, but the CAM Rule should be consulted for guidance on the type of parametric monitoring that might satisfy periodic monitoring [3]. An additional source of information that includes additional monitoring parameters beyond those used in the CAM Rule is the "Ohio EPA's Operation and Maintenance (O&M) Guidelines for Air Pollution Control Equipment".

When parametric monitoring is used for continuous compliance monitoring, the equipment requirements can be similar to CEMS. Although the gas sampling systems used by emissions monitors are not likely to be components of parametric monitoring systems, some type of calibration and data acquisition systems are likely to be required. The type of process, control equipment and pollutant to be monitored determine the selection of a parametric monitoring system. Data reduction, record-keeping, and reporting are performed independently of sampling in a parametric system, however, they are inherent to regulatory compliance demonstration. For many sources, a combination of parametric monitoring and a data acquisition system is sufficient to comply with CAM. Some forms of parametric monitoring may use the same types of data acquisition, record keeping and reporting as CEMS.

> "When using parametric data to satisfy the periodic monitoring requirement, the permit should specify a range which will assure that the source is in compliance with the underlying requirement. Wherever possible, the proposed range should be supported by documentation indicating a correlation between the parameter(s) and compliance with the emission limit, although it is not required that the range be set such that an excursion from the range will indicate noncompliance with the associated limit. The permit should also include some means of periodically verifying this correlation.
>
> For example, the permit may require periodic stack testing to verify direct compliance with the applicable requirement. At the same time, the test data could be used to set the parameter ranges that will be used to determine compliance between tests.
>
> The permit should also specify what happens when a parameter exceeds the established range. For example, the permit should specify whether excursion from the established range is considered a violation or whether it will instead trigger corrective action and/or additional monitoring or testing requirements to determine the compliance status of the source."

Most monitoring is required to demonstrate compliance with applicable emissions limitations for specific pollutants. Although multiple pollutants may at some times be correlated to the same parameter, in most cases, the parametric monitoring method depends on the pollutant of interest. Sample collection, analysis, and data reduction methods are specific to the type of contaminant or process measurement being monitored.

A brief discussion and examples of parametric monitoring are given in the following sections for a variety of pollutants including PM, SO_2, CO, NO_x, VOCs, and opacity. The costs for parametric monitoring of a single unit is also presented at the end of each section in Tables 4.5 - 4.10. [18]

Cost estimates for parametric monitoring were taken from the supporting information related to the regulatory impact analysis for the CAM rulemaking. The cost estimates contained in this section are not sensitive to the size of the equipment. In general, they represent medium sized units that do not already have applicable monitoring requirements under NSPS or other federal programs. These costs represent monitoring for one control device such as a single thermal unit or baghouse. The costs reported are generic in nature, while the true cost will depend on a number of factors (size for instance). Larger units may have multiple control devices and would require multiple parametric monitoring devices. In addition, larger units typically already have monitoring systems in place. Many of these units are required to upgrade their monitoring under the CAM Rule. Rather than relying solely on the cost estimates provided by this document, an "expert" on the design and choice of parametric monitoring equipment should be consulted to determine the true cost.

4.3.1 Particulate Matter (PM)

The two principal methods of controlling PM emissions currently in use by U.S. industry are electrostatic precipitators (ESPs) and fabric filters, also called baghouses. Parametric monitoring has been used for many years to monitor ESP performance. Items such as gas volume and velocity, temperature, moisture, rapping (cleaning) frequency, and the electrostatic field's voltage and current applied are indicators that can be monitored to assure continued ESP performance. ESPs are typically used by larger sources that may already be subject to NSPS or other monitoring requirements. ESPs are not typically viewed as cost effective control devices for smaller sources.

The CAM Rule used parametric monitoring of a baghouse as its basis for establishing PM parametric monitoring costs. Fabric filtration can be applied to a wide range of sources, from small shot-blast units to large steel mills. This section uses monitoring of the pressure drop across the baghouse as an example of parametric monitoring. A baghouse operates much like a vacuum cleaner with a fan either blowing dirty air through (positive pressure) the filter or drawing air into (negative pressure) the filter. In either case, it takes substantial air pressure to force the air through the filter. The pressure drop is a measurement of this difference in pressure between the clean and dirty sides of the filter. Static pressure gauges can be installed at the inlet and outlet of the fabric filter to determine the unit's pressure drop. As the fabric becomes clogged with dust there is more resistance to air flow, resulting in an increased pressure drop.

Typically, a baghouse is cleaned in sections, with jets of counter-flowing air used to blow captured dust off the filter and into a hopper. In many installations, the baghouse will follow a routine cycle with the pressure drop increasing as the bag becomes coated with dust, and dropping back to a baseline value after it is cleaned. Pressure drop measurements are used to determine if the fabric is being properly cleaned and that the baghouse is operating as designed. Abnormally high values may indicate that the filter media is becoming "blinded" by materials, such as organic aerosols, that cannot be removed. This is a potential indication of a failure to capture and control the process PM. Abnormally low values may indicate holes in the filter media or mechanical failure of baghouse components. Table 4.5 provides cost estimations for parametric monitoring of PM emissions using pressure drop across the filter fabric.

As with other types of CAM, monitoring of pressure drop is a useful indicator of baghouse performance, but does not guarantee compliance with emission standards. Any parametric monitoring program for fabric filtration control equipment should be considered part of an overall compliance program that includes routine inspections and maintenance logs that help to predict and eliminate equipment problems before they occur. Routine monitoring of the key operating parameters will improve the performance of a fabric filter and increase its effective service life. Establishing an effective operation and maintenance program is an important component of predicting baghouse failures.

There are several other methods for monitoring. PM visual opacity monitoring by certified smoke readers is one method. Other methods include use of PM CEMS which are now on the market. However, PM CEMS are still considered a new technology. These methods are generally more expensive than parametric monitoring of PM.

Another type of PM control that is typically applied to organic aerosols is thermal treatment. Although this is primarily a VOC control technique, it is effective for the control of high molecular weight organic compounds that can condense to form PM. Combustion temperatures are measured by thermocouples installed in thermal treatment units. Temperature measurements can be used to evaluate combustion practices and, if maintained within designated operating ranges, would provide a reasonable level of confidence for compliance with a PM emission limitation. Temperature monitoring of a thermal treatment device does not require installation of additional equipmentexcept possibly for a DAS [9].

4.3.2 Sulfur Dioxide

The two principal methods of control of sulfur dioxide (SO_2) in use in the U.S. today are wet gas scrubbing and spray dryers. Spray dryers are becoming more prevelant on new and start-up installations, but wet gas screbbers are still more widely used overall.

Table 4.5: Cost Summary for Parametric Monitoring of Particulate Emissions Using Pressure Drop Across Fabric Filter.

Item	Total Cost, $
Capital and other initial costs[a]	**1,070**
Planning[b]	240
Equipment selection[c]	2,050
Install and calibrate sstem[d]	630
Total capital Investment (TCI)	3,990
Annual Costs, $/yr	
Operation and maintenance[e]	270
Recordkeeping[f]	2,015
Property taxes, insurance, and administrative[g]	160
Capital recovery (CRF =)[h]	380
Total Annual Cost, $/yr	2,825

[a] Engineer, 32hrs @ $30/hr + managerial review 2hrs @ $50/hr + $10 telephone charges
[b] Engineer and purchasing agent 4 hrs @ $30/hr
[c] Equipment manufacturer cost
[d] In house and contractor combined labor cost of $360
[e] 10% of purchased equipment cost + In house and contractor labor cost of $65
[f] 5 min. per shift 3 shifts per day x (365 daysyr) @ $17.50/hr of operator time for managerís review @ $50/hr, 10% of operator time for clerical support @ $10/hr and $100 for supplies.
[g] Based on 4% of TCI
[h] CRF = 0.0944 x TCI based on 20 year life and 7% interest.

The CAM Rule used wet scrubbers (gas-absorbers) to determine its RIA SO_2 monitoring costs. Wet scrubbers use a variety of techniques including packing materials, perforated trays, and sprayers to force close contact between the dirty gas and the gas scrubbing liquid (liquor) flowing through the scrubber. One SO_2 parameter used to indirectly monitor emissions is the pressure drop across a wet scrubber measured by a differential pressure gauge or manometer. Similar to our discussion of the baghouse, abnormally high and abnormally low pressure drops can indicate operational problems. Abnormally low pressure drops indicate that the dirty gas is probably not being forced into adequate contact with the scrubber liquor and that SO_2 is probably being released without adequate treatment. Abnormally high pressure drops are likely to indicate mechanical problems such as flooding (excessive liquor) or clogging (contamination of the packing material). These problems indicate failure to adequately capture and control SO_2. The CAM techniques used in this example are generally applicable to other pollutants beyond SO_2. [10]

Monitoring the pressure drop in a gas scrubber is less expensive than using SO_2 CEMS, but it only gives an indication of scrubber operation and is not necessarily an indication of compliance with applicable regulations. For a true indication of compliance, parametric monitoring should be used. Table 4.6 provides cost estimates for parametric monitoring of a wet scrubber using pressure drop.

One of the simplest forms of parametric monitoring is monitoring of fuel sulfur content and fuel useage. Fuel sulfur content is typically available as a maximum specification from the fuel vendor. It can also be sampled on-site and provided as a weight percent sulfur. The molecular weight of SO_2 is twice that of elemental sulfur. Therefore, by monitoring the rate of fuel use, the SO_2 emissions rate can be easily calculated by assuming complete combustion of all fuel sulfur to SO_2. Fuel purchase records may be adequate to monitor fuel use. If this information is not adequate to demonstrate compliance with the applicable standard, fuel monitoring devices can be purchased.

Liquid and gaseous fuels can be monitored using a totalizer, which measures gallons or cubic feet of gas used. Totalizers are available with electronic signals for use with DAS. Solid fuel monitoring could be accomplished by weighing of fuel. Another approach would be to measure the heat output of the equipment. For example, boiler steam output monitored and converted to heat input. A relationship between the fuel required and steam produced for a particular fuel can easily be established for most industrial boilers. Once this relationship is established, steam production could be used as a surrogate for monitoring fuel use.

4.3.3 Carbon Monoxide

Carbon monoxide results from incomplete combustion of carbon based fuels. Some types of combustion equipment, such as incinerators may produce relatively high levels of carbon monoxide. Thermal treatment of the off-gas may be used to burn carbon monoxide and other products of incomplete combustion. Most industrial combustion equipment, including stationary turbines and other stationary engines, produce relatively small amounts of carbon monoxide. For these sources, combustion optimization is the typical control method. Control of key engine operating parameters, such as fuel, air, and engine load, optimizes combustion and lets the engine operate at a low and compliant emissions level. Oxides of nitrogen, VOCs, and other pollutants can also be effectively limited through combustion optimization.

Some industrial combustion equipment requires a fairly narrow set of operating parameters. For this type of equipment, periodic testing can establish an emissions pattern that correlates to optimum operating conditions. The operating conditions that correlate to violations of emissions limitations can be monitored using parametric monitoring techniques. The critical aspect of this type of monitoring is to establish the relationship between operating conditions and emissions. During a periodic compliance test, the key parameters, such as operating temperature, excess air and load can be monitored concurrently with CO. By establishing a correlation between these parameters and CO emissions rates for the range of operating conditions, algorithms can be developed to predict emissions.

These algorithms can be programmed into a DAS. The DAS can then monitor operations and determine if any of the conditions that produce excess emissions occur. Portable combustion analyzers are an acceptable monitoring option for CO sources and can be used to measure excess air or O2, air flow, and temperature.

Table 4.6: Cost Summary for Pressure Drop Across Wet Scrubber

Item	Total Cost, $
Capital and other initial costs	
Planning[a]	4,890
Equipment selection[b]	0
Support facilities[c]	2,000
Purchased equipment cost[d]	3,260
Install and check DAS[e]	5,680
Data collection text[f]	16,140
Total Capital Investment (TCI)	31,970
Annual Costs, $/yr	
Operation and maintenance[g]	900
Annual RATA[h]	10,930
Recordkeeping and reporting[i]	2,020
Property taxes, insurance, and administrative[g]	1,280
Capital recovery[h]	3,020
Total Annual Cost, $/yr	26,650

[a] Based on $ 4,250 labor to review regulations, define monitoring requirements and develop CAM plan plus $640 in supplies.
[b] Cost of selecting PC-based data acquisitions system included in planning costs.
[c] Cost of installing sampling ports in stack.
[d] Cost based on Pentium class PC, monitor, printer, and operating software.
[e] PC installation and interconnection for sensor signals, equipment calibrations and start-up services.
[f] Cost for data collection testing is based on the cost for initial RATA testing on a CEM.
[g] Based on 10% of purchased equipment cost + 10% of installation labor cost.
[h] Cost for data collection testing is based on the cost for annual RATA testing on a CEM.
[i] 5 min. per shift 3 shifts per day x(365 days/yr) @ $17.50/hr for operators. Add 2.5% of operator time for engineerís review @ $30/hr, 2.5% of operator time for managerís review @ $50/hr, 10% of operator time for clerical support @ $10/hr and $100 for supplies.
[j] QA planning, training, and equipment inventory estimated to be 50% of CEM cost.
[k] Based on 4% of TCI
[l] CRF = 0.0944 x TCI based on 20 year life and 7% interest.

This type approach can be a cost effective manner of parametric monitoring, particularly when several identical units are operated by a company. The costs of developing parametric monitoring techniques for additional identical units should be substantially less than for the first unit.

Cost estimates for the initial development of this type of parametric monitoring of CO on an individual combustion unit are contained in Table 4.7. In this example, portable analyzers are used for a short period of time to establish a relationship between operating conditions and emissions. The purchased equipment cost is lower than using a CO CEM, however, a data acquisition system is required. For most combustion equipment that operates within a predictable range, this method offers greater assurance of compliance than pressure drop monitoring described in the previous two examples. Some industrial combustion equipment operates at near steady-state conditions, and simpler parametric monitoring may be adequate. Many industrial boilers already monitor operating parameters such as load and combustion airflow using strip chart recorders. Some units may be able to demonstrate that their existing monitoring is adequate to maintain compliance.

4.3.4 Nitrous Oxides

NO_x emissions from industrial combustion equipment can be monitored in the same manner as CO emissions discussed above. NO_x emissions will vary with load and will typically increase as the load increases. To limit NO_x generation, load, combustion zone temperature and excess air need to be minimized. Although the algorithm that describes the relationship between NO_x and operating conditions is obviously going to be different than the one developed for CO, the basic approach is identical. Stationary turbines produce more NO_x than CO and may operate much closer to regulatory limits for NO_x. The parametric monitoring approach may need additional periodic direct testing of NO_x emissions if the margin of compliance is small.[12] Cost estimates for the initial development of parametric monitoring of NO_x on an individual combustion unit are contained in Table 4.8.

4.3.5 Opacity

Opacity regulations are intended to support compliance with PM emissions limitations. Opacity standards can be thought of as surrogate or parametric approaches to determining PM compliance. Opacity can be measured using an opacity monitor or through the use of EPA Methods 9 and 22. It is possible that parametric approaches, such as those discussed for CO and NO_x that rely on correlating operating status of the equipment to emissions rates, can be used. However, for most processes, high opacity is not a typical operation and probably cannot easily be correlated to typical operating parameters.

The CAM Rule proposed EPA Method 9 as a method of establishing compliance with opacity regulations and can also be considered a method or supporting method of verifying compliance with PM emissions limits. Using EPA Method 9, opacity is measured by a certified smoke reader who visually observes the opacity or optical density of the plume. The readers eyes are "calibrated" by undergoing recertification every six months. This method is useful for plants with control devices that normally produce no visible emissions, but when controls fail, visible emissions occur. For example, consider a printing press with a drying oven that produces visible smoke. To eliminate the smoke, thermal combustion control equipment is installed. For this process, any visible emissions are likely to indicate operating problems with the control equipment.

Figure 4.7: Cost Summary for Parametric Monitorying of CO Emissions Using Temperature and other Combution Operating Parameters

Item	Total Cost, $
Capital and other initial costs	
Planning[a]	4,890
Equipment selection[b]	0
Support facilities[c]	2,000
Purchased equipment cost[d]	3,260
Install and check DAS[e]	5,680
Data collection text[f]	16,140
Total Capital Investment (TCI)	31,970
Annual Costs, $/yr	
Operation and maintenance[g]	900
Annual RATA[h]	10,930
Recordkeeping and reporting[i]	2,020
Property taxes, insurance, and administrative[g]	1,280
Capital recovery[h]	3,020
Total Annual Cost, $/yr	26,650

[a] Based on $ 4,250 labor to review regulations, define monitoring requirements and develop CAM plan plus $640 in supplies.
[b] Cost of selecting PC-based data acquisitions system included in planning costs.
[c] Cost of installing sampling ports in stack.
[d] Cost based on Pentium class PC, monitor, printer, and operating software.
[e] PC installation and interconnection for sensor signals, equipment calibrations and start-up services.
[f] Cost for data collection testing is based on the cost for initial RATA testing on a CEM.
[g] Based on 10% of purchased equipment cost + 10% of installation labor cost.
[h] Cost for data collection testing is based on the cost for annual RATA testing on a CEM.
[i] 5 min. per shift 3 shifts per day x(365 days/yr) @ $17.50/hr for operators. Add 2.5% of operator time for engineerís review @ $30/hr, 2.5% of operator time for managerís review @ $50/hr, 10% of operator time for clerical support @ $10/hr and $100 for supplies.
[j] QA planning, training, and equipment inventory estimated to be 50% of CEM cost.
[k] Based on 4% of TCI
[l] CRF = 0.0944 x TCI based on 20 year life and 7% interest.

Table 4.8: Cost Summary for Parametric Monitoring of NO_x Emissions Using Temperature and other Combustion Parameters

Item	Total Cost, $
Capital and other initial costs	
Planning[a]	4,890
Equipment selection	0
Support facilities[c]	2,000
Purchased equipment cost[d]	3,260
Install and check DAS[e]	5,680
Data collection text[f]	16,140
Total Capital Investment (TCI)	31,970
Annual Costs, $/yr	
Operation and maintenance[g]	900
Annual RATA[h]	10,930
Recordkeeping and reporting[i]	2,020
Property taxes, insurance, and administrative[g]	1,280
Capital recovery[h]	3,020
Total Annual Cost, $/yr	26,650

[a] $4,250 labor to review regulations, define monitorying requirements and develop CAM plan plus $640 in supplies.
[b] Cost of selecting PC-based data acquisitions system included in planning costs.
[c] Cost of installing sampling ports in stack.
[d] Cost based on Pentium class PC, monitor, printer, and operating software.
[e] PC installation and interconnection for sensor signals, equipment calibrations and start-up services.
[f] Cost for data collection testing is based on the cost for initial RATA testing on a CEM.
[g] Based on 10% of purchased equipment cost + 10% of installation labor cost.
[h] Cost for data collection testing is based on the cost for annual RATA testing on a CEM.
[i] 5 min. per shift 3 shifts per day x(365 days/yr) @ $17.50/hr for operators. Add 2.5% of operator time for engineerís review @ $30/hr, 2.5% of operator time for managerís review @ $50/hr, 10% of operator time for clerical support @ $10/hr and $100 for supplies.
[j] QA planning, training, and equipment inventory estimated to be 50% of CEM cost.
[k] Based on 4% of TCI
[l] CRF = 0.0944 x TCI based on 20 year life and 7% interest.

Most air pollution emissions points are also subject to opacity regulations. For opacity regulations, Methods 9 and 22 are enforceable reference methods and not parametric methods. Opacity reading is less expensive than direct emissions monitoring using CEMs. PM CEMs are now on the market, but are a relatively new technology (see Section 4.2.2). However, opacity reading does have its drawbacks. The presence of water vapor in the stack, the color of smoke emitted, and the position of the sun can substantially influence apparent opacity. In spite of these complicating factors, opacity reading remains in wide use because of the lack of alternative methods for easily determining PM emissions.

Cost estimates for parametric monitoring of opacity using visual opacity readings on an individual unit are contained in Table 4.9.

4.3.6 VOCs

The use of temperature monitoring to assure thermal destruction of organic particles is primarily applied to assuming VOC destruction. Periodic testing, such as a compliance test, establishes the performance of the thermal treatment (e.g., 98% destruction of VOC) at the minimum operating temperature achieved during the test. Provided this temperature is maintained and the type and amount of VOC feed to the thermal unit do not change substantially, the performance of the unit is demonstrated.

In order to evaluate control costs for the CAM Rule, EPA developed a parametric monitoring approach for carbon adsorbers, which are frequently used to abate VOC emissions. Periodic or continuous direct measurement of outlet VOC concentration is one type of parametric monitoring applied to VOC adsorbent control devices. The purpose of this monitoring is to detect “breakthrough” of VOC through the carbon, which occurs when the carbon becomes saturated with VOCs and can longer remove them from the gas stream. VOCs then pass through the carbon uncontrolled. The adsorbtion capacity of the carbon and the VOC concentration in the gas stream help determine an appropriate monitoring approach.

Larger systems typically regenerate the carbon onsite, often many times a day. As a result, the potential for breakthrough is high in these systems, so many other parameters are typically monitored to maintain safety and performance. Measuring the inlet gas temperature and the temperature of the carbon bed can detect potential fires. Monitoring of a pressure drop across the carbon adsorber is an indicator of proper gas flow, carbon bed plugging, or carbon bed channeling. Static pressure gauges, magnehelic gauges, or manometers can be installed at the inlet and outlet to determine pressure drop. Continuous VOC monitoring may also be appropriate, for these systems. If a low resolution VOC monitor is used, VOC monitoring becomes a parametric method rather than a CEM method. The monitor used could be less sensitive and expensive than a VOC CEM since it is only required to detect the VOC concentrations after the carbon absorber has risen to a level that indicates breakthrough [13].

Table 4.9: Cost Summary for Parametric Monitoring of Opacity Using the Visible Emissions Method

Item	Total Cost, $
Capital and other initial costs	
Planning[a]	1,070
Course selection[b]	240
Training Course[c]	550
Certification[d]	1,100
Total Capital Investment (TCI)	2,960
Annual Costs, $/yr	
15 minute daily observation[e]	1,700
Semiannual certification[f]	1,100
Recordkeeping and reporting[g]	2,015
Property taxes, insurance, and administrative	120
Capital recovery	280
Total Annual Cost, $/yr	5,215

[a] Engineer, 32 hrs @ $30/hr + managerial review 2hrs @ $50/hr + $10 telephone charges.
[b] Engineer and purchasing agent 4 hrs @ $30/hr.
[c] One-day training course for two plant operators @ $17/hr + $200 to contractor + $50 other costs.
[d] Two days for two operators to pass certification tests @ $17/hr.
[e] 15 min. per day opacity observation for operator @ $17/hr
[f] 5 min. per shift 3 shifts per day x(365 days/yr) @ $17.50/hr for operators. Add 2.5% of operator time for engineerís review @ $30/hr, 2.5% of operator time for managerís review @ $50/hr, 10% of operator time for clerical support @ $10/hr and $100 for supplies.
[g] Based on 4% of TCI
[h] CRF = 0.0944 x TCI based on 20 year life and 7% interest.

Smaller systems may not regenerate the carbon onsite. Periodic replacement of the carbon or the entire system are common practices. The system can be as simple as a 55 gallon drum filled with carbon and a hose that can be connected to a source of VOCs (such as a small storage tank). Multiple drums can be stored onsite and switched out when the carbon becomes saturated with VOCs. A recycling vendor can then recycle the used drums, leaving fresh drums as replacements. For these systems, periodic testing with sample tubes may be adequate for detecting when the carbon is saturated and drum replacement is required. This periodic testing can be used to establish a reasonable replacement schedule. Cost estimates for parametric monitoring of VOCs using carbon absorption capacity on an individual unit are contained in Table 4.10.

4.3.7 DAS

The type of recordkeeping used to demonstrate compliance should be reasonably consistent with the size, complexity and regulatory requirements of the source and the source's potential for excess emissions. In the cost summaries presented in the previous sections, a DAS price was only included in the cost estimates for CO and NO_x parametric monitoring. For other examples, such as monitoring the pressure drop across a baghouse, simple manual methods can be adequate; recordkeeping can consist of an operator manually logging the pressure drop once per shift. However, larger sources, or sources with more stringent regulatory requirements, may necessitate the use of a DAS.

The data acquisition systems involved with parametric monitoring do not differ greatly from DAS for CEMS. The need to acquire an electronic signal, then process, store, check, and summarize the signal as a reporting parameter is identical. Some special signal conditioning may

Table 4.10: Cost Summary for Parametric Monitoring of VOCs Using Carbon Absorption Capacity

Item	Cost, $
Capital and other initial costs	
Planning[a]	1,070
Equipment selection[b]	240
Purchased equipment cost[c]	620
Install and calibrate system[d]	630
Total Capital Investment (TCI)	2,960
Annual costs, $/yr	
Operation and maintenance[e]	130
Recordkeeping[ff]	9,795
Property taxes, insurance, and administrative	100
Capital recovery	240
Annual Cost, $/yr	10,265

[a] Engineer, 32 hrs @ $30/hr + managerial review 2hrs @ $50/hr + $10 telephone charges
[b] Engineer and purchasing agent 4 hrs @ $30/hr
[c] Equipment manufacturer/supplier cost
[d] In house and contractor combined labor cost of $630
[e] 10% of purchased equipment cost + In house and contractor combined labor cost of $65
[f] 5 min. per shift 3 shifts per day x(365 days/yr) @ $17.50/hr for operators. Add 2.5% of operator time for engineerís review @ $30/hr, 2.5% of operator time for managerís review @ $50/hr, 10% of operator time for clerical support @ $10/hr and $100 for supplies.
[g] Based on 4% of TCI
[h] CRF = 0.0944 x TCI based on 20 year life and 7% interest.

be required, however, most DAS are equipped or easily upgraded to handle signals such as temperatures provided by different types of thermocouples. In the CO and NO_x examples, a DAS and computer are used to develop correlations between process parameters and observed emission profiles. In this example, the DAS is essential in acquiring process operating information that is correlated by the computer to an emissions profile.

4.4 Estimating Capital and Annual Costs for CEMS

The U.S. Environmental Protection Agency (EPA) developed a computer software program for estimating the cost of CEMS titled Continuous Emission Monitoring System Cost Model, Version 3.0 (CEMS Cost Model). The CEMS cost estimation methods in this chapter represent a simplified version of this model appropriate for use with the spreadsheets used throughout this manual. With the exception of rounding errors, the costs estimates produced from this method match the values obtained with the CEMS Cost Model.

This approach represents an adequate estimation method for permit engineers verifying equipment costs during permit analysis or for engineers performing initial costs of equipment at typical installations. Total Capital Investment (TCI) and Total Annual Cost (TAC) can be estimated for numerous CEMS configurations, without going to the more complex CEMS Cost Model. The equations provided in this section do not cover all of the scenarios and monitor types and equipment combinations that are available in the CEMS Cost Model.

This methodology estimates study-level costs for a single CEMS to monitor emissions from one source at a facility. The value obtained for a single CEMS should not be multiplied by the number of CEMS required for a multiple source facility since this overestimates the cost of multiple CEMS. A more detailed approach would require consideration of additional factors that impact the accuracy, reliability and cost of installing and maintaining a monitoring system. Detailed cost estimates should rely on the more complete CEM Cost Model along with vendor or other expert analysis of application specific requirements.

4.4.1 Development of Cost Equations

The cost equations for TCI and TAC in this section were developed from the CEMS Cost Model using multiple linear regression techniques. Factors that impacted capital costs, annual costs, personnel cost factors, and equipment cost factors, functioned as variables in the regression analysis. These factors are assigned default values from CEMS Cost Model data.

This manual assumes the necessary personnel to install a CEMS includes a corporate environmental engineer (CEE), two plant technicians, a CEMS consultant, and test personnel. The cost factors associated with these personnel include wages, overhead, travel time, travel fare, per diem, and fees. The TCI and TAC equations are derived assuming the values given in Table 4.15 located in Appendix A. These assumptions must be considered when determining the applicability of the cost equations. The default values from the CEMS Cost Model for personnel cost factors are supplied in Table 4.11. The data in Table 4.11are fully loaded hourly rates for each employee type. The default values can be modified if location specific or vendor specific information is available (e.g., local labor rates).

The equipment cost factors include the cost of the CEMS monitors and analyzers and auxiliary equipment. The monitor and analyzer costs are specific to the CEMS configuration (Extractive, In Situ, and FTIR) and the pollutant(s) or parameter(s) monitored. Auxiliary costs include the sampling system, DAS equipment, shelter for equipment, and controls. It also includes equipment, such as access ladders and platforms, and both system fabrication and installation. The TCI and TAC equations are derived assuming the values given in 4.16 located in Appendix A. The default values from the CEMS Cost Model for the equipment cost factor is supplied in Table 4.12. The equipment costs presented in Table 4.12 are averages of costs provided by several vendors for development of the CEMS Cost Model. These default values can be modified if vendor specific information is available.

Table 4.11: Default Personnel Hourly Rates and Cost Factors

Cost Item	CEE	Plant Technicial	Plant Technician II	CEMS Consultant	Test Personal
Wage rate, $/hr w/o OH	30.00	18.00	27.00	27.00	16.00
Overhead (OH), % of wage rate	40	40	40	200	200
Fee, % profit	N/A	N/A	N/A	10	10
Hourly Rate[1]	42.00	25.20	37.8	89.1	52.8

[1] Loaded hourly rate, $/hr (wage rate with OH & Fee)

Muli-variable linear regression was performed using the default cost factors to produce regression constants for various CEMS sampling configurations and pollutant monitors. There are unique regression constants for both the TCI and TAC cost equations, which act as “correction factors” for the default values of the cost factors. The set of constants to be utilized in the cost equations is determined by the CEMS design. Design options which are accounted for include:

- Device Type - the CEMS sampling configuration (Extractive, In Situ, and FTIR),
- Parameter Monitored - single pollutant, multiple pollutants, opacity, and flow,
- Pre-control sample - additional sampling location prior to the pollution control device, and

Table 4.12: Default Analyzer and Monitor Equipment Costs for CEMS ($)

Pollutant or Parameter	Extractive	In-situ	FTIR
Gaseous Compound Analyzers			
NO_x	10,440	N/A	N/A
SO_2	12,500	35,000	N/A
CO	8,490	28,000	N/A
CO_2	7,890	N/A	N/A
O_2	5,860	6,600	N/A
THC	10,200	N/A	N/A
HCl	12,390	N/A	N/A
SO_2/NO_x	N/A	37,000	N/A
$SO_2/NO_x/O_2$	N/A	45,000	N/A
CO/CO_2	N/A	34,000	N/A
Monitors[a]			
Opacity	25,000	25,000	25,000
PM	37,700	37,700	37,700
Flow	18,000	18,000	18,000
FTIR analyzer	N/A	N/A	100,000[b]

[a] All CEMS use identical opacity, PM, and flow monitors.

[b] Add $8,000 for capability to monitor before control as well as after control.

ï New Installation - installation on a new facility versus retrofit on an existing facility.

The user must first select between an Extractive, In Situ, or FTIR installation, thenselect the pollutant(s) or parameter(s) to be monitored. The equations assume one CEMS sampling location installed downstream ofthe pollution control device. The cost for an additional sampling location prior to the control can be included using the Pre-control sample parameter. The equations assume retrofit installation of the CEMS on an existing facility and correct for the cost of installation on a new facility using the New installation parameter. The regression constant sets are located in Table 4.13 for capital costs and Table 4.14 for annual costs.

Table 4.13: Coefficients for Calculating Total Capital Investment (TCI) for CEMS

Parameter Measured	Pre-Control Sample	Installation	*k1*	*k2* (hrs)	*k3* (hrs)	*k4* (hrs)	*k5* (hrs)	*k6* (hrs)	*k7* (hrs)
Device Type	**Extractive**								
NO_x		X	$88,366	332.5	152.5	0	109.9	90.7	1
NO_x	X	X	$150,130	368.5	248.1	0	120.8	135.0	2
NO_x			$88,634	342.7	167.7	0	109.9	90.7	1
NO_x	X		$150,606	383.1	282.1	0	120.8	135.0	2
HCl	X		$88,866	332.5	152.5	0	109.9	95.7	1
HCl	X	X	$150,630	368.5	248.1	0	120.8	140.0	2
HCl			$89,134	342.7	167.7	0	109.9	95.7	1
HCl	X		$151,106	383.1	282.1	0	120.8	140.0	2
CO_2		X	$88,280	261.5	152.5	0	109.9	90.7	1
CO_2	X	X	$150,037	293.0	248.1	0	120.8	135.0	2
CO_2			$88,548	272.5	167.7	0	109.9	90.7	1
CO_2	X		$150,513	308.0	282.1	0	120.8	135.0	2
Flow		X	$22,470	192.1	98.5	0	62.7	42.0	1
Flow	X	X	$25,095	205.5	128.8	0	69.1	43.2	2
Flow			$22,638	199.1	100.5	0	62.7	42.0	1
Flow	X		$25,371	214.6	131.6	0	69.1	43.2	2
Opacity		X	$22,033	192.1	98.5	0	62.7	6.0	1
Opacity	X	X	$24,657	205.5	128.8	0	69.1	7.2	2
Opacity			$22,201	199.1	100.5	0	62.7	6.0	1
Opacity	X		$24,933	214.6	131.6	0	69.1	7.2	2
CO		X	$88,366	332.5	152.5	0	109.9	90.7	1
CO	X	X	$150,130	368.5	248.1	0	120.8	135.0	2
CO			$88,634	342.7	167.7	0	109.9	90.7	1
CO	X		$150,606	383.1	282.1	0	120.8	135.0	2
SO_2		X	$88,366	332.5	152.5	0	109.9	90.7	1
SO_2	X	X	$150,130	368.5	248.1	0	120.8	135.0	2
SO_2			$88,634	342.7	167.7	0	109.9	90.7	1
SO_2	X		$150,606	383.1	282.1	0	120.8	135.0	2
O_2		X	$88,280	261.5	152.5	0	109.9	90.7	1
O_2	X	X	$150,037	293.0	248.1	0	120.8	135.0	2
O_2			$88,548	272.5	167.7	0	109.9	90.7	1
O_2	X		$150,513	308.0	282.1	0	120.8	135.0	2
PM		X	$28,855	211.2	153.9	0	64.7	27.1	1
PM	X	X	$36,482	224.9	200.4	0	71.1	28.6	2
PM			$29,223	218.2	155.9	0	64.7	27.1	1
PM	X		$37,158	234.0	203.2	0	71.1	28.6	2
THC		X	$85,086	332.9	152.7	0	109.9	93.2	1
THC	X	X	$143,350	369.3	248.5	0	120.8	137.5	2
THC			$85,354	343.1	167.9	0	109.9	93.2	1
THC	X		$143,826	383.9	282.5	0	120.8	137.5	2
Device Type	**In-Situ**								
CO/CO_2		X	$39,228	288.1	101.0	0	105.1	91.8	1
CO/CO_2	X	X	$45,992	328.8	151.9	0	122.1	137.2	2
CO/CO_2			$39,501	298.3	108.6	0	105.1	91.8	1
CO/CO_2	X		$46,479	343.0	167.5	0	122.1	137.2	2
CO		X	$38,028	283.8	97.4	0	105.1	91.8	1
CO	X	X	$43,592	320.3	144.7	0	122.1	137.2	2
CO			$38,301	294.0	105.0	0	105.1	91.8	1
CO	X		$44,079	334.5	160.3	0	122.1	137.2	2
SO_2		X	$38,028	283.8	97.4	0	105.1	91.8	1
SO_2	X	X	$43,592	320.3	144.7	0	122.1	137.2	2
SO_2			$38,301	294.0	105.0	0	105.1	91.8	1
SO_2	X		$44,079	334.5	160.3	0	122.1	137.2	2
O_2		X	$38,028	287.0	97.4	0	105.1	91.8	1
O_2	X	X	$43,592	323.5	144.7	0	122.1	137.2	2
O_2			$38,301	298.0	105.0	0	105.1	91.8	1
O_2	X		$44,079	338.5	160.3	0	122.1	137.2	2

Table 4.13: Coefficients for Calculating Total Capital Investment (TCI) for CEMS (Cont.)

Parameter Measured	Pre-Control Sample	Installation	*k1*	*k2* (hrs)	*k3* (hrs)	*k4* (hrs)	*k5* (hrs)	*k6* (hrs)	*k7* (hrs)
Device Type	**Extractive**								
Flow		X	$25,875	253.5	98.6	0	64.3	42.0	0.367
Flow	X	X	$32,737	290.6	158.8	0	71.2	86.4	0.733
Flow			$26,049	260.5	100.6	0	64.3	42.0	0.367
Flow	X		$33,223	302.9	167.2	0	71.2	86.4	0.733
SO_2/NO_x		X	$39,228	289.7	101.0	0	105.1	91.8	1
SO_2/NO_x	X	X	$45,992	330.4	151.9	0	122.1	137.2	2
SO_2/NO_x			$39,501	300.3	108.6	0	105.1	91.8	1
SO_2/NO_x	X		$46,479	345.0	167.5	0	122.1	137.2	2
$SO_2/NO_x/O_2$		X	$40,428	293.9	104.6	0	105.1	91.8	1
$SO_2/NO_x/O_2$	X	X	$48,392	338.9	159.1	0	122.1	137.2	2
$SO_2/NO_x/O_2$			$40,701	304.5	112.2	0	105.1	91.8	1
$SO_2/NO_x/O_2$	X		$48,879	353.5	174.7	0	122.1	137.2	2
Device Type	**FTIR**								
NO_x		X	$168,674	352.5	77.6	109.0	109.9	91.6	0
NO_x	X	X	$226,296	376.2	108.4	131.8	120.8	135.6	0
NO_x			$168,966	363.5	71.6	109.0	109.9	91.6	0
NO_x	X		$226,788	391.2	98.4	131.8	120.8	135.6	0
SO_2		X	$168,674	352.5	77.6	109.0	109.9	91.6	0
SO_2	X	X	$226,296	376.2	108.4	131.8	120.8	135.6	0
SO_2			$168,966	363.5	71.6	109.0	109.9	91.6	0
SO_2	X		$226,788	391.2	98.4	131.8	120.8	135.6	0
CO		X	$168,674	352.5	77.6	109.0	109.9	91.6	0
CO	X	X	$226,296	376.2	108.4	131.8	120.8	135.6	0
CO			$168,966	363.5	71.6	109.0	109.9	91.6	0
CO	X		$226,788	391.2	98.4	131.8	120.8	135.6	0
HCl		X	$168,674	352.5	77.6	109.0	109.9	91.6	0
HCl	X	X	$226,296	376.2	108.4	131.8	120.8	135.6	0
HCl			$168,966	363.5	71.6	109.0	109.9	91.6	0
HCl	X		$226,788	391.2	98.4	131.8	120.8	135.6	0
CO_2		X	$168,674	281.6	77.6	109.0	109.9	91.6	0
CO_2	X	X	$176,931	283.8	79.6	121.0	120.8	92.4	0
CO_2			$168,966	292.6	71.6	109.0	109.9	91.6	0
CO_2	X		$177,223	294.8	73.6	121.0	120.8	92.4	0
O_2		X	$168,674	281.6	77.6	109.0	109.9	91.6	0
O_2	X	X	$176,931	283.8	79.6	121.0	120.8	92.4	0
O_2			$168,966	292.6	71.6	109.0	109.9	91.6	0
O_2	X		$177,223	294.8	73.6	121.0	120.8	92.4	0
Flow		X	$184,793	301.3	115.1	89.0	62.7	72.0	1
Flow	X	X	$236,742	332.1	171.3	100.7	69.1	116.4	2
Flow			$184,993	312.3	109.1	89.0	62.7	72.0	1
Flow	X		$237,250	348.4	162.1	100.7	69.1	116.4	2

Table 4.14: Coefficients for Calculating Total Annual Costs (TAC) for CEMS

Parameter Measured	Pre-Control Sample	Installation	k8 (hrs)	k9 (hrs)	k10 (hrs)	k11 (hrs)	k12 (hrs)	k13 (hrs)	k14 (hrs)
Device Type	***Extractive***								
NO_x		X	$3,860	44.2	390.3	0	1.7	76.9	0.1
NO_x	X	X	$5,110	50.8	548.9	0	1.8	113.9	0.2
NO_x			$3,860	44.2	390.3	0	1.7	76.9	0.1
NO_x	X		$5,110	50.8	548.9	0	1.8	113.9	0.2
HCl		X	$4,360	44.2	390.3	0	1.7	80.9	0.1
HCl	X	X	$5,610	50.8	548.9	0	1.8	117.9	0.2
HCl			$4,360	44.2	390.3	0	1.7	80.9	0.1
HCl	X		$5,610	50.8	548.9	0	1.8	117.9	0.2
CO_2		X	$3,860	42.2	389.2	0	1.7	74.7	0.1
CO_2	X	X	$5,110	48.8	547.6	0	1.8	111.4	0.2
CO_2			$3,860	42.2	389.2	0	1.7	74.7	0.1
CO_2	X		$5,110	48.8	547.6	0	1.8	111.4	0.2
Flow		X	$1,655	22.1	386.6	0	0.0	34.0	0.05
Flow	X	X	$1,885	27.3	652.1	0	0.0	34.0	0.1
Flow			$1,655	22.1	386.6	0	0.0	34.0	0.05
Flow	X		$1,885	27.3	652.1	0	0.0	34.0	0.1
Opacity		X	$1,218	22.1	386.6	0	0.0	0.0	0.05
Opacity	X	X	$1,448	27.3	652.1	0	0.0	0.1	0.1
Opacity			$1,218	22.1	386.6	0	0.0	0.0	0.05
Opacity	X		$1,448	27.3	652.1	0	0.0	0.1	0.1
CO		X	$3,860	44.2	390.3	0	1.7	76.9	0.1
CO	X	X	$5,110	50.8	548.9	0	1.8	113.9	0.2
CO			$3,860	44.2	390.3	0	1.7	76.9	0.1
CO	X		$5,110	50.8	548.9	0	1.8	113.9	0.2
SO_2		X	$3,860	44.2	390.3	0	1.7	76.9	0.1
SO_2	X	X	$5,110	50.8	548.9	0	1.8	113.9	0.2
SO_2			$3,860	44.2	390.3	0	1.7	76.9	0.1
SO_2	X		$5,110	50.8	548.9	0	1.8	113.9	0.2
O_2		X	$3,860	42.2	389.2	0	1.7	74.7	0.1
O_2	X	X	$5,110	48.8	547.6	0	1.8	111.4	0.2
O_2			$3,860	42.2	389.2	0	1.7	74.7	0.1
O_2	X		$5,110	48.8	547.6	0	1.8	111.4	0.2
PM		X	$2,723	32.7	521.4	0	1.5	89.3	0.1
PM	X	X	$2,953	37.9	861.5	0	1.5	89.3	0.2
PM			$2,723	32.7	521.4	0	1.5	89.3	0.1
PM	X		$2,953	37.9	861.5	0	1.5	89.3	0.2
THC		X	$4,060	44.2	390.8	0	1.7	78.9	0.1
THC	X	X	$5,310	50.8	549.8	0	1.8	115.9	0.2
THC			$4,060	44.2	390.8	0	1.7	78.9	0.1
THC	X		$5,310	50.8	549.8	0	1.8	115.9	0.2
Device Type	**In-Situ**								
CO/CO_2		X	$4,948	48.0	502.3	0	1.8	77.6	0.05
CO/CO_2	X	X	$6,257	61.5	795.2	0	2.0	115.0	0.1
CO/CO_2			$4,948	48.0	502.3	0	1.8	77.6	0.05
CO/CO_2	X		$6,257	61.5	795.2	0	2.0	115.0	0.1
CO		X	$4,948	43.7	406.3	0	1.7	77.1	0.05
CO	X	X	$6,257	52.9	603.2	0	1.8	114.0	0.1
CO			$4,948	43.7	406.3	0	1.7	77.1	0.05
CO	X		$6,257	52.9	603.2	0	1.8	114.0	0.1
SO_2		X	$4,948	43.7	406.3	0	1.7	77.1	0.05
SO_2	X	X	$6,257	52.9	603.2	0	1.8	114.0	0.1
SO_2			$4,948	43.7	406.3	0	1.7	77.1	0.05
SO_2	X		$6,257	52.9	603.2	0	1.8	114.0	0.1
O_2		X	$4,948	41.7	405.2	0	1.7	74.9	0.05
O_2	X	X	$6,257	50.9	602.1	0	1.8	111.8	0.1
O_2			$4,948	41.7	405.2	0	1.7	74.9	0.05
O_2	X		$6,257	50.9	602.1	0	1.8	111.8	0.1

Table 4.14: Coefficients for Calculating Total Annual Costs (TAC) for CEMS (Cont.)

Parameter Measured	Pre-Control Sample	Installation	k8 (hrs)	k9 (hrs)	k10 (hrs)	k11 (hrs)	k12 (hrs)	k13 (hrs)	k14 (hrs)
Device Type	***Extractive***								
Flow		X	$1,875	26.4	485.1	0	1.7	42.5	0.05
Flow	X	X	$2,054	36.3	854.5	0	1.8	79.0	0.1
Flow			$1,875	26.4	485.1	0	1.7	42.5	0.05
Flow	X		$2,054	36.3	854.5	0	1.8	79.0	0.1
SO_2/NO_x		X	$4,948	48.0	502.5	0	1.8	77.9	0.05
SO_2/NO_x	X	X	$6,257	61.5	795.4	0	2.0	115.3	0.1
SO_2/NO_x			$4,948	48.0	502.5	0	1.8	77.9	0.05
SO_2/NO_x	X		$6,257	61.5	795.4	0	2.0	115.3	0.1
$SO_2/NO_x/O_2$		X	$4,948	52.3	598.5	0	1.9	78.4	0.05
$SO_2/NO_x/O_2$	X	X	$6,257	70.1	987.4	0	2.2	116.3	0.1
$SO_2/NO_x/O_2$			$4,948	52.3	598.5	0	1.9	78.4	0.05
$SO_2/NO_x/O_2$	X		$6,257	70.1	987.4	0	2.2	116.3	0.1
Device Type	**FTIR**								
NO_x		X	$22,375	35.5	30.2	301.2	1.7	76.9	0
NO_x	X	X	$24,861	41.7	36.2	439.9	1.8	113.9	0
NO_x			$22,375	35.5	30.2	301.2	1.7	76.9	0
NO_x	X		$24,861	41.7	36.2	439.9	1.8	113.9	0
SO_2		X	$22,375	35.5	30.2	301.2	1.7	76.9	0
SO_2	X	X	$24,861	41.7	36.2	439.9	1.8	113.9	0
SO_2			$22,375	35.5	30.2	301.2	1.7	76.9	0
SO_2	X		$24,861	41.7	36.2	439.9	1.8	113.9	0
CO		X	$22,375	35.5	30.2	301.2	1.7	76.9	0
CO	X	X	$24,861	41.7	36.2	439.9	1.8	113.9	0
CO			$22,375	35.5	30.2	301.2	1.7	76.9	0
CO	X		$24,861	41.7	36.2	439.9	1.8	113.9	0
HCl		X	$22,375	35.5	30.2	301.2	1.7	76.9	0
HCl	X	X	$24,861	41.7	36.2	439.9	1.8	113.9	0
HCl			$22,375	35.5	30.2	301.2	1.7	76.9	0
HCl	X		$24,861	41.7	36.2	439.9	1.8	113.9	0
CO_2		X	$22,375	33.5	30.2	300.1	1.7	74.7	0
CO_2	X	X	$24,674	39.7	30.8	435.0	1.8	75.4	0
CO_2			$22,375	33.5	30.2	300.1	1.7	74.7	0
O_2	X		$24,674	39.7	30.8	435.0	1.8	75.4	0
O_2		X	$22,375	33.5	30.2	300.1	1.7	74.7	0
O_2	X	X	$24,674	39.7	30.8	435.0	1.8	75.4	0
O_2			$22,375	33.5	30.2	300.1	1.7	74.7	0
O_2	X		$24,674	39.7	30.8	435.0	1.8	75.4	0
Flow		X	$2,616	27.1	397.6	21.2	0.0	34.0	0.05
Flow	X	X	$2,913	32.3	666.8	25.6	0.0	70.0	0.1
Flow			$2,616	27.1	397.6	21.2	0.0	34.0	0.05
Flow	X		$2,913	32.3	666.8	25.6	0.0	70.0	0.1

4.2 Total Capital Investment

Total Capital Investment (TCI) includes direct and indirect costs associated with purchasing and installing equipment. Costs include the equipment cost, which can be composed of the following components: CEM sampling system cost, monitor cost, DAS cost, auxiliary equipment cost, and both direct and indirect installation costs. The estimate includes costs associated with planning for the CEMS, equipment selection, purchase, installation, support facilities, performance testing (Functional Acceptance Test), and quality assurance evaluations. Finally, the TCI includes the installation of any required platforms & ladders for routine access and service. TCI is calculated from the following equation:

$$TCI = k_1 + (k_2 \times A) + (k_3 \times B) + (k_4 \times C) + (k_5 \times D) + (k_6 \times E) + (k_7 \times F) \quad (4.1)$$

where k_1 through k_7 are the regression constants for capital costs given in Table 4.13. The cost factor variables *A* through *F* are the personnel and equipment cost factors as defined below:

A = CEE hourly cost (includes Rate, Overhead, and Fee)
B = Plant Technician hourly cost (includes Rate, Overhead, and Fee)
C = Plant Technician II hourly cost (includes Rate, Overhead, and Fee)
D = CEMS Consultant hourly cost (includes Rate, Overhead, and Fee)
E = Test Crew hourly cost (includes Rate, Overhead, and Fee)
F = Cost of Equipment

Default values for personnel cost factors *A* through *E* are given in Table 4.11. Default values for the equipment cost factor, *F*, are given in Table 4.12.

4.4.3 Total Annual Costs

Total annual cost (TAC) is the sum of the annual direct and indirect costs. Direct annual costs include variable, semi-variable, and fixed costs. Variable direct annual costs account for purchase of calibration gas, water, and electrical power or other consumables required by the CEMS. Fixed and semi-variable direct annual costs include operating and supervisory labor cost, maintenance cost, and equipment replacement cost. In general, indirect annual costs include the capital recovery cost, property taxes, insurance, administrative charges, and overhead. Capital recovery cost is based on the anticipated equipment lifetime and the annual interest rate employed. Equipment lifetime of 10 years is typical for CEMS. *TAC* is calculated from the following equation:

$$TCI = k1 + (k2 \times A) + (k3 \times B) + (k4 \times K) + (k5 \times D) + (k6 \times E) + (k7 \times F) \quad (4.2)$$

where *k8* through *k14* are the regression constants for annual cost given in Table 4.14 and *A* through *F* are the default cost factors given in Tables 4.11 and 4.12 as defined in the capital cost section. *TCI* is the total capital cost as calculated in the previous section and *CRF* is the Capital Recovery Factor.

The Capital Recovery Factor, *CRF*, in Equation 4.2 can be calculated from the following equation:

$$CRF = \frac{i\,(1+i)^n}{\left[(1+i)^n - 1\right]} \qquad (4.3)$$

where

i = interest rate (e.g., i = 0.07 for a 7% interest rate)
n = equipment life (in number of years)

For CEMS systems, the agency typically assumes an equipment life of 10 years.

4.5 Sample Calculation

What is the cost for a Extractive SO_2 gas analyzer on a new facility with sampling locations before and after the control device? Assume an interest rate of 7% and that the monitor has a 10-year life.

Step 1: Calculate Total Capital Investment, *TCI*, from Equation 4.1:

$$TCI = k1 + (k2 \times A) + (k3 \times B) + (k4 \times K) + (k5 \times D) + (k6 \times E) + (k7 \times F)$$

Loaded labor rates from Table 4.11:

A = CEE Rate = \$42.0/hr
B = Plant Technician I Rate = \$25.2/hr
C = Plant Technician II Rate = \$37.8/hr
D = Consultant Rate = \$89.1/hr
E = Test Crew Rate = \$52.8/hr

Equipment Cost from Table 4.12:

F = Equipment cost for an Extractive SO_2 CEMS = \$12,500

Coefficients k_1, k_2, k_3, k_4, k_5, k_6 and k_7 from Table 4.13:

k_1 = \$150,130
k_2 = 368.5 hrs

k_3 = 248.1 hrs
k_4 = 0 hrs
k_5 = 120.8 hrs
k_6 = 135.0 hrs
k_7 = 2

Substituting these values into equation 4.1 gives:

$$TCI = \$150{,}130 + \$15{,}477 + \$6{,}252 + \$0 + \$10{,}763 + \$7{,}128 + \$25{,}000$$
$$= \$214{,}750$$

Step 2: Calculate Capital Recovery Factor, *CRF*, from Equation 4.3:

$$CRF = \frac{0.07 \times (1 + 0.07)^{10}}{\left[(1 + 0.07)^{10} - 1\right]}$$

$$CRF = 0.1424$$

Step 3: Calculate Total Annual Cost, *TAC* from Equation 4.2:

$$TAC = k_8 + (k_9 \times A) + (k_{10} \times B) + (k_{11} \times C) + (k_{12} \times D)$$
$$+ (k_{13} \times E) + (k_{14} \times F) + (CRF \times TCI)$$

Loaded labor rates from Table 4.11:

A = CEE Rate = \$42.0/hr
B = Plant Technician I Rate = \$25.2/hr
C = Plant Technician II Rate = \$37.8/hr
D = Consultant Rate = \$89.1/hr
E = Test Crew Rate = \$52.8/hr

Equipment Cost from Table 4.12:

F = Equipment cost for an Extractive SO_2 monitor = \$12,500

Coefficients k_8, k_9, k_{10}, k_{11}, k_{12}, k_{13} and k_{14} from Table 4.14:

k_8 = \$5,110
k_9 = 50.8 hrs

k_{10} = 548.9 hrs
k_{11} = 0 hrs
k_{12} = 1.8 hrs
k_{13} = 113.9 hrs
k_{14} = 0.2

From Step 1, *TCI* = $214,750. Substituting these values into equation 4.2 gives:

$$
\begin{aligned}
TAC &= \$5{,}110 + \$2{,}134 + \$13{,}832 + \$0 + \$160 + \$6{,}014 + \$2{,}500 + (CRF \times TCI) \\
&= \$29{,}750 + (0.1424 \times \$214{,}750) \\
&= \$60{,}330
\end{aligned}
$$

The total capital investment is $214,750 and the total annual cost is $60,330 for a SO_2 extractive CEMS with sampling locations before and after the control device.

4.6 Acknowledgements

We gratefully acknowledge the following companies for contributing data to this section:

- CiSCO Systems
- Monitor Labs
- Analect Instruments

References

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[3] Draft Periodic Monitoring Guidance, May 11, 1998

[3a] Continuous Emissions Monitoring Systems Market Analysis, October 1994, p2-1.

[4] User Manual: United States Environmental Protection Agency's Continuous Emissions Monitoring System Cost Model Version 3.0, p 3-2.

[5] Continuous Emissions Monitoring Systems Market Analysis, October 1994, p2-6.

[6] User Manual: United States Environmental Protection Agency's Continuous Emissions Monitoring System Cost Model Version 3.0, p 3-3.

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Appendix A

ASSUMPTIONS FOR PERSONNEL AND EQUIPMENT COST FACTORS

Appendix A consists of tables of assumed values for personnel and equipment cost factors. The total capital investment (TCI) and total annual cost (TAC) equations, Equations 4.1 and 4.2, were derived with these values built into them. These assumptions must be considered in determining the applicability of the equations to a specific source. See the CEMS Cost Model for additional information regarding these tables and their development.

Table 4.15: Default Personnel Travel and Per Diem Cost Factors

Cost Item	CEE Technicial	Plant Technician II	Plant Consultant	CEMS Personal	Test
Wage rate, \$/hr w/o OH	30.00	18.00	27.00	27.00	16.00
Overhead (OH), % of wage rate	40	40	40	200	200
Fee, % profit	N/A	N/A	N/A	10	10
Hourly Rate1	42.00	25.20	37.	89.1	52.8

Table 4.16: Default Auxiliary Equipment Costs for CEMS (\$)

Equipment	Extractive	In-situ	FTIR
Sampling system			
After control	40,000	1,000	38,000
Before control	50,000	2,000	48,000
Data acquisition system	20,000	20,000	16,000[a]
CEMS shelter	12,000	N/A	10,000
Fabrication of system in shelter	12,800	N/A	7,700
Monitor control unit	N/A	10,000	N/A

[a] Only needed if system includes opacity or PM monitor.

TECHNICAL REPORT DATA

(Please read Instructions on reverse before completing)

1. REPORT NO. 452/B-02-001	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE The EPA Air Pollution Control Cost Manual		5. REPORT DATE January, 2002 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Daniel Charles Mussatti		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Air Quality Standards and Strategies Division Innovative Strategies and Economics Group Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Director Office of Air Quality Planning and Standards Office of Air and Radiation U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/200/04
15. SUPPLEMENTARY NOTES Updates and revises EPA 453/b-96-001, OAQPS Control Cost Manual, fifth edition (in English only)		
16. ABSTRACT In Spanish, this document provides a detailed methodology for the proper sizing and costing of numerous air pollution control devices for planning and permitting purposes. Includes costing for volatile organic compounds (VOCs); particulate matter (PM); oxides of nitrogen (NOx); SO2, SO3, and other acid gasses; and hazardous air pollutants (HAPs).		

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Economics Cost Engineering cost Sizing Estimation Design	Air Pollution control Incinerators Absorbers Adsorbers Filters Condensers Electrostatic Precipitators Scrubbers	

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(Report)* Unclassified	21. NO. OF PAGES 1,400
	20. SECURITY CLASS *(Page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE