Continuous Emission Monitoring (CEM) System Application and Maintenance Guide

Technical Report

Plant Maintenance Support

Reduced Cost

Equipment Reliability

FMAC

Continuous Emission Monitoring (CEM) System Application and Maintenance Guide

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REPORT SUMMARY

Large quantities of gases and particulate matter are emitted daily from industrial plants and fossil-fueled steam generating facilities. The gases include sulfur dioxide (SO_2), the nitrogen oxides (NO_x), and carbon dioxide (CO_2). All of these gases affect the environment in some manner. Sulfur dioxide and the nitrogen oxides are precursors to acid rain. High levels of nitrogen oxides lead to the generation of photochemical smog, while carbon dioxide is implicated in climate change (global warming).

Background

Continuous emission monitoring (CEM) systems have been in use since the late 1960s. Although the sample extraction techniques and analytical methods in CEM systems are often the same as those used by process control systems ("process monitoring systems"), when these methods are applied for environmental reporting, the systems become more complex.

Objectives

- To provide a guidance document for plant personnel (primarily technicians) responsible for maintaining CEM systems
- To review failure data and equipment performance to establish a basis for maintenance recommendations
- To improve reliability of equipment used for continuous emissions monitoring
- To provide guidance for effort reduction associated with operating emission monitoring equipment

Approach

The issue of equipment obsolescence is a key concern and is addressed in this guide. Any CEM system can be made to operate with high availability and to meet U.S. Environmental Protection Agency (EPA) performance and quality control specifications. The difference between good and bad systems is the level of attention required for them to meet specifications. As systems age, the level of attention required to maintain performance increases. Over time, newer instrumentation becomes available on the market that can reduce the frequency of maintenance. Retiring old equipment is often a political and/or economic issue rather than a technical issue. The issues faced by management associated with such obsolescence decisions are discussed.

The general approach of this guide is to direct the technician's attention to the fact that CEM systems used for regulatory reporting require attention to both the hands-on common sense techniques necessary to fix instrumentation and the regulatory requirements that specify how they are to perform. The fundamental regulatory requirements are reviewed here, but the major focus is on the common sense approaches that can be taken to meet requirements.

EPRI Perspective

The information provided in this guide responds to the need for consistent operation and maintenance practices for continuous emission monitoring systems. By providing a resource for the technician, maintenance practices are recommended that can improve the efficiency of monitoring programs by reducing corrective maintenance events and increasing system availability.

The report provides the technician with information that can assist in identifying CEM system problems. Rather than continually reacting to recurring problems, a technician should be in a position to find the causes of systems' problems in order to reduce incidences of corrective maintenance. Through the establishment of preventive maintenance schedules related to known failure rates, the use of control charts to identify developing malfunctions, and consistent logbook documentation, less downtime can be realized.

Keywords

Continuous emission monitoring
Maintenance
Gas monitors
Acid rain program
NO_x budget program
Instrumentation and control

EXECUTIVE SUMMARY

Continuous emission monitoring (CEM) systems are used to measure the levels of sulfur dioxide, nitrogen oxides, and carbon dioxide released into the atmosphere from facilities that burn fossil fuels. A wide variety of instrumentation has been applied for this purpose since the 1960s, which has evolved with developments in technology and technology-forcing regulations. The electric utilities, first meeting the monitoring requirements of the New Source Performance Standards in the 1970s through the 1980s, later faced the more demanding requirements of the Acid Rain Program in the 1990s. Over 30 years of monitoring applications has led to a mature technology that can provide emissions data of known precision and accuracy.

The principal factor in the evolution of CEM system technology was the growing realization in the 1980s that CEM performance is dependent upon the quality of the maintenance performed on the systems. The institution of quality assurance requirements through the EPA reinforced this understanding by specifying criteria for the operation and maintenance, documentation, and performance audits. The Acid Rain Program extended and refined these requirements to the point where data of known quality can be practically assured if its prescriptive procedures are followed.

Central to the success of these monitoring programs is the person or persons who operate and maintain the systems and analyzers. The CEM system technician conducting routine preventive maintenance, emergency repairs, and performance evaluations has been found to be the key to a successful facility monitoring program. Skilled and dedicated technicians, given the necessary resources, can make CEM systems operate to the most stringent regulatory mandates. This guide focuses on the role of the technician in the world of CEM systems. Most of the CEM literature has been directed to the engineer, the environmental manager, who has been given the task of managing the monitoring program—selecting the system, overseeing its certification, and documenting and reporting its operation, where reporting the details of operation as well as operating data allows little room for error. However, the importance of the details is not always relayed to those operating and maintaining the systems. This guide attempts to focus on those details that are central to the effective maintenance of a CEM system. It attempts to provide a perspective for the technician for his or her part in helping the plant to meet its environmental commitments.

Section 1 of the manual introduces the purpose and scope of the manual to the reader. Section 2 provides an overview of CEM systems, to offer a perspective on equipment that other plants might be using and alternatives to those currently in use.

Section 3 discusses the responsibilities of the CEM technician and different approaches to maintaining monitoring systems.

Section 4 focuses on the daily calibration check, probably the single most important test, beside the relative accuracy test, for the CEM analyzers. Although perhaps overemphasized, performance of the daily calibration check is often an indicator of the quality of maintenance, which reflects the job performance of the technician.

Performance audits of the equipment, the relative accuracy test, and the linearity test are discussed in Section 5. The equations that these tests require should be understood and are given in this guide not just to repeat the regulations but to encourage their independent calculation during the tests so that source testers and associated computer programs can be cross-checked.

Section 6 contrasts different approaches to preventive maintenance and discusses the importance of predictive and proactive activities in developing an efficient maintenance program. Examples of different forms used for system inspections are offered for reader applications.

Section 7 offers approaches for troubleshooting systems to a level where the root cause of system problems can be determined so that problems will not have to be repeated. Section 9 complements this discussion by noting that in some cases, the best solution may be to move on and purchase a new system. Section 8 lists those areas where documentation is required or traditional, such as the keeping of a logbook.

The material given in the appendices of the manual is provided to assist the technician when it is necessary to reference the work of others or to contact those vendors who might be able to assist with technical problems. To those newly entering the field of CEM systems, at first it may appear that no one has ever done this before. The CEM literature is typically not well referenced and not widely circulated, leading to the ongoing discovery of problems and solutions that were well known 20 years ago. It is intended that the lists of references, when consulted, may assist in clarifying or supplementing information on specific issues when they arise.

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1 INTRODUCTION

Restrictions have been placed on the emission of combustion products in order to reduce environmental effects. These restrictions and emissions controls have caused changes in plant operational methods. To control emissions, one must know what gases or materials are being emitted and how these substances are being emitted. Monitoring instruments provide detection and control of monitored materials. Operating as "continuous emission monitors," they serve to provide emissions data both for plant operational control and for regulatory reporting of emissions (see Figure 1-1).

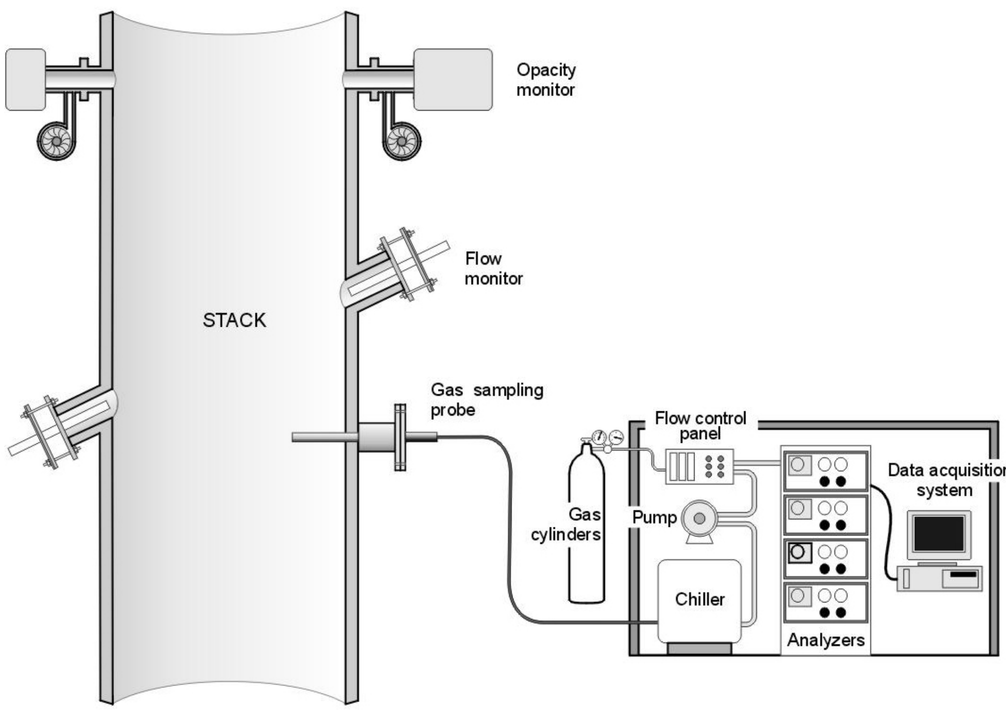

Figure 1-1
Typical Continuous Emission Monitor (CEM) System

Because the CEM systems required by regulatory programs must meet mandated levels of performance, the resources necessary to maintain and operate CEMs are greater than those for process monitors. Extra requirements such as daily calibration checks using certified gases, annual accuracy testing conducted by source testing companies, and validated electronic data reporting cost money; but in return, the data quality can be more defensible. Knowing the precision and accuracy of CEM system data, operators can be confident in using the data for operational control, particularly when required to stay within mandated NO_x emission limits or for maintaining the reduction efficiency of pollution control equipment (for example, SO_2 scrubbers or NO_x selective catalytic reduction systems).

1.1 Purpose

Much of the current literature on CEM systems is written for the environmental engineer, either in the agency or in industry, who will be implementing a CEM program. With the advent of allowance trading programs such as the Acid Rain and NO_x Budget Programs, CEM programs are often managed at different levels of authority than process instrumentation. A corporate engineer or a plant environmental engineer may manage the purchasing, installation, and certification of the system. Management of the day-to-day operation of the system typically resides with the Instrumentation and Controls Supervisor, but reports route through the engineer. The EPA has provided guidance for the engineer [1], as has the EPRI (Electric Power Research Institute) [2]. Bias issues have been discussed for CEM systems on installation and certification [3].

1.2 Scope

The technician assigned the responsibility of operating and/or maintaining a CEM system is in the position of not just having to maintain the system but to maintain the system to levels of expectation specified in a rule. In this way, CEM systems are distinct from process monitors in that both technical factors and regulatory conditions affect their operation and maintenance. Maintenance schedules must be adhered to; preventive and corrective maintenance must be documented; and performance audits must be conducted, passed, and reported on schedule. CEM systems must, in general, operate properly for more than 95% of the time a unit is operating. The data must be defensible.

Because the regulatory application of CEM systems implies a different level of attention than that necessary for other plant instrumentation, technicians must be aware that such attention is needed. This guide provides the technical and regulatory perspectives needed by the instrumentation technician to work with CEM systems. Its purpose is to provide information on the maintenance of CEM systems, to offer approaches seeking the causes of system problems, and to describe accepted documentation procedures. To accomplish these objectives, some background information is given on options available in CEM system design and the regulations that have mandated their use.

1.3 Background

Electric utilities that burn coal, oil, or gas are required through the U.S. EPA Acid Rain Program to report SO_2 and NO_x emissions. The State/Federal NO_x Budget Program requires utilities and industrial sources to report NO_x emissions during the summer ozone season. These programs require that the monitoring systems used meet:

- Certain design and installation specifications
- Initial performance in order to be certified
- Continuing operation standards (quality control check)

Process monitors have no such requirements and are typically operated at levels sufficient for their purpose.

1.4 Pop Outs

Throughout this guide, key information is summarized in "Pop Outs." Pop Outs are bold lettered boxes that succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Pop Out is to emphasize information that will allow individuals to take action for the benefit of their plant. FMAC personnel, the consultants, and utility personnel selected information included in these Pop Outs.

The Pop Outs are organized according to three categories: O&M Costs, Technical, and Human Performance. Each category has an identifying icon, as shown below, to draw attention to it when quickly reviewing the guide.

Key O&M Cost Point

Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent injury or damage or to ease completion of the task.

Appendix E contains a listing of all key points in each category. The listing restates each key point and provides reference to its location in the body of the report. By reviewing this listing, users of this guide can determine if they have taken advantage of key information, the writers of the guide believe would benefit their plants.

2
CONTINUOUS EMISSION MONITORING (CEM) SYSTEMS

This section reviews the primary commercial CEM systems in use:

- Extractive dilution systems
- Extractive source-level systems
- *In situ* systems

To maintain these systems, knowledge of their design and inherent biases must be understood so as not to mistake their limitations for system or analyzer malfunctions.

Extractive systems are designed to draw gas from the stack, condition it, and direct it to an analyzer or bank of analyzers. *In situ* systems do not extract the gas but measure it in place (*in situ*) in the stack or duct. For pollutant gas measurements, the extractive systems have been more popular in the United States (U.S.). *In situ* gas monitors are more widely installed in Europe, Canada, and Asia. Either type of system can be designed to satisfy the performance specifications of the U.S. Environmental Protection Agency (EPA). The choice of a system should be dependent upon the limiting factors of the application; however, rigorous technical evaluations are not always conducted. Instead, other factors (such as popularity, cost, blanket contracts, or user recommendations) may override an analytical approach to CEM system installation decisions.

The extractive systems can be separated into two categories:

- Dilution systems
- Source-level or non-dilution systems

In dilution systems, clean, dry air is mixed with the flue gas sample at a ratio of from 50 to 1 to 300 to 1. The gas concentrations are then sent to analyzers capable of measuring at the lower levels. Dilution systems have been extensively applied by the electric utilities industry to meet the monitoring requirements of the U.S. EPA Acid Rain Program given in Part 75 of Title 40 of the U.S. Code of Federal Regulations (40 CFR 75). Because the flue gas moisture is usually not removed in a dilution system, the pollutant gas concentrations are determined on a wet basis.

The wet basis concentration times the flue gas volumetric flow rate (wet basis) gives simply the emission rate in pounds per hour (lbs/hr) [kilograms per hour (kg/hr)] (see Equation 2-1).

$$pmr = cQ \qquad \textbf{Eq. 2-1}$$

where:

pmr = pollutant mass rate (lbs/hr) (kg/hr)

c = pollutant gas concentration (wet basis) (lbs/ft^3) (kg/m^3)

Q = flue gas volumetric flow rate (wet basis, ft^3/hr) (m^3/hr)

This, of course, is ideal for reporting emissions in tons per year, which are the emissions allowances traded in the Acid Rain Program.

Source-level systems have been used by the electric utilities in the Acid Rain Program, particularly on gas turbines. The lower emissions levels exhibited by gas turbines can be more difficult to measure at the higher dilution ratios. Source-level systems are more flexible in the choice of analytical techniques and more easily modified than dilution systems. Because of their flexibility, they are used extensively in municipal and hazardous waste incinerators and in the process industries, such as petroleum refineries, pulp mills, and cement plants.

Key Technical Point

Source-level systems are more flexible in the choice of analytical techniques and more easily modified than dilution systems. They are used extensively in municipal and hazardous waste incinerators and in the process industries, such as petroleum refineries, pulp mills, and cement plants.

In situ monitors, such as opacity monitors, flow monitors, and in-stack oxygen monitors all have wide application in fossil-fueled electric power generating stations. Opacity monitors are required under most state programs and the Acid Rain Program mandates the use of flue gas flow monitors for coal-fired sources affected by the program. There are two general classes of *in situ* monitors:

- Path monitors
- In-stack or point monitors

Path monitors project a light beam across a stack and measure the effects of the flue gas on the beam at a detector on the other side of the stack or reflect the beam to measure the effects at the "transceiver" (the sender/receiver). The point in-stack oxygen monitors and the zirconium oxide sensors are used worldwide as process monitors for combustion control and for the measurement of flue gas dilution caused by excess air used for combustion. *In situ* monitors designed to measure SO_2 and NO_x have not been popular in the U.S. The path monitors, in particular, have difficulty in accommodating the daily calibration gas checks and quarterly gas linearity checks mandated in Part 75 and few have been applied in Part 75 programs. *In situ* monitors, as a class, require less maintenance than extractive systems when installed for appropriate applications. However, due to the sophistication of these monitors, when problems occur, a factory service representative most often must perform troubleshooting and maintenance.

Key O&M Cost Point

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Key Technical Point

Path monitors, in particular, have difficulty in accommodating the daily calibration gas checks and quarterly gas linearity checks mandated in Part 75.

Table 2-1 gives the distribution of 2700 new CEM systems installed by the electric utility industry to meet the requirements of the Acid Rain and NO_x Budget programs.

Table 2-1
Types of CEM Systems Installed at the Electric Utilities

Sampling Method	SO_2 CEM Systems (%)	NO_x CEM Systems (%)
Dilution (In-Stack)	77	50
Dilution (Out-of-Stack)	10	8
Source-Level Extractive	9	40
In Situ	4	2

Two other types of emission monitoring techniques are available but have been limited in their application. These are remote sensing and predictive emission monitoring systems (PEMS). In remote sensing techniques, infrared radiation emitted from hot molecules in the flue gas plume is collected by a telescope and measured, or light is beamed up to or through a flue gas plume, and the light scattering and/or absorption is measured. Performance specifications have not been developed for these instruments (except for the use of Lidar in EPA Test Method 9A, a noncontinuous opacity measurement method), nor has the option for their use been addressed in regulation.

Predictive emission monitoring systems are computer models that use operating parameters as inputs. Operating parameters (such as steam flow, temperature, pressure, and so on) are correlated against stack test data to generate the model. As long as the correlation holds, a PEMS can provide valid emissions data. However, if the conditions under which the correlation was developed change, then the emissions data become uncertain. Predictive monitoring systems have been successful when applied to sources where the correlation does not vary appreciably, but their wider use has been limited.

2.1 Extractive Dilution Systems

Extractive dilution systems incorporate probes that dilute the flue gas with air that has been conditioned to remove water (CO_2) and the pollutants that will be measured. Commonly used dilution probes have two basic designs:

- One with the dilution conducted in-stack, within the probe itself
- The other, which uses a dilution assembly close-coupled to the probe at the probe port

2.1.1 The In-Stack Dilution Probe

The in-stack dilution probe is the most common type of dilution system used in Acid Rain Program installations. The probe design is shown in Figure 2-1.

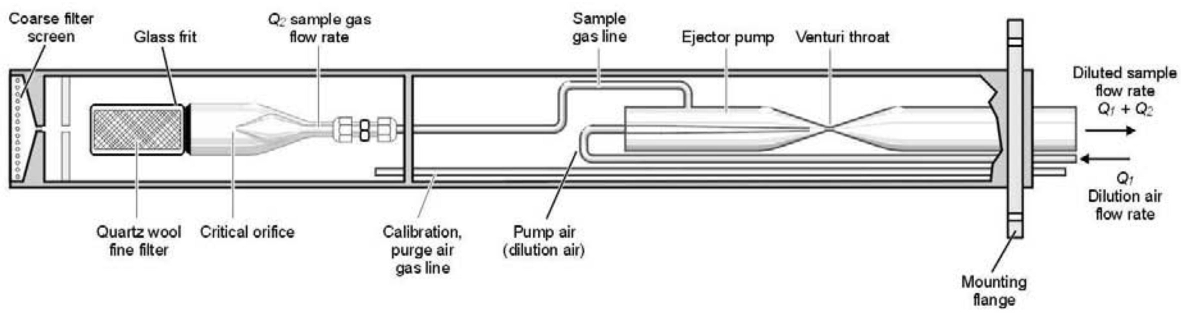

Figure 2-1
The EPM In-Stack Dilution Probe

The in-stack dilution probe is designed to dilute the flue gas at the end of the probe. Inserted into the stack or duct, gas is extracted at only one point in the gas stream. The probe itself serves both as a pump and dilution system. The dilution air provides the motive force for the pump as well as the dilution air. The dilution ratio is expressed as:

$$D_0 = \frac{(Q_1 + Q_2)}{Q_2} \qquad \textbf{Eq. 2-2}$$

where:

Q_1 = the flow rate of the dilution air

Q_2 = sample flow rate

The dilution air flow rate (Q_1) is controlled by a pressure regulator on the system control panel, whereas the sample flow rate is fixed by a critical orifice inside the probe. In the EPM probe shown in Figure 2-1, the critical orifice is incorporated in a glass assembly that includes a glass wool filter and the orifice. The orifice filter is secured to the probe using a compression fitting with a graphite ferrule. A coarse steel mesh particulate filter at the end of the probe and the fine quartz wool within the probe are designed to prevent plugging of the orifice.

The condition for obtaining a critical flow for the gas sonic orifice is that the ratio of the absolute pressure at the venturi throat (the pump vacuum) to the stack static pressure be less than or equal to 0.53 psi (3.65 kPa). This critical flow rate is dependent upon the size of the orifice and the gas density, which is dependent upon the gas temperature, pressure, and molecular weight. Typical flue gas flow rates through the orifice are on the order of 1.22 in^3/min–3.05 in^3/min (20 cc/min–50 cc/min). Typical dilution air flow rates are on the order 244 in^3/min–305 in^3/min (4000 cc/min–5000 cc/min).

The probe can be equipped with a heater to eliminate condensation at the probe tip and minimize the effect of temperature variation on the dilution ratio. Compensation for changes in ambient and stack pressure can be made by incorporating a pressure transducer in the system and either correcting the dilution ratio in the control or data acquisition system or by adjusting the dilution air pressure in correspondence with changes in the total stack pressure.

A calibration gas line extends into the probe, so that calibration gas, at the same concentration levels as the flue gas components, purges flue gas out from the inside of the probe assembly and is drawn into the orifice to check the operation of the system. This in-stack dilution probe is efficient in its design and requires skill in its manufacture.

An umbilical line transports the calibration gases and dilution air to the probe and the diluted sample to the sample controller and analyzers. For dilution systems, the sample may or may not be heated. Because the sample is diluted to a dew point of -40ºF (-40ºC) (that is, moisture in the sample gas) until the umbilical temperature decreases to below -40ºF (-40ºC), it is not necessary to heat the sample line above the flue gas temperature. However, it is common to provide "freeze protection," where the line is heated to a temperature of 70ºF (21.1ºC) or somewhat higher.

2.1.2 Out-of-Stack Dilution Systems

Out-of-stack dilution systems draw a sample and dilutes the sample outside of the stack, usually close-coupled to the stack or duct at the end of the sample probe. Two designs, one manufactured by Thermo Environmental (formerly known as the STI probe) and the other by M&C Products, Inc., have seen numerous applications.

In the STI probe, the sample is extracted and filtered from particulate matter at the inside of a tubular fiber filter (see Figure 2-2). The sample is extracted at low flow rates and particles will deposit either in the probe or inside the filter. An ejector pump (educator) again pulls in the sample, with the pump air also providing the air for dilution. The flue gas is drawn through the filter, through a glass capillary, and then combines with the dilution air to continue to the analyzers. The capillary serves as the critical orifice, which again controls the sample flow rate as in the in-stack probe. In this design, the assembly is maintained at a constant temperature.

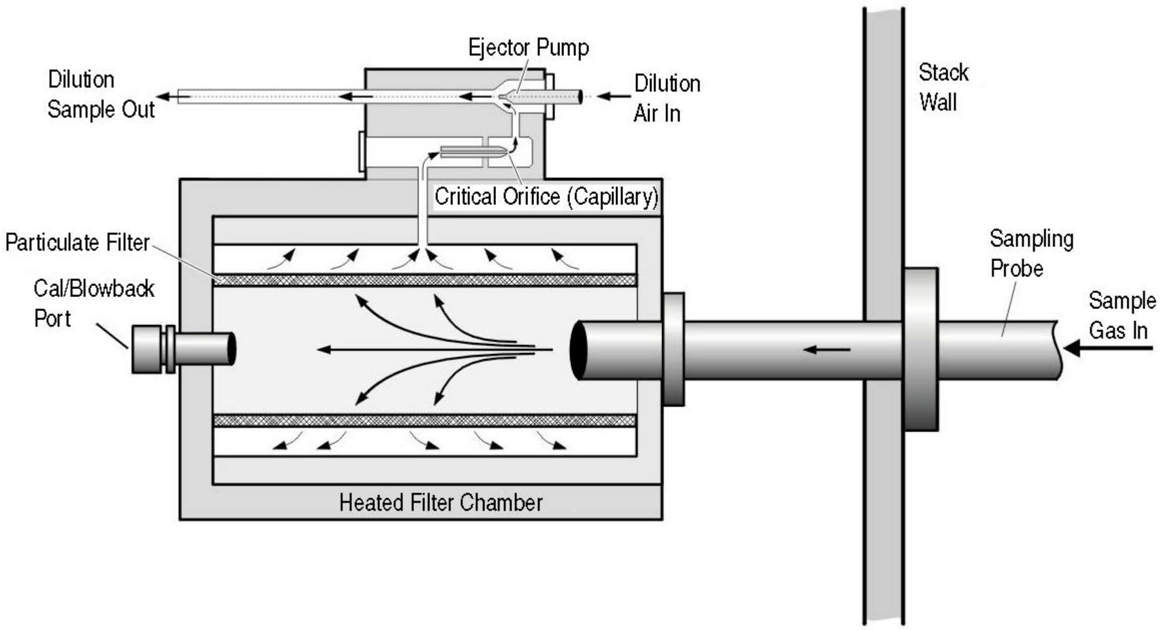

Figure 2-2
STI Probe

The M&C probe incorporates a sintered metal particulate filter inside an external dilution box (see Figure 2-3). Here, particulate matter is collected on the outside of the filter, rather than on the inside, as in the STI probe. In this design, the ejector pump, the critical orifice, and a fine filter are all located into a cross fitting. Because the dilution ejector pump pulls the flue gas at such a low flow rate [typically 1.22 in^3/min–3.05 in^3/min (20 cc/min–50 cc/min)], the response time to flue gas concentration changes can be relatively slow. Adding a booster pump to the system can decrease the sample transit time down the probe. In the M&C design, another ejector pump (eductor) brings in the sample at a faster rate and the dilution eductor located in a connector cross and draws a sample slipstream from the bypass pump flow. The filter located in the cross and another in the dilution air line prevents particles from plugging the orifice or dilution eductor.

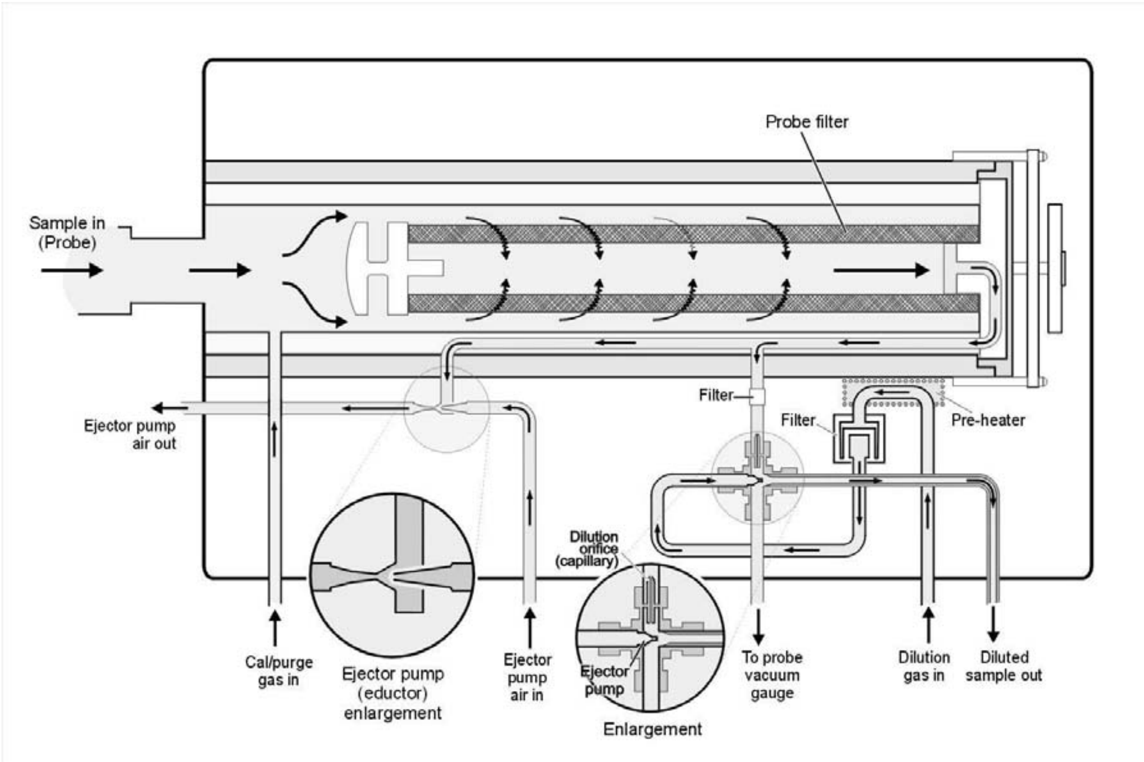

Figure 2-3
M&C Probe

Other companies (Teledyne-Monitor Labs and Thermo Environmental) also manufacture out-of-stack dilution systems. The temperature of out-of-stack systems can be maintained relatively independently of flue gas temperature changes, a factor that allows calibration checks of the system when the utility or process unit is down. Also, the out-of-stack design allows modification for the diversion of part of the undiluted sample gas stream to an oxygen analyzer. This offers an advantage for those who wish to measure flue gas oxygen, because once diluted with air, the sample is swamped with oxygen and the flue gas oxygen concentration cannot be determined.

The extractive system that accompanies the probe is shown in Figure 2-4.

Key Technical Point

The out-of-stack design allows modification for the diversion of part of the undiluted sample gas stream to an oxygen analyzer. This offers an advantage for those who wish to measure flue gas oxygen.

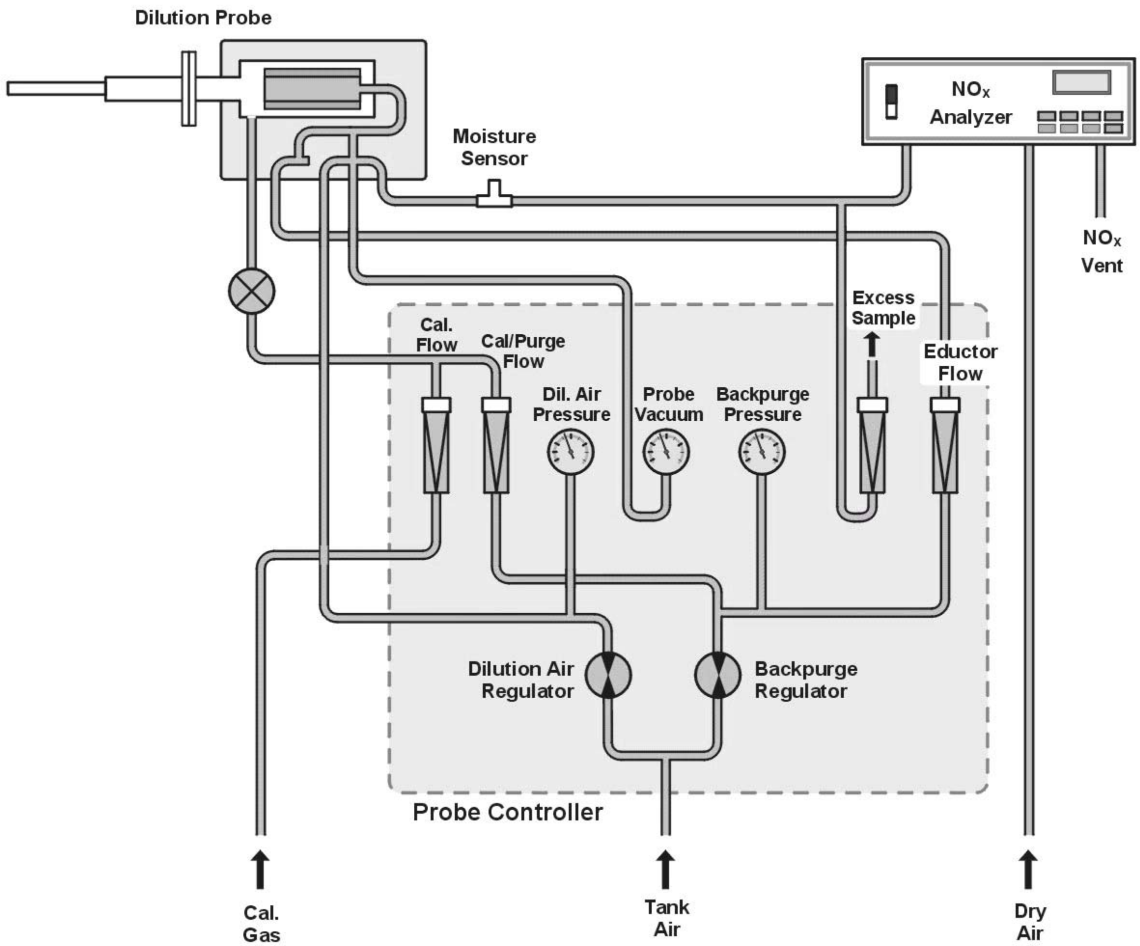

Figure 2-4
A Dilution Probe Extractive System

2.1.3 The Air-Cleanup Subsystem

The air used for dilution in any dilution system must be clean and dry in order to avoid interference effects when the sampled gas is analyzed for SO_2, NO_x, CO_2, or other gases. In addition to its use as dilution air, air cleaned in the air-cleanup system may also serve as zero air for the analyzers or in some systems, as blowback air to purge the probe of particulate matter. Figure 2-5 shows a typical air-cleanup system.

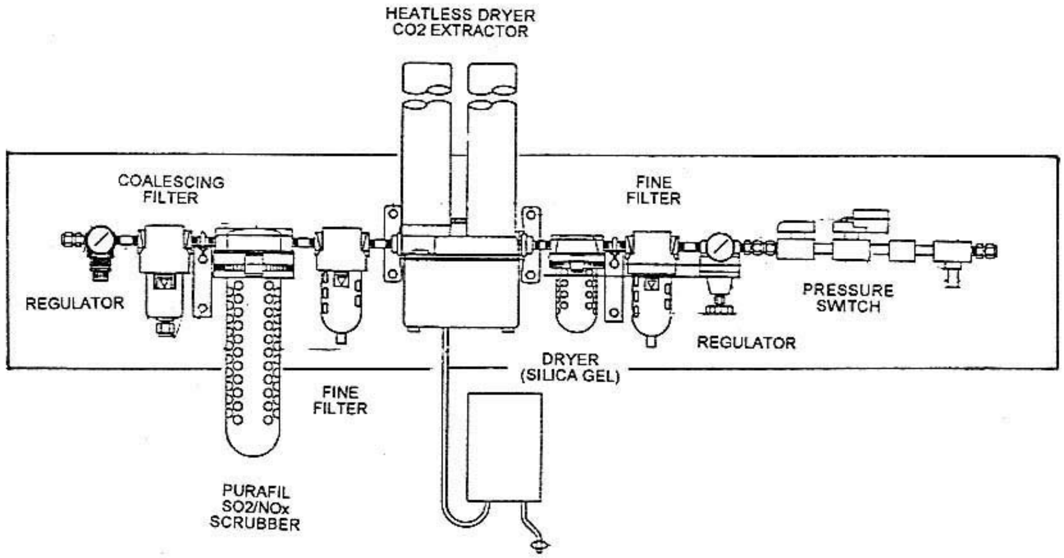

Figure 2-5
Air-Cleanup System

The air-cleanup system removes particulate matter by filtering to less than five microns nominal particle size using a replaceable high-efficiency fiber filter. Moisture removal is performed using a regenerative dryer system that reduces the moisture content of the air supply to dew points on the order of -40ºF (-40ºC). In addition to particulate and moisture removal, the air filter/dryer system is equipped with chemical scrubbers to remove traces of NO_x and CO_2 from the inlet air (usually plant instrument air) that is being treated. Activated charcoal and the material Purafil™, which has an alumina-based substrate impregnated with potassium permanganate and sodium bicarbonate, has the capacity to remove NO_x and SO_2 as well as other lower molecular weight gases.

Regenerative dryers remove moisture or both moisture and CO_2, depending upon the materials placed in the columns. The regenerative desiccant dryers designed to remove moisture typically contain silica gel in two identical towers. The silica gel (or other materials, such as molecular sieves or activated alumina) condenses and absorbs moisture in the pores of the material. While one tower is drying the gas, the other is being reactivated by the flow of dry, compressed air. Dryers can be either cold (heatless) regenerative or heat regenerative. In the heatless units, a portion of the unheated, dried air from one tower is sent to the other tower to regenerate the desiccant. In heated regenerative dryers, the purge air is heated to 300ºF (148.9ºC) to 400ºF (204ºC) before being directed to the regenerating dryer.

Coalescing filters are used as pre-filters to remove moisture droplets and oil from plant air before entering the system. They contain masses of microfilament that trap particulate matter, moisture, and oil mists. In their passage through the filter, small droplets coalesce into larger droplets that settle by gravity into a filter bowl at the bottom of the filter. The collected liquid can then be removed either manually or automatically.

Air-cleanup systems are generally operated automatically; however, the system components do require periodic attention. Filters and adsorbents do have to be checked and replaced. Solenoid valves also require periodic replacement.

Key Technical Point

Although air-cleanup systems operate automatically, the system components require periodic maintenance.

2.1.4 Dilution Probe Controller

The typical dilution system is monitored and controlled using a probe controller typically installed in a CEMS instrument rack. The dilution air regulator and purge air regulator valves (if applicable) are usually incorporated into the controller. On the panel, gauges for the dilution air and the probe vacuum are typically installed. Flowmeters (rotometers) that provide ejector pump flow, back-purge flow, and calibration gas flow may be installed. The gauge and flowmeter readings are normally checked on a daily or weekly schedule.

The dilution air pressure regulator maintains a constant air flow independent of upstream pressure. Mass flow controllers have been used in some systems to maintain the dilution air flow at a constant level.

2.1.5 The Gas Handling Subsystem

Gas handling subsystems are integral to any CEM system designed to meet EPA Part 75 or Part 60 requirements. The subsystem provides a means for automatically injecting zero and span gases through the probe to the analyzers. Most monitoring systems also provide for the automatic injection of the certified gases used in the quarterly linearity checks or for the cylinder gas audits required under Appendix F of 40 CFR 60.

Although gas handling systems are relatively simple, for the technician, they account for a considerable amount of the time spent working with CEM systems. Cylinders expire, new gases have to be ordered, and the cylinder pressures have to be regularly checked.

Key O&M Cost Point

Although gas handling systems are relatively simple, for the technician, they account for a considerable amount of the time spent working with CEM systems.

The gas handling system distributes the gas from gas cylinders through gas regulators and solenoid valves, and the controls are timed for automatic calibration checks or linearity test sequences. The cylinder gas pressures should not fall below 150 psi (1034 kPa) where the gas concentrations may become uncertain, and the delivery pressures are set at a fixed value. The analyzers are checked daily with a zero gas (that contains less than 0.1 ppm of SO_2 or NO). The dilution air may serve this purpose, but it is recommended that the analyzer zero levels be checked periodically with gas from a reference air cylinder to ensure that the dilution air is free of contaminants. The concentration of the gases used for daily calibration checks is based on the "span value," a value determined using the procedures of Appendix A of Part 75 or a value otherwise mandated in Part 60 or Part 75.

Single-blend or multiblend calibration gases can be used for the daily calibration error checks or quarterly linearity checks. A single-blend gas contains just one pollutant with a background of either nitrogen or air. A multiblend calibration gas contains more than one pollutant gas. Multiblends of SO_2, NO, and CO_2 in nitrogen are commonly used in dilution systems because of their gas density.

2.1.6 Dilution Probe Issues

The first installations of dilution systems installed for meeting U.S. Part 60 requirements appeared relatively straightforward. However, Part 60 emissions for SO_2 and NO_x are reported in units of lbs/mmBtu, which is calculated using the F factor method as follows:

$$E = c_s F_c \left(\frac{100}{\% CO_2} \right) \qquad \textbf{Eq. 2-3}$$

where:

E = emissions in lbs/mmBtu (kg/MW)

c_s = pollutant gas (SO_2 or NO_x) concentration

F_c = F factor (ratio of volume of CO_2 emitted per unit of fuel to mmBtu generated per unit of fuel on a stoichiometric basis)

$\left(\frac{100}{\% CO_2} \right)$ = correction term for excess air (100 divided by the % of CO_2 in the flue gas)

Changes in the flue gas temperature, pressure, or molecular weight will affect the dilution ratio equally for the determination of the pollutant gas concentration and the CO_2 concentration. In the determination of the emission rate (E), the concentration of the pollutant gas is divided by the flue gas CO_2 concentration, and these effects cancel. They will introduce no biases in the measurement.

However, when reporting emissions in units of lbs/hr, as in the Acid Rain and NO_x Budget Programs (see Eq. 2-1), the pollutant concentration is multiplied times the flue gas volumetric flow rate and no such cancellation takes place. Therefore, if a dilution system analyzer is calibrated under one given set of conditions (atmospheric pressure, flue gas temperature, single-blend gas) and those conditions should change, the next calibration error check will differ from the initial calibration. A weather front passing the plant, going from a plant shutdown to startup, or changing the calibration gas from a single-blend to a triple-blend gas will all affect the pounds per hour measurement and the next calibration check.

Key Technical Point

A weather front passing the plant, going from a plant shutdown to startup, or changing the calibration gas from a single-blend to a triple-blend gas, will all affect the pounds per hour measurement and the next calibration check.

These phenomena were not well understood in 1993, after the first Acid Rain CEM systems were installed (noting that the critical flow through the orifice is density dependent). They are now obvious, and various strategies can be applied to correct the small errors that affect the calibration. A pressure sensor can be added to the system to provide a signal that can be used to correct the data in the DAHS or to adjust the dilution air pressure to compensate. The dilution orifice can be kept at a constant temperature using a properly sized heater. One can compensate for molecular weight changes mathematically or just by being consistent in one's use of calibration gases.

Dilution probes provide a wet-basis measurement and are well suited for reporting emissions in pounds per hour. They also sample at a relatively low flow rate and do not draw in the larger particles in the flue gas stream. Because of these properties and the fewer subsystem components, maintenance for dilution probes is less than that required for source-level extractive systems.

Key O&M Cost Point

Because dilution probes provide a wet-basis measurement; have a relatively low flow rate; do not draw large particles; and have fewer components, less maintenance is required when compared to source-level extractive systems.

2.1.7 Analytical Techniques Used with Dilution Systems

Luminescence and nondispersive infrared (NDIR) spectroscopic techniques are used for the measurement of gas concentrations in dilution systems. The phenomenon of fluorescence is applied in the measurement of SO_2 and chemiluminescence for the measurement of NO. The infrared techniques are used for the measurement of CO_2 and sometimes CO.

2.1.7.1 Fluorescence Analyzers

Fluorescence instruments are commercially available that can measure SO_2 at ambient level and source-level concentrations. This wide dynamic range is suitable for application of the technique in dilution systems. In the phenomenon of fluorescence, a molecule irradiated by light of a wavelength that causes an excitation in its electronic structure will absorb light energy, dissipate some of that energy in its normal vibrations and rotations, and then emit light to come back to its original state. Materials that glow under ultraviolet light are commonly observed in today's novelty shops, museums, and entertainment centers.

In SO_2 fluorescence, light in the ultraviolet region of the spectrum, around 210 nm, excites the molecule, and emits light in a broad range of wavelengths from 240 nm–410 nm. The fluorescence process can be illustrated as:

$$SO_2 + hv_{210} \rightarrow SO_2^* \rightarrow SO_2 + hv_{240-410}$$

In the instruments designed to capitalize on this process, an ultraviolet lamp provides the light source to excite the SO_2 molecules. In addition, a detector in combination with a filter measures the light emitted in the region of 350 nm (see Figure 2-6).

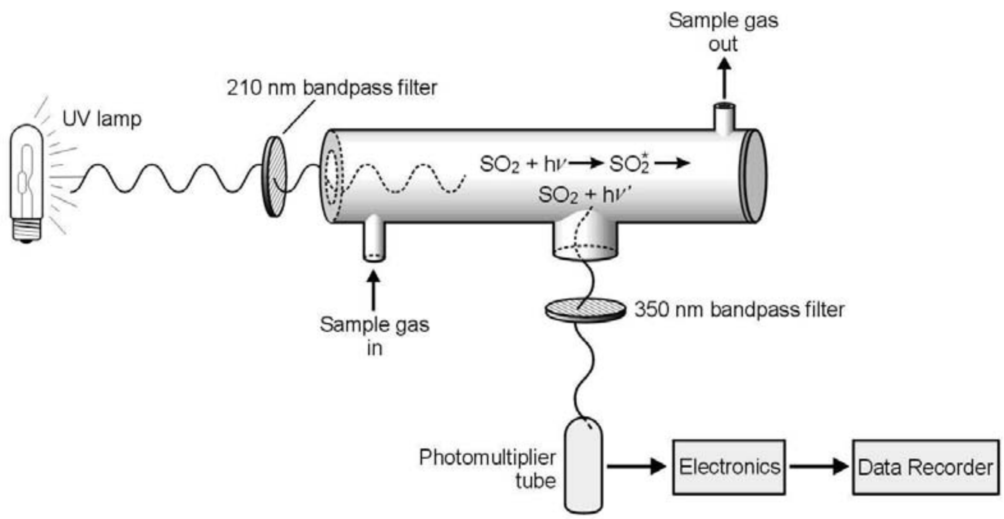

Figure 2-6
Operation of a Typical SO_2 Fluorescence Analyzer

No other molecules in a combustion source flue gas fluoresce at 210 nm, so one would expect the technique to be relatively free of interference. However, if a molecule should hit the excited SO_2* molecule, the light will be quenched, and the energy that would otherwise be released is transformed into kinetic energy. Quenching becomes important when gas concentrations at percent levels vary in the sample. This is generally not a problem in dilution system applications, where the background of clean and dry dilution air minimizes the effect.

2.1.7.2 Chemiluminescence Analyzers

Chemiluminescence is the emission of light from a molecule that exists in an excited state when produced in a chemical reaction. The molecule has more energy than it would normally have and releases this energy as light to become stable. The familiar “light sticks” that are found commercially as emergency light sources and in various novelty items react hydrogen peroxide with derivatives of luminol to chemiluminesce.

The reaction of NO with ozone (O_3) creates an excited molecule of nitrogen dioxide (NO_2*). The excited molecule then emits light over the region of 400 nm to 3000 nm.

$$NO + O_3 \rightarrow NO_2^* \rightarrow NO_2 + hv_{400-3000}$$

In a chemiluminescence analyzer, the sample gas and ozone are introduced into a reaction chamber, where the NO_2* is generated. A photodetector measures the light emitted in the region of 600 nm–900 nm (see Figure 2-7).

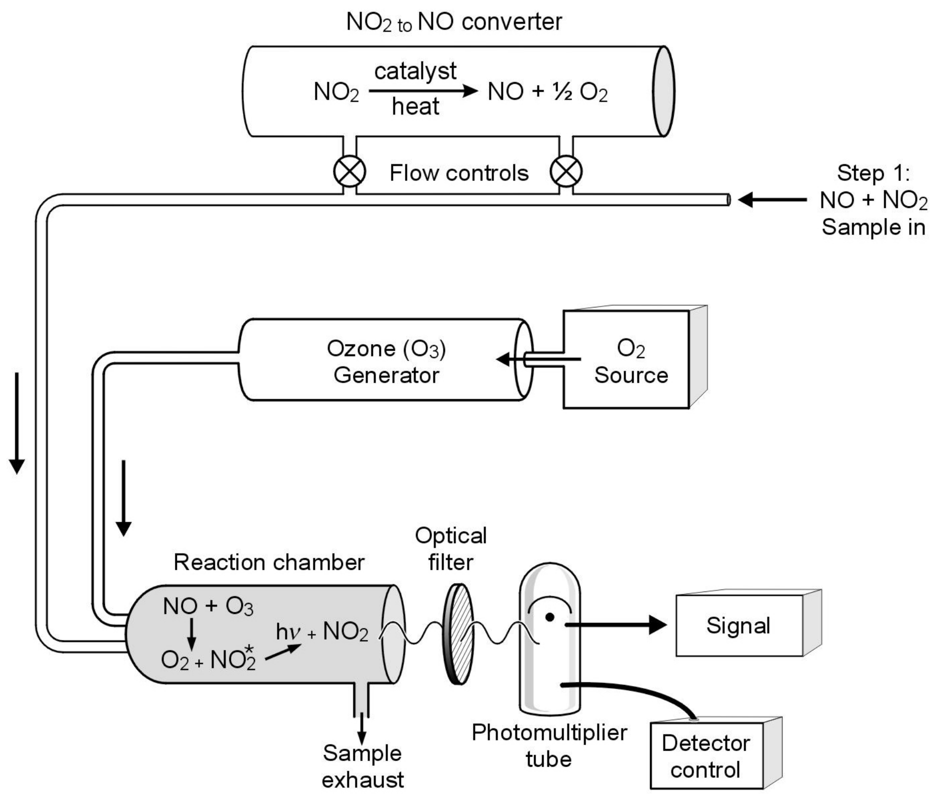

Figure 2-7
Operation of a Typical NO_x Chemiluminescence Analyzer

To measure NO_2, the NO_2 must first be reduced to NO in a converter. The converter can be a simple chamber of heated stainless steel or the conversion can be done at lower temperatures by using activated charcoal or molybdenum chips. The total nitrogen oxides (NO_x) are measured in this step by reacting the converted NO_2 and the NO in the sample with ozone. To obtain the NO_2 concentration, the instrument response obtained when the sample bypasses the converter is subtracted from the response obtained when the sample passes through the converter. Converter efficiency can decrease over time and annual checks are recommended.

Quenching also occurs in this type of analyzer but is reduced by keeping the reaction chamber under vacuum and diluting the sample with the ozone gas stream. In dilution system applications, quenching is of little concern. However, the problem becomes more serious when these analyzers are used in source-level systems, particularly on gas turbine low NO_x applications.

2.1.7.3 Nondispersive Infrared Analyzers

In nondispersive infrared (NDIR) analyzers, infrared light is used to generate vibrational and rotational excitations in the molecules being measured. The wavelengths of light used are specific to the molecule like a fingerprint, although the "fingerprints" of other molecules can overlap or interfere with the molecule of interest. When the molecule is excited by the light, energy is absorbed by the molecule and the net energy in the light beam is reduced. The amount of this reduction is measured to give a concentration of the molecules of interest in the sample. NDIR analyzers use light only over a short wavelength region (only part of the fingerprint), whereas dispersive analyzers (spectrometers) scan over many wavelengths to characterize the fingerprint.

The energy of infrared light is relatively weak compared to visible or ultraviolet light and it is therefore harder to detect small differences in energy due to infrared light absorption. The pneumatic detector was one of the first detectors to serve this purpose and is used in a number of commercial instruments. This technique is used in the California Analytics, Inc. CO_2 monitor, which was used in approximately 45% of the Part 75 installations. A schematic diagram of this instrument is shown in Figure 2-8.

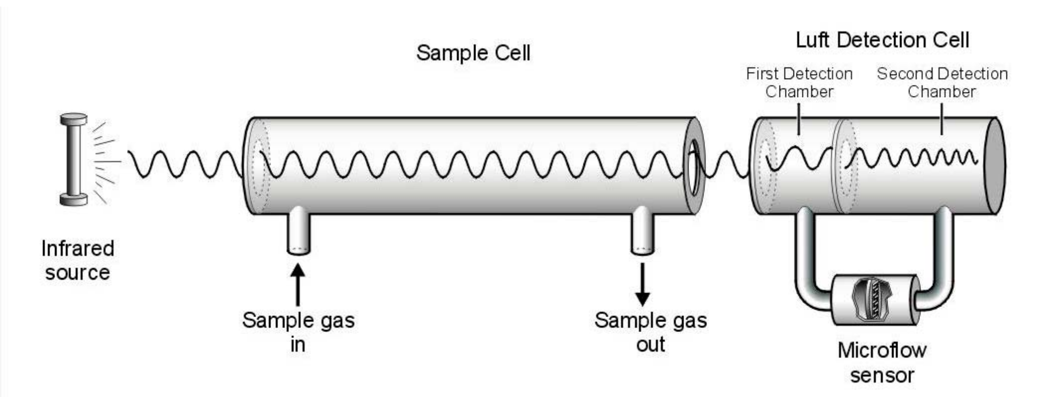

Figure 2-8
An Infrared CO_2 Analyzer with Pneumatic Detector

Absorption of light energy in the cells causes the CO_2 in one detector cell to flow into the other and cool the thermal sensor. The amount of cooling is related to the concentration of CO_2 in the sample cell. Because of the stacked design of the pneumatic sensor, the instrument is relatively insensitive to interference from water in the sample. However, it does contain a space between the sample and detector that is open to ambient air. For dilution systems, elevated CO_2 concentrations in the CEM shelter can enter this space and cause the instrument to read high.

Another NDIR technique used for measuring CO_2 is gas filter correlation (GFC), which is used by over 40% of the analyzers installed under Part 75. In this technique, a gas cell filled with 100% CO_2 is periodically moved in front of the light beam. This cell filters out all of the light wavelengths that would excite a CO_2 molecule, acting as a 100% reference. When the beam does not pass through the gas filter cell, its energy is reduced by a smaller amount by the CO_2 in the sample cell to make a comparative measurement.

Gas filter correlation instruments employ light over a relatively long wavelength region where the CO_2 molecule absorbs energy and can get a large enough energy differential that can be measured using solid state detectors. Solid state detectors are materials, such as lead selenide (PbSe), where absorbed light energy changes its electric conductivity. The more light that is absorbed, the more the electrical resistance will drop. The current through the sensor will correspondingly increase with an applied voltage. These detectors are often cooled with Peltier coolers (see Section 2.1.9.3) to reduce thermal noise.

The GFC technique is widely used in both extractive and *in situ* CEM systems. GFC monitors for carbon monoxide have been developed. By using multi-reflecting sample cells to increase sensitivity, CO instruments range as low as 0 ppm to 1 ppm can be reached. This has made monitoring of CO in some dilution systems possible.

2.1.8 Source-Level Extractive (Non-Dilution) Systems

Although the majority of CEM systems installed for the Acid Rain Program were dilution systems, system choices for the NO_x Budget Program became more evenly divided between source-level extractive systems and dilution systems (see Table 2-1). One of the reasons for this was that many of the combustion turbines affected by the NO_x Budget rules emit NO_x at very low levels—levels less than 10 ppm. Some local permit emission limits have even been set at levels as low as 1.5 ppm. There was some concern that once the flue gas is diluted that dilution systems would be incapable of measuring at such low levels, although NO_x analyzers are manufactured that can measure at part per billion levels. However, issues of averaging times, luminescence quenching effects, and system sample losses arise at these low concentrations. Also, it is often desired to measure carbon monoxide concentrations in order to optimize turbine operations. In this case, if one applied a dilution system with a dilution ratio of 100:1 to measure CO at a 10 ppm level, one would have to have a CO monitor capable of reading at 0.1 ppm. There are only a few conventional CO monitors with ranges as low as 0 to 1 ppm and these require a long response time to average out noise.

Key Technical Point

Source-level extractive systems are inherently more flexible than dilution systems.

One important reason why source-level extractive systems are a viable option to dilution systems is that they are inherently more flexible. If design problems arise in a dilution system, there are only a limited number of options for fixing the problems. In a source-level extractive system, flows, pressures, vacuums, filters, and so on can be changed until a system is made workable. If one needs to measure other gases, analyzers can be added without too great a concern of their monitoring ranges. As a result of this flexibility, the source-level extractive systems have tended to be favored in industries such as municipal waste combustors, cement plants, and hazardous waste incinerators, where numerous gases are required to be monitored.

Source-level extractive systems can be classified into two types: cool-dry systems and hot-wet systems. The cool-dry systems, where the flue gas is cooled and the water removed, are more common in application than the hot-wet systems, where the flue gas remains hot and wet all the way through the analysis.

2.1.9 Cool-Dry Systems

Cool-dry systems extract the sample, filter out particulate matter, transport it, and remove the moisture before analysis. More components are necessary to do this than in dilution systems, so maintenance tends to be more frequent than in the dilution systems. However, the maintenance required is usually straightforward. Figure 2-9 illustrates a typical cool-dry extractive system.

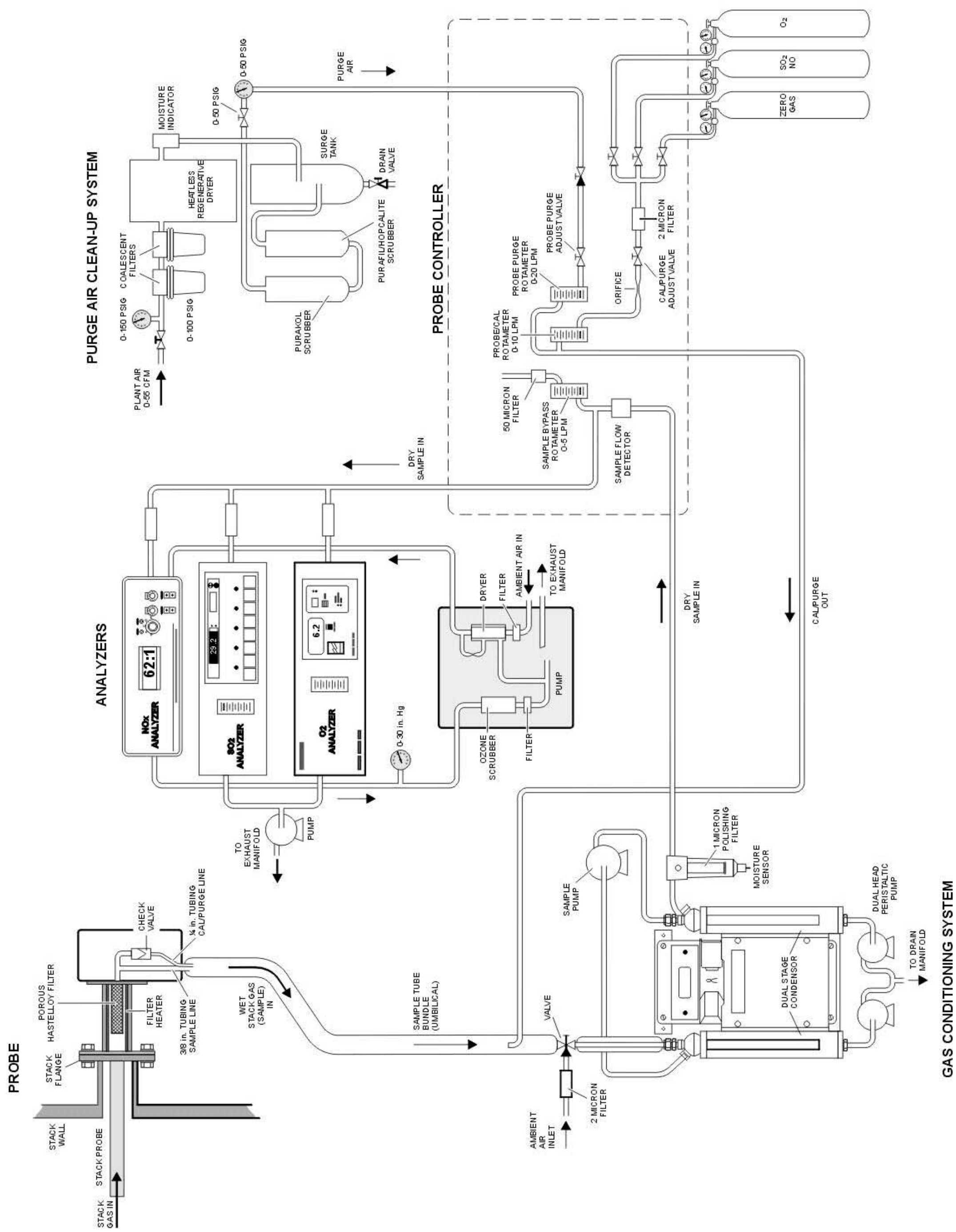

Figure 2-9
A Typical Cool-Dry Extractive System

Source-level extractive systems can be discussed in terms of their parts. The systems are essentially modular and the CEM systems integrator (vendor) should assemble the best parts available to meet the requirements of a given application. These parts include the probe, filters, umbilical sample line, moisture removal systems, pumps, valves, and fittings.

2.1.9.1 Sample Probes

Sample probes can be as simple as a stainless steel tube inserted into the stack, but more commonly, a particulate filter is placed at the end of the tube to prevent plugging of the tube and sampling line. Another option is to place the filter at the end of the probe, outside at the port. This external filter is typically heated with a ring heater to prevent condensation on the filter. Filters are usually made of sintered stainless steel, sintered alloys, or ceramic materials, having porosities for particles anywhere from 1 μm to 20 μm in diameter. Typical probe designs are shown in Figure 2-10.

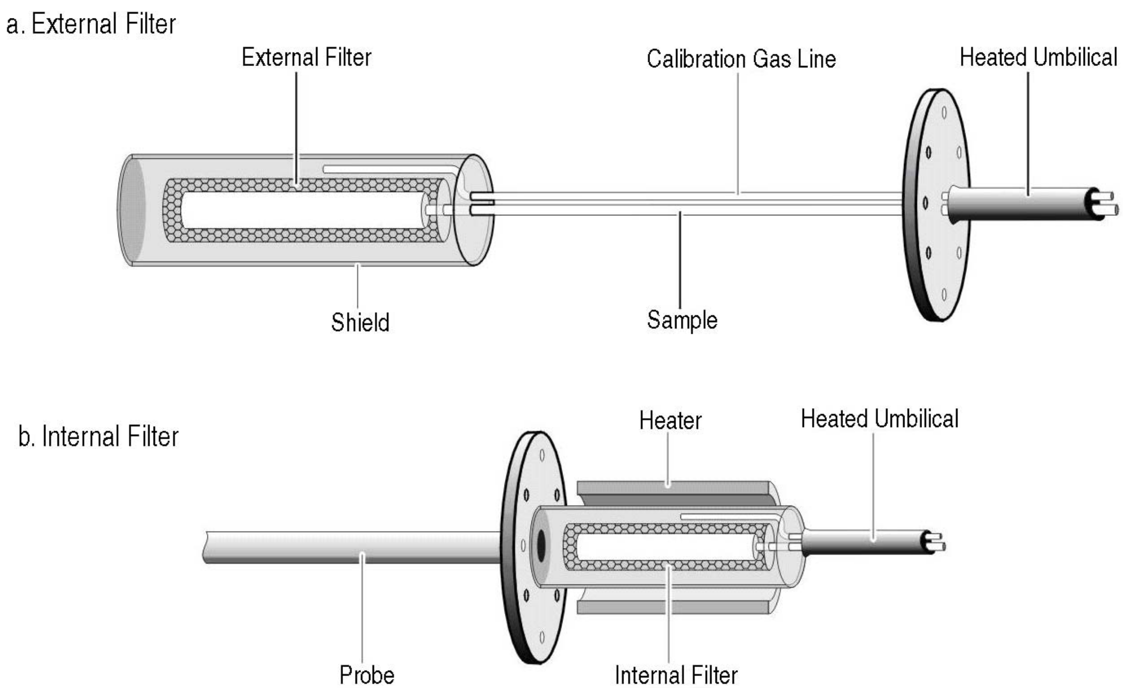

Figure 2-10
Typical Source-Level Extractive System Probe Designs (See Figure 5-1)

Particulate matter can eventually plug the filters. This matter can be removed by blowing high pressure air through the back of the probe. However, the blowback should be dry or heated in order to prevent moisture condensation from cooling as it expands out of the pores.

One advantage of source-level extractive systems is that in cases where the flue gas concentrations are severely stratified, sampling “rakes” or multi-point sampling probes can be designed to sample at multiple points in a stack or duct. This requires more hardware to be placed in a stack or duct and may lead to more maintenance than a single probe.

Key Technical Point

One advantage of source-level extractive systems is that in cases where the flue gas concentrations are severely stratified, sampling “rakes” or multi-point sampling probes can be designed to sample at multiple points in a stack or duct.

Key O&M Cost Point

Sample rakes or multi-point sampling probes will require more hardware to be placed in a stack or duct and may lead to more maintenance than a single probe.

2.1.9.2 Umbilical Sample Lines

Sample lines consist of tubing bundles that are electrically heat traced. Steam heated sample lines are not typically used in the electric utility industry. There are two types of electrical tracing: self-limited and parallel circuit constant wattage heaters. The self-limiting (self-regulating) heaters contain a conductive polymer that runs extruded between two bus connectors. The heat output of the conductive polymer core increases its heat output when the temperature falls and decreases its output when the temperature rises. The self-regulating heaters usually run through the center of the umbilical. The parallel constant wattage heating elements consist of nichrome wire connected to bus conductors.

The tube bundle may contain a sample tube and a tube for calibration:

- One for blowback
- One or two tubes for monitoring probe pressure or vacuum
- One or two spare tubes

The tubes are usually Teflon or other fluoropolymers that may go to higher temperatures than PTFE Teflon or may be less susceptible to diffusion of gases through the material.

The time that it takes for a sample to flow through a line is dependent upon the sample tube diameter, its length and the flow rate. The time lag can be calculated approximately from the expression [4]:

$$t = \frac{V}{Q_{s1}}$$ **Eq. 2-4**

where:

t = the lag time in minutes

V = sample line volume

Q_{sl} = volumetric flow rate of gas through the line

For a flow rate of a standard liter per minute, the lag time for a 100 ft (30.48 m) section of 0.25 in. (0.635 cm) internal diameter tube is about 30 seconds.

Properly installed umbilicals should slope at a minimum of 5º from the probe and contain no loops or kinks. The line should be supported in cable trays or, at a minimum, fastened with tie wraps. A heated sample line should never touch itself or other sample lines; if this occurs, hot spots can develop. For sample line heated above 250ºF (121.1ºC), the CEM system should be designed to limit the sample line length to less than 250 ft (76.2 m). Un-heated or freeze protect lines used in dilution systems can extend longer. However, the longer the line the maintenance problems will be more severe once a problem occurs.

Key O&M Cost Point

Long lines tend to have more severe problems, which can lead to higher maintenance cost.

2.1.9.3 Moisture Removal Methods

In CEM systems, three types of water removal devices have been used; refrigerated chillers, thermoelectric chillers, and permeation dryers. The refrigeration chiller was the first technique applied, where flue gas, still hot from its transport through the umbilical, is transported through a coil of Teflon, Kynar, or glass tubing submerged in a bath of ethylene glycol cooled by a refrigerator. The temperature is kept slightly above freezing to avoid plugging the tubing with ice, and the condensed water is continuously removed, usually with a peristaltic pump. To remove additional water, the sampling pump can be placed after the conditioner to push the initially dried flue gas into a second refrigerated conditioner.

Semiconductor thermoelectric chillers (TE chillers) are used more commonly today. By coupling arrays of N- and P-type semiconductor pellets through plated copper junctions. Applying a voltage across the device, a current will circulate. On one side of the device, the current flow must climb a voltage gradient and on the other side it falls down a voltage gradient. On the downward gradient, heat is released and on the other side heat will be absorbed from the surroundings to balance the current flow. The charge carriers in the semiconductor pellets essentially pump heat through the device. This heat absorption reduces the temperature on the surroundings or attached heat sink.

Impingers are placed next to the cold side and are designed to rapidly cool the flue gas on the impinger walls as the gas enters from a vacuum jacketed tube (see Figure 2-11).

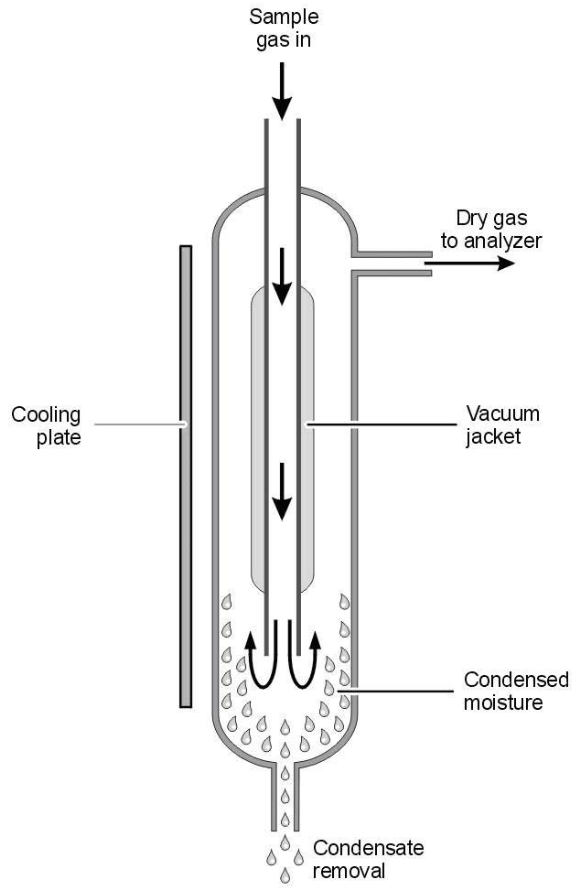

Figure 2-11
Impinger for a Thermoelectric Cooler

A fan is incorporated in these systems to remove the heat generated on the hot side of the cooler.

Permeation driers can also be used to remove flue gas moisture. In these systems, wet gas enters a tube made of a material (such as Nafion) which allows moisture to pass through it if the partial pressure of the water vapor is less on the outside of the tube. This can be done by blowing dry air on the outer side of the tube. Permeation driers are usually made up of a bundle of multiple tubes having a diameter of less than a millimeter. Particulate matter, water droplets, and other condensates will easily plug these tubes, so permeation driers (see Section 2.1.9.3) are usually used after a refrigerator or TE cooler, to remove residual moisture. Heating the entrance to the drier can minimize condensation. Problems from particulate plugging and precipitation of salts can be avoided by using larger diameter tubing.

2.1.9.4 Pumps

Sample pumps are necessary elements of source-level extractive systems. Ejector pumps that use compressed air are the simplest; however, mechanical diaphragm pumps are the most common.

The mechanical pumps do require periodic maintenance; operating continuously, the diaphragms and valves will eventually leak and the motors will fail. The maintenance, however, is usually predictable and is commonly performed on a routine preventive maintenance schedule.

Diaphragm pumps utilize a motor that drives a piston connected by an eccentric drive to a flexible diaphragm that moves to decrease and increase the volume of the pump cavity. The diaphragm can be made of Teflon, Kynar, stainless steel, or other materials. As the diaphragm is drawn down, the volume of the cavity increases, creating a vacuum that brings in the sample gas. When it is pushed upward, the gas in the cavity exhausts from the pump. The flow is pulsating and the pumps can transmit vibrations into the monitoring system. This can cause problems in a system, but the CEM system integrator generally resolves them before installation.

The pump cavity can be heated for use in hot-wet systems and can be coated with or made of materials that will resist corrosion if condensation of acid gases in the pump head should occur.

2.1.9.5 Valves and Fittings

Valves are essential to any extractive system. They perform a variety of functions in controlling the flow of sample and reference gases through the system. Valves perform functions such as regulating gas flow, isolating flow, and protecting the system by venting or checking gas.

Regulating valves are designed to adjust the rate of gas flow. These are typically needle valves that have tapered stems, that when closed, fit into the valve seat. As the stem is adjusted upward, gas flows between the seat and the tip of the stem. The rate of flow is dependent upon the distance of the stem from the seat.

Rotameters provide a means for visually observing gas flow rate by noting the position of a floating ball in the rotameter flow tube. Rotameters can also incorporate a needle valve at the gas inlet to adjust the gas flow. For rotameters without a valve, condensate formed from the pressure drop across the ball may sometimes be observed in the flow tube.

Solenoid valves are used to initiate or stop the flow of gas and are used to automate the injection of daily calibration, linearity, and blowback gases into the CEM system. They are also found in air-cleanup systems, where they alternate the flow through the moisture and CO_2 removal towers. Solenoid valves are activated electrically using a solenoid driver coil and a plunger designed with a valve seat on its end. When the solenoid is energized, the magnetic field lifts the plunger and gas to flow through the valve. Solenoid valves can also be installed in a normally open configuration. Particulate matter or condensate can affect valve performance by weakening the valve spring or damaging the valve seat, allowing gas to leak through the valve. Solenoid valves should be periodically inspected and cleaned, if necessary (see Section 6).

A typical check valve is designed to allow flow in one direction. When flow ceases or the direction of flow changes, the valve releases an internal spring-loaded “poppet” to prevent reverse flow. These valves are rated to release at specified pressures and remain closed otherwise. Back pressure reseats the valve to prevent reverse flow in the system.

Connections in CEM systems are made using compression fittings. Two ferrule fittings are used to lessen rotational strain on the tubing when they are tightened. Compression fittings are used on Teflon tubing and stainless steel tubing in CEM systems. When an EPM probe is used, graphite ferrules are used to connect the glass orifice tube to the probe's metal sample gas line.

2.1.10 Hot-Wet Systems

Hot-wet systems do not condition the sample gas, except for filtering it from particulate matter. Hot-wet systems measure pollutant gas concentrations on a wet basis, as do dilution systems, and are therefore well-suited for determining emissions in the units of lbs/hr. Hot-wet systems are useful for monitoring gases such as hydrochloric acid, ammonia, or volatile organic compounds (VOC) because these gases are lost in the chillers of cool-dry systems and are difficult to measure in dilution systems. A hot system can also minimize the adsorption of gases on the internal surfaces and minimize the formation of compounds such as ammonium chloride and ammonium sulfate that can foul a system.

Key Technical Point

Hot-wet systems are useful for monitoring gases such as hydrochloric acid, ammonia, or volatile organic compounds.

Key Technical Point

A hot system can also minimize the adsorption of gases on the internal surfaces and minimize the formation of compounds, such as ammonium chloride and ammonium sulfate, that can foul a system.

A few hot-wet systems were installed in the Acid Rain Program, using heated ejector pumps to bring the gas into a heated sample chamber. These systems have fewer parts; however, if a power failure should occur, acid gases can condense throughout the system. If the system is not immediately cleaned, stainless steel tubing and other metal surfaces will begin to corrode and reduce the lifetime of the system.

2.1.11 Close-Coupled Systems

A newer and unique type of extractive system is the "close-coupled" system. These have seen few applications in the Acid Rain or NO_x Budget Programs but have been installed in the pharmaceutical industry to meet the VOC monitoring requirements of the MACT (Maximum Achievable Control Technology) program.

Close-coupled systems can be either cool-dry or hot-wet in design. Any conditioning, however, is done directly after the probe and directed to the analyzer, which is also at the stack or duct location. This design avoids the use of sampling line and minimizes adsorptive and reactivity losses. Close-coupled VOC monitors use an ejector pump that draws the sample through a heated filter to provide sample for a heated flame ionization detector (FID). Another close-coupled option is to condition the gas after the probe and then use either an unheated sample line or freeze protect line to the analyzers, thus avoiding problems with heated sample line.

Close-coupled systems that monitor four different gases (less data acquisition system) are now available. Instrument shelters and much of the associated hardware associated with extractive systems is not necessary, thus reducing costs of manufacture, installation, and maintenance.

2.1.12 Analytical Techniques Used with Source-Level (Non-Dilution) Systems

The chemiluminescence technique used for monitoring NO_x is also used in non-dilution extractive systems (see Section 2.1.7.2). The method is suitable for both low and high range analyzers. However, when used in non-dilution systems, quenching of the chemiluminescent light by other molecules can be more problematic. Particularly, in low NO_x gas turbine applications, special attention must be paid to either correcting or minimizing this problem. It is more difficult to correct for quenching effects in source-level SO_2 fluorescence monitors and are seldom used in non-dilution systems. Instead, nondispersive ultraviolet (NDUV) absorption techniques are the most common methods for monitoring SO_2 in non-dilution systems.

The nondispersive infrared analyzers (also discussed in Section 2.1.7.3) on dilution system analytical techniques are well suited for monitoring CO_2 and CO in the non-dilution systems. In the non-dilution, source-level systems, the concentrations will be higher and therefore much easier to measure. However, source-level systems do have the option of monitoring oxygen instead of CO_2 to measure the diluting effects of excess combustion air on the flue gas concentrations. Because of their reliability and usage, oxygen monitors have been incorporated in many source-level extractive systems.

2.1.12.1 Non-Dispersive Ultraviolet Analyzers

As in nondispersive infrared analyzers, the nondispersive ultraviolet analyzers do not scan the molecular fingerprint spectra but use the light absorptive properties of a few light wavelengths or a small band of wavelengths to make an analysis. The most common NDUV method is that of differential absorption spectroscopy. The technique of second derivative spectroscopy is used in UV *in situ* monitors and also in infrared diode laser systems.

In differential absorption spectroscopy, the difference in light absorption (by the molecules of interest) is measured at two wavelengths using optical filters (see Figure 2-12).

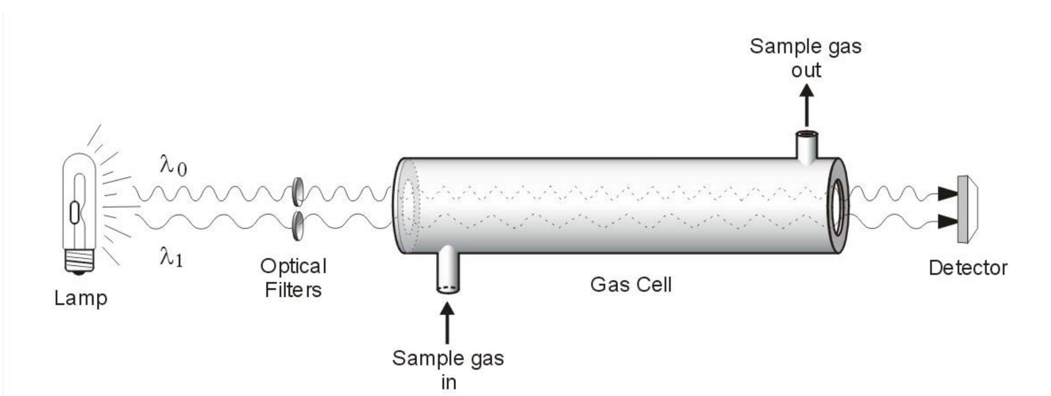

Figure 2-12
The Differential Absorption Analyzer

At one wavelength (the reference wavelength), the light does not resonate with the SO_2 molecule, nothing happens and no light is absorbed. At the other wavelength (the measurement wavelength), the light causes an electronic transition to occur in the molecular orbitals of the SO_2 molecule and light is absorbed. The energy reaching the detector is less than that from the reference beam and through the Beer-Lambert law, the concentration of the SO_2 can be determined. For SO_2, the measurement wavelength is in the region of 280 nm in the UV and the reference wavelength is in the region of 436 nm.

Water vapor does not interfere in the measurement and the technique can be used in cool-dry, hot-wet, and *in situ* systems. Because UV light has a relatively high energy, differences in light absorption are relatively easy to detect, in contrast to detection sensitivity problems of infrared analyzers. However, UV lamps are high energy devices and are expensive. One of the early problems associated with analyzers using UV lamps was related to obtaining lamps that had a stable output and a lifetime long enough for the instrument to be economically viable. The NDUV analyzers are not able to measure SO_2 concentrations in the sub ppm range as can the fluorescence analyzers, the lowest range being typically 0 ppm–50 ppm. This can be decreased by increasing the length of the measurement cell, but this takes up space and, in an extractive system, will use up calibration gas at a faster rate.

The differential absorption NDUV technique has led to the development of analyzers that are both accurate and rugged. The simplicity of the design allows components to be replaced relatively easily and some hot-wet NDUV systems have been in service for over 30 years, although practically every part may have been replaced at some time during this period. They are favored by source testers and are the most common type of SO_2 analyzer found in source testing vans.

Key O&M Cost Point

The simplicity of the NDUV designs allows for component replacement and is favored by source testers.

The differential absorption technique is also used in extractive and *in situ* infrared analyzers. Again, optical filters can be used, but in tunable diode laser systems, the light wavelengths are switched by changing the temperature or the voltage across the laser.

2.1.12.2 Oxygen Monitoring Techniques

Over 50% of the oxygen monitors installed in source-level extractive systems operate by paramagnetic techniques. Oxygen is a paramagnetic material and is attracted to a magnet (at the level of several thousand gauss). This phenomenon has allowed the manufacture of three types of paramagnetic analyzers (thermomagnetic, magnetodynamic, and magnetopneumatic), each being unique and rather clever in design. The most common of the techniques is the magnetodynamic method, where a torsion balance consisting of a dumbbell made of two glass spheres [each about 0.0787 in. (2 mm) in diameter] swings in a magnetic field (see Figure 2-13).

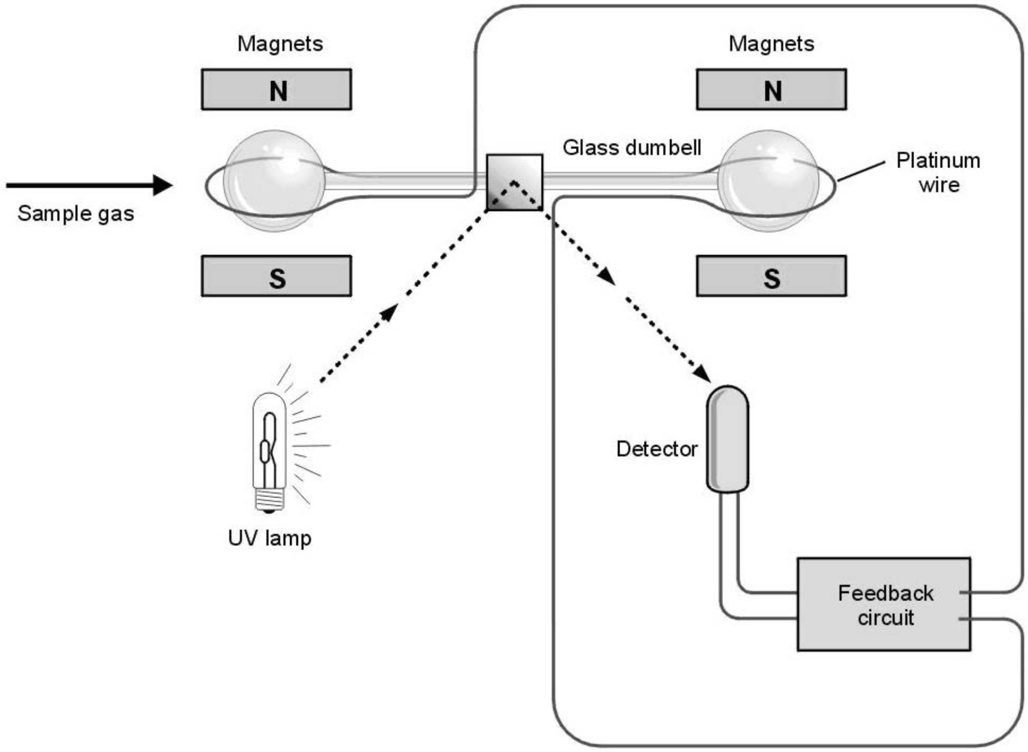

Figure 2-13
A Paramagnetic Oxygen Sensor

The glass spheres are encircled with platinum wire and are slightly diamagnetic or repelled by the magnetic field. The spheres are pushed away from the most intense part of the magnetic field. When the gas surrounding the dumbbells contains oxygen, the oxygen will be attracted to the magnet and change the magnetic field lines, causing the dumbbell to swing to a new position. This new position is detected by light reflected from a small mirror placed in the center of the dumbbell to a photocell. A current is sent through the platinum wire, creating a magnetic field around the wire that restores the dumbbell to its original condition. The current necessary to do this is proportional to the O_2 concentration.

Another type of oxygen analyzer is an electrocatalytic device that evolved from fuel cell research. This instrument is used in both source-level and *in situ* systems and is widely applied for boiler control. In the instrument, a ceramic material, zirconium oxide (ZrO_2) acts as an electrolyte when heated to 1562ºF (850ºC) (see Figure 2-14).

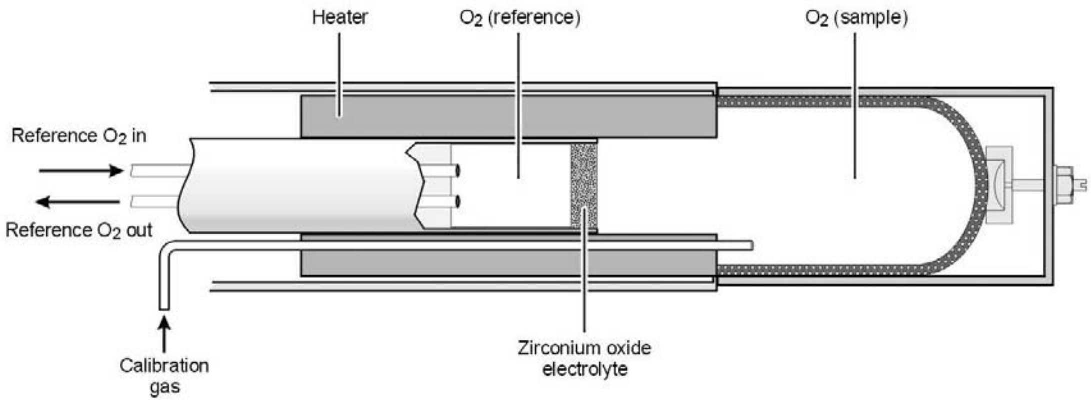

Figure 2-14
The Zirconium Oxide Sensor

When the partial pressure of O_2 is different on each side of the ZrO_2, oxygen will pass from the side of higher concentration to the side of lower concentration until equilibrium is reached. Electrons are transferred in the process to generate an electric current, which is logarithmically related to the ratio of the partial pressures. In practice, one side of the ZrO_2 is maintained at the reference level of 21% O_2 ambient air, and the flue gas O_2 with a concentration on the order of 2%–6% is on the other side. These analyzers are quite reliable and can be part of hot-wet or cool-dry extractive systems.

If the flue gas oxygen is measured both hot and wet (by splitting the gas stream), the flue gas moisture content can be determined as follows:

$$\%H_2O = \left[1 - \frac{\%O_{2wet}}{\%O_{2dry}}\right]100 \qquad \textbf{Eq. 2-5}$$

The accuracy of this technique is improved if one oxygen analyzer instead of two are used due to the imprecision associated with calibrating one analyzer only. Close-coupled moisture analyzers using dielectric techniques are now commercially available and provide an option to the complexity of the wet-dry oxygen monitoring method.

Key Technical Point

Close-coupled moisture analyzers using dielectric techniques are now commercially available and provide an option to the complexity of the wet-dry oxygen monitoring method.

2.2 *In Situ* Systems

The problems associated with extracting a gas for measurement can be avoided if the gas is measured directly in a stack or duct. Instruments have been designed to do this and have a number of advantages over extractive systems when properly applied. Opacity monitors and flow monitors are *in situ* systems and are in common use.

In situ systems can be categorized into two types, whether they are gas, opacity, or flow monitors. The first category is the path monitor, where the measurement is taken across the stack or duct diameter. The second is the point monitor, where the measurement is still made in-stack but at point or a path that is short relative to the stack diameter (EPA characterizes a point monitor as one having a measurement path less than 10% of the stack diameter).

2.2.1 In Situ Gas Monitors

Less than 4% of the gas monitoring systems installed for the Acid Rain Program are *in situ* systems. Some of these were path monitors manufactured by Opsis, Inc.; the others were point monitors, manufactured by Monitor Labs, Inc. The fundamental issue associated with *in situ* gas monitors is their capability of accepting calibration gases to perform a daily calibration check or a linearity test. Although these instruments have other ways of checking calibration, these methods are internal to the instrument and do not involve the comparison to a known standard. Part 75 does not allow optional procedures in lieu of the use of NIST traceable calibration gases.

Key Technical Point

Part 75 does not allow optional procedures for daily calibration checks or linearity tests. This limits the usefulness of *in situ* monitors for regulatory gas testing in the U.S.

2.2.1.1 Path Monitor Designs

A number of path monitors were installed in the electric utilities in the late 1970s and in the 1980s. During this time, the New Source Performance Standards Part 60 monitoring requirements allowed the use of internal gas cells or other means to perform daily calibration checks. However, when the Quality Assurance requirements of 40 CFR 60 Appendix F were promulgated in 1987, quarterly cylinder gas audits (or abbreviated relative accuracy tests) were required on certain sources. Reconfiguring a path monitoring system to accept calibration gases requires after-installation engineering fixes, an expensive proposition in most cases. This issue, which was pressed hard by competitive extractive systems manufacturers, led to a lessening of popularity of *in situ* systems in the U.S.

Another problem associated with both the path and point *in situ* monitoring systems was that many were sold into applications where they should never have been considered. When mounted on a stack where the summertime temperature can exceed 140ºF (60ºC) or where lightning strikes are frequent, electronic malfunctions are common. Also, being at heights of 200 ft (61 m) or more, they are difficult to work on, particularly if a change in optics or electronics adjustments requires the instrument internal temperature to be constant.

However, the instruments have a faster response than extractive systems. In flue gas streams where gas concentrations may be stratified, path monitors average the concentration over the measurement line. Maintenance is also minimal. If calibration gases are not needed to perform a daily calibration and the instrument check itself, there is not much for the technician to do. In fact, the box that just sits on the stack and delivers data to the computer is the conceptual ideal for the utility manager. *In situ* systems can do this and some have operated routinely for 2 to 3 years without major failure. Because calibration check requirements are not as stringent in other countries, the *in situ* monitors see wider application in Europe, Canada, and the Far East. In Canada, 50% of the gas monitoring CEM systems installed are either point or path *in situ* systems.

A path, gas monitoring instrument typically sends a light beam across the stack or duct, where the gas or gases being measured will absorb some of the light energy, either in the infrared or ultraviolet region of the spectrum, depending upon the monitor design. The analytical techniques are usually differential absorption (both in the IR or UV) or gas filter correlation (in the IR). The detector may be on the side of the stack opposite from the light beam or it may reflect from a mirror and return to a "transceiver" assembly that holds the light source, detector, and associated optics and electronics. If the light passes only once through the flue gas, the instrument is called a single-pass unit; if it passes through twice, it is termed a double-pass unit. Blowers on the transceiver and retroreflector assemblies keep optical windows free of particulate matter.

In the double-pass systems, a gas cell can be inserted into the light path where calibration gas can be flowed as an independent check of the system. A problem arises here because the path-length of the cell is usually much shorter (a few cm) than the path-length of the light in the stack (on the order of feet). There are more molecules in a 16.4 ft. (5 m) path than in a 2 in. (5 cm) path and an instrument designed to measure 200 ppm of SO_2 across a 16.4 ft. (5 m) path would not be sensitive enough to measure 200 ppm of SO_2 in a 2 in. (5 cm) path. In this example, to get an equivalent response to the stack measurement, the gas in the cell would have to have a concentration of 20% SO_2. NIST traceable gases are not available at these levels and if one wanted to calibrate a path CO_2 monitor in this manner, the cell CO_2 concentration would have to be greater than 100%, an impossibility without pressurizing the cell.

Opsis resolved these issues in a single-pass path unit designed for the Acid Rain Program by installing a tube across the stack and dividing the light beam into two paths, one for calibration and one for flue gas measurement (see Figure 2-15).

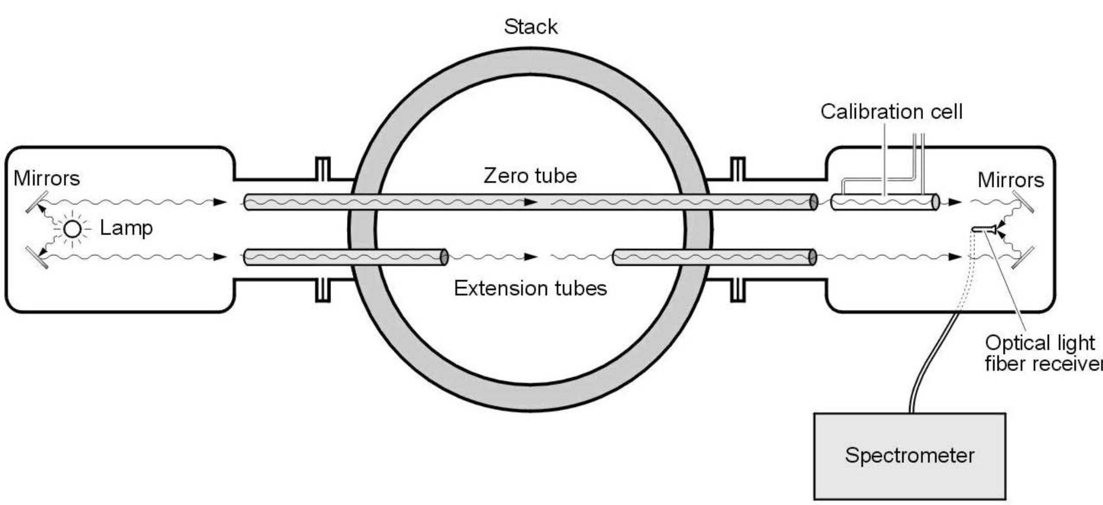

Figure 2-15
The Opsis Part 75 Compliant Path Monitor

A flow-through gas cell was placed after the tube and by flushing air through the tube, a zero value can be obtained. By flooding the gas cell, an upscale calibration check can be conducted. However, in order to use Protocol gases, the length of the measurement path has to be reduced to be on the same order of length as the gas cell. This effectively transforms the instrument from a path to a point monitor.

With the advent of low-cost lasers from the communications industry, tunable diode lasers (TDLs) are now being used in path monitoring instruments. The path monitoring TDLs are particularly useful for monitoring reactive gases such as ammonia (NH_3) and hydrogen fluoride (HF) that are difficult to transport in extractive systems.

2.2.1.2 Point Monitor Designs

Point *in situ* gas monitors have seen wider application than have the path monitors. The in-stack zirconium oxide monitors have been reliable for use in boiler control as well as monitoring flue gas dilution by excess or tramp air. Gas monitors using infrared or ultraviolet differential absorption and gas filter correlation techniques are available in a variety of probe-type instruments. The Teledyne-Monitor Labs point monitor utilizes a second derivative technique. In this method, an absorption peak is scanned to generate a signal that is proportional to the second derivative of the peak intensity seen at the detector, which is proportional to the gas concentration. The method is merely a refinement of the use of the Beer-Lambert law to minimize problems caused by:

- Variations in the lamp intensity
- Interference from other gases
- Scattering by particulate matter

Also, the technique is used in many *in situ* monitors that use tunable diode lasers.

Probe designs for the in-stack monitors are vendor specific and are each company’s engineering solution to problem of performing a calibration *in situ* using calibration gases. Different in-stack monitor designs are shown in Figure 2-16.

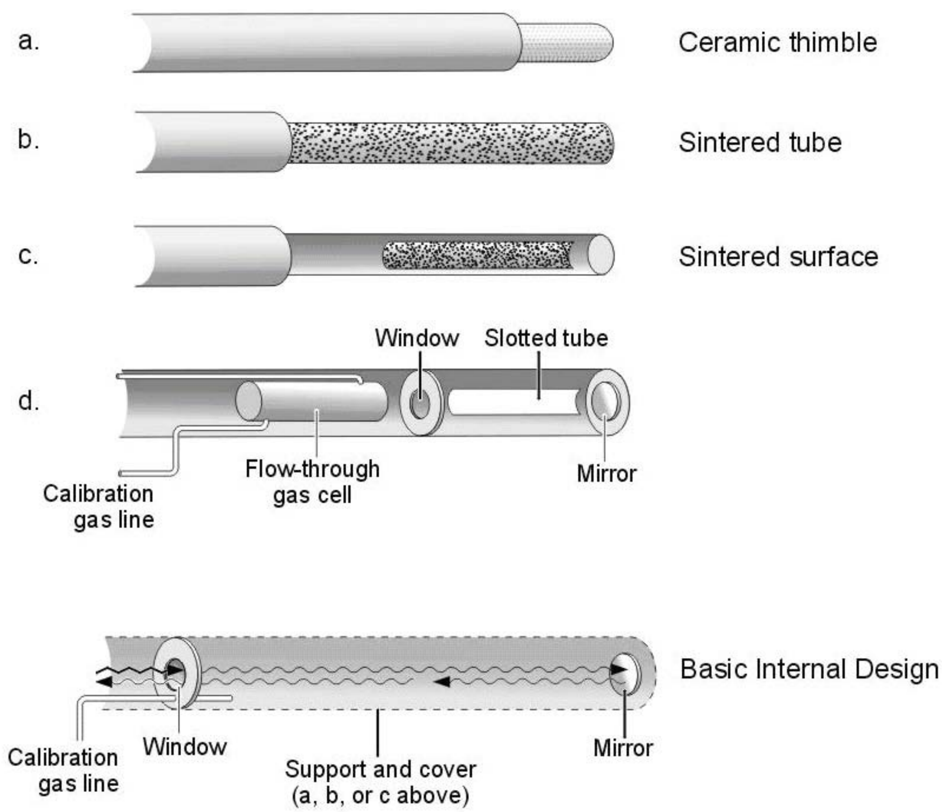

Figure 2-16
Designs for Point (In-Stack) *In Situ* Monitors

In the pollutant gas monitors, light is sent from the transceiver assembly down the probe to a retroreflector that sends it back to a detector in the transceiver. In the oxygen, zirconium oxide instruments, a ceramic zirconium oxide material is placed at the end of the probe, where flue gas oxygen undergoes an electrocatalytic reaction that diffuses through the material to generate a measurable electric current.

In most of the probes, the probe is made either of sintered stainless steel, sintered hastelloy, or ceramic material. In others, a sintered strip is welded into an otherwise solid tube. Flue gas diffuses through the probe filter and the majority of the particulate matter is prevented from entering the probe. To perform a calibration, zero gas or span gas is injected at a pressure sufficient to purge the probe of the flue gas. However, a problem arises in that the concentration measurement is dependent upon the pressure. Without strict quality controls, the pressure could be varied to achieve a desired calibration outcome.

Many of these analyzers also have an internal calibration device. This may be a gas cell that periodically passes into the light beam, a reference spectrum in the instrument microprocessor, or an optical calibration filter. These are normally used to perform a daily calibration check in international use. Because these methods are internal and electronically activated, any drift from the reference can then be corrected automatically by the instrument microprocessor. Depending upon how the reference values are reported, these instruments may never appear to drift and may be viewed as being amazingly stable.

2.2.2 Flow Monitors

All flow monitors are *in situ* in design, it making little sense to extract a slip-stream or sample on which to perform a flow measurement. Sixty-five percent of flow monitors used in the electric utilities to meet Part 75 requirements were the ultrasonic monitors, 27% used differential pressure sensing methods, and 6% used thermal techniques. Time-of-flight methods are more recent and are beginning to see applications.

2.2.2.1 Ultrasonic Monitors

The ultrasonic flow monitors are path instruments that send sound pulses with and against the flue gas using vibrating transducers that both send and receive the sound (see Figure 2-17).

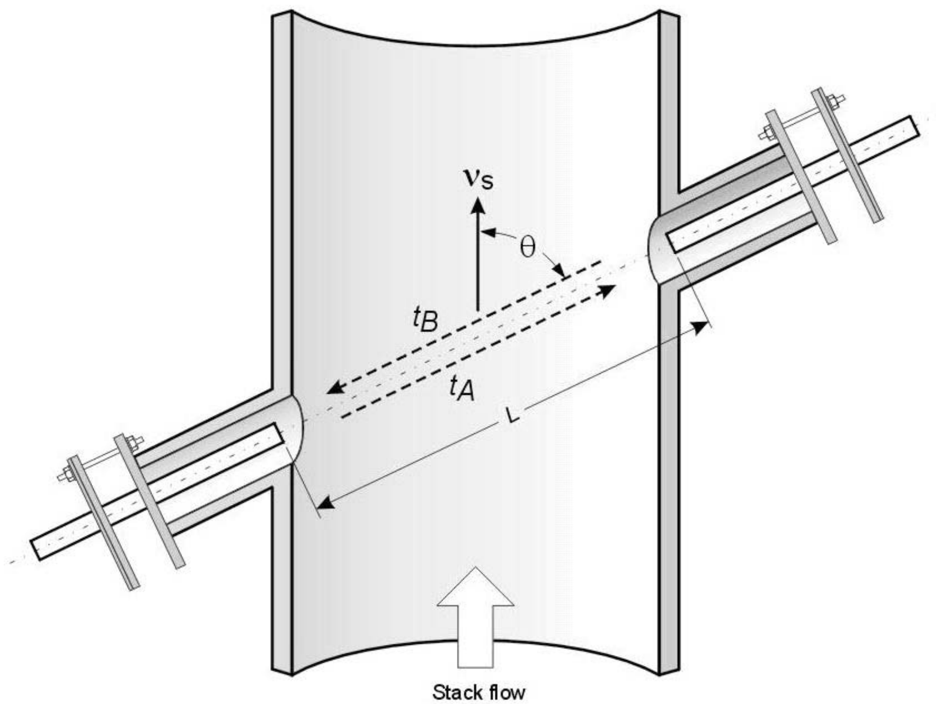

Figure 2-17
An Ultrasonic Flow Monitor

The transducers are typically placed at an angle of 45º so that the sound pulse traveling in the direction of the flow will be carried with the flue gas flow, whereas the sound pulse traveling against the flow will be retarded by the flow. The two velocities will be different and can be used to calculate the actual flue gas velocity.

The ultrasonic method gives a path average that helps to average out the flow value in situations where the flue gas velocity is stratified over the stack or duct stratification. In severe stratification cases, another ultrasonic monitor placed 90º away on the cross section gives values that, when averaged with the other monitor values, can give results that are more consistent with the area average of EPA Test Method 2. It should be noted that path monitors, be they gas or flow monitors, give an average of the measured parameter over the measurement line. That is, each point on the line contributes to the average. This is different than an area average, particularly in circular ducts or stacks, where the flow value is determined by averaging the gas velocity or gas concentration measurements made at the centroidal points of equal areas that divide up the total cross-sectional area.

The ultrasonic path monitors designed with a 45º angular transducer displacement usually require the installation of an additional platform and access ladder on the stack. This can be costly, particularly for large diameter stacks. Some vendors have been able to design these instruments so that an angle of only 5º is required, thus avoiding the need for extra stack platforms. In another design, a support holds a transducer approximately a meter away from the other to make a probe that can be inserted at an angle into a single port to make a point ultrasonic monitor.

2.2.2.2 Differential Pressure Monitors

Differential pressure monitors can be as simple as a pitot tube connected to a pressure transducer or as complex as an assembly of tubes with pressure sensing ports at each of centroidal locations specified by EPA Test Method 1. Pitot tubes are an arrangement of two tubes, one having an opening facing the direction of flow and the other tube having a port 90° or 180° from the direction of the flow. The facing port senses the impact pressure of the flow, the other either a static or “wake” pressure. By connecting the end of each of these tubes to a manometer or pressure transducer, the pressure differential (Δp), between them can be measured (see Figure 2-18).

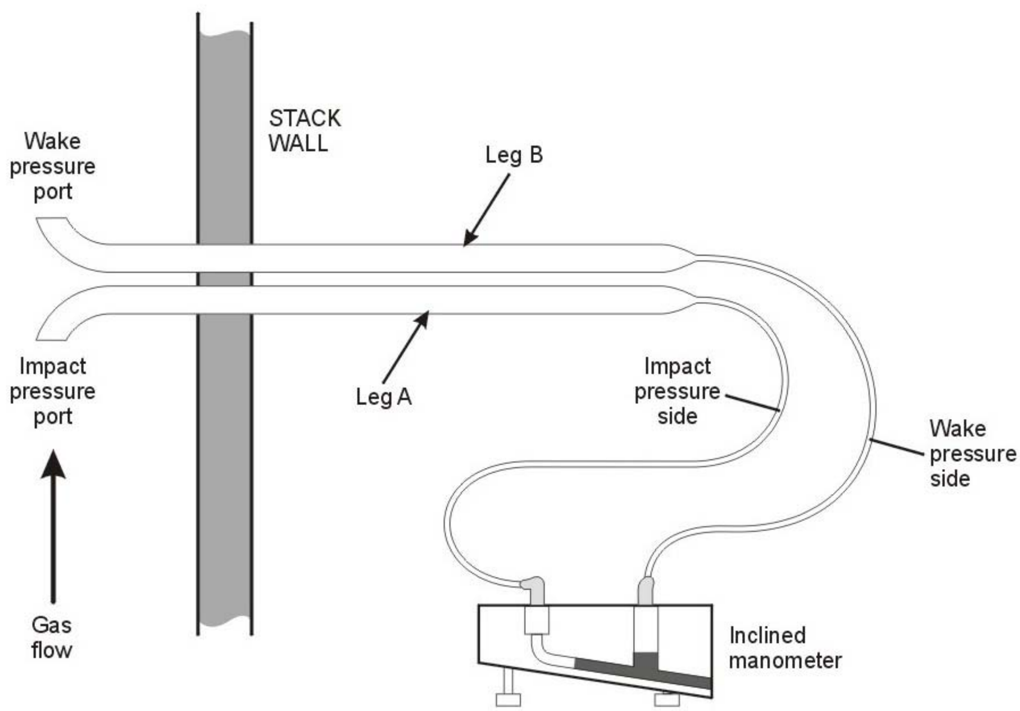

Figure 2-18
Pressure Differential Across a Pitot Tube

This pressure differential is related to the gas velocity by using the Bernoulli equation. The following expression can be derived:

$$v_s = K_p c_p \sqrt{\frac{T_s \Delta p}{M_s P_s}}$$ **Eq. 2-6**

where:

K_p = units constant

c_p = pitot tube calibration factor

v_s = flue gas velocity at the measurement point

T_s = flue gas temperature (absolute)

Δp = pressure differential across the pitot tube

M_s = flue gas molecular weight

P_s = flue gas pressure (absolute)

The volumetric flow rate is determined from this expression simply as follows:

$$Q_s = v_s A_s$$ **Eq. 2-7**

where:

Q_s = flue gas volumetric flow rate

A_s = stack cross sectional area at the measurement location

These expressions are given in order to note that there are a number of variables that must be determined in order to calculate the volumetric flow. Of those given above, T_s, Δp, and A_s are the most important. An error in these values will cause an error in the determination of the volumetric flow.

A major problem in the determination of flue gas volumetric flow is stratification of the gas velocity over the measurement concentration. The gas velocity in stack and ducts is not constant across the face of the cross-section. The flow is usually fully developed turbulent flow. The velocity falls to zero at the walls of the duct or stack and it is typically bullet shaped, with a maximum at the center of the cross-section. To obtain accurate flow measurements, multiple sensors would have to be placed at the centroids of cross-sectional equal areas and their responses averaged. Corrections would also be necessary for wall effects.

To obtain an average value, multiple pitot tubes can be used, or averaging pitot tubes can be designed. The averaging pitot tubes have multiple ports along the length of the tube, located at points that will measure at the centroidal points of the equal areas. One averaging tube may be used, or an array of tubes can be used, depending upon the degree of stratification (see Figure 2-19).

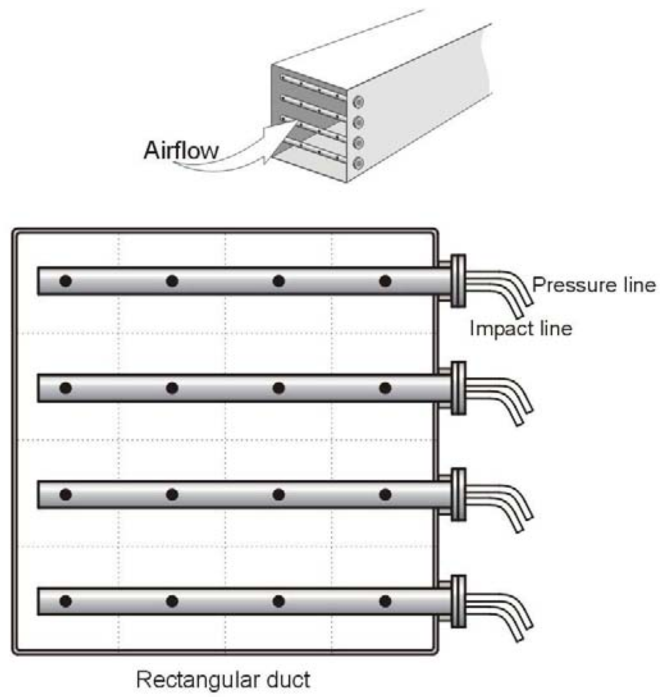

Figure 2-19
An Array of Averaging Pitot Tubes

A familiar term for averaging tubes is the “annubar™”; however, this is the trademarked name for the device made by the company Dietrich Standard.

The differential between the impact and wake and the wake pressure ports is measured by an electronic transducer. Because of the requirements of Part 75 for a daily zero and span check of the system, the plumbing of the system can become more complex than one would expect from the concept of measuring a differential pressure. Figure 2-20 shows the transducer and its associated calibration checking system in the monitor manufactured by EMRC.

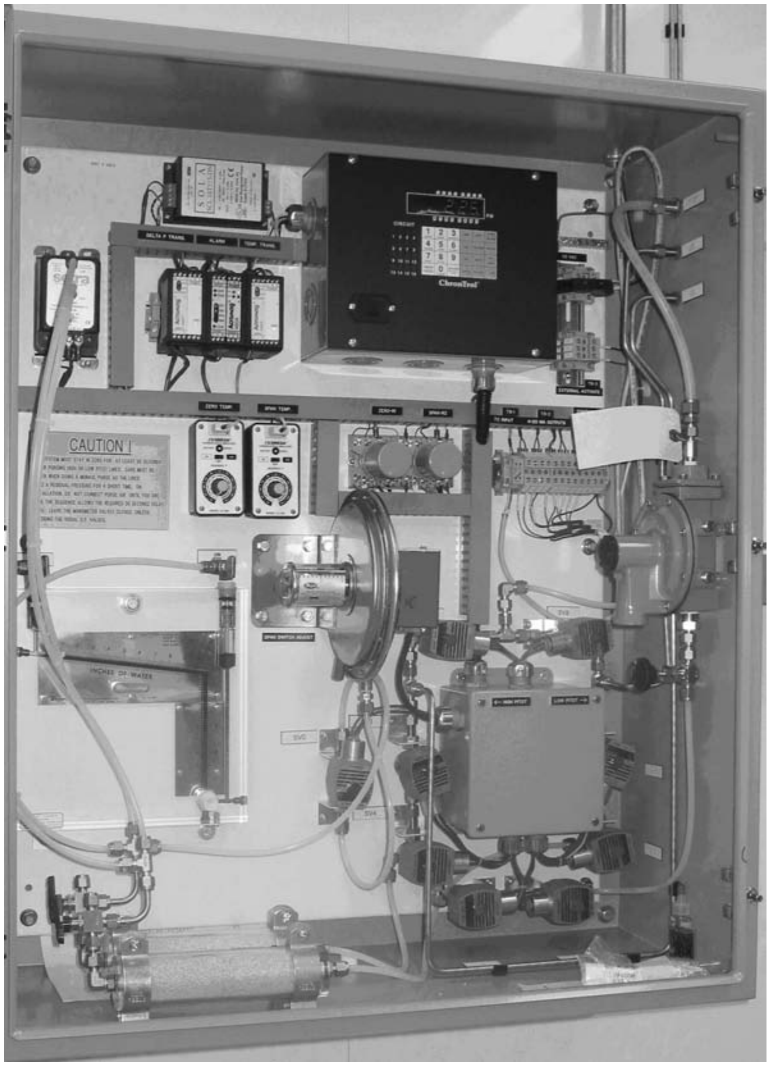

Figure 2-20
Transducer and Plumbing System Associated with an EMRC Differential Pressure Flow Monitoring System

Pitot tubes and the averaging pitot devices can clog with particulate matter and water can condense in the tubes. Pressurized air is blown back through the tubes periodically to clean them. The tubes are exposed constantly to flue gas temperatures, acid gases, and the bombardment of fly ash. They can corrode, plug, twist, sag, and even fall off. Daily calibration checks are performed only on the transducer and do not check the probe itself. Use of a Part 75 data validation technique, called the flow-to-load ratio test, can be a valuable tool in detecting problems in these systems.

Key Technical Point

Use of a Part 75 data validation technique, called the flow-to-load ratio test, can be a valuable tool in detecting problems in these systems.

2.2.2.3 Thermal Sensors

In a thermal sensor, electric current heats platinum resistance wire, wound about a ceramic rod. In the stack, the flue gas flow will cool the wire. The devices are designed to maintain a constant temperature, so the current is increased to sustain a temperature usually 75ºF to 100ºF (23.8ºC to 37.8ºC) above the flue gas temperature. The power necessary to sustain the temperature is related to the mass flow rate of the gas, which can be related to the flue gas velocity.

Thermal sensors can be used either singly or in arrays. Agglomerating fly ash can blind the sensors, so a variety of aerodynamic designs has been devised to minimize collection of material on the sensors. They can also be heated to higher temperatures to essentially "bake off" collected particulate matter.

Thermal sensors cannot be used in flue gas streams where water droplets are present because their evaporation on the sensors will be misinterpreted as convective cooling.

2.2.2.4 Time-of-Flight Monitors

Several time-of-flight monitors have been designed that monitor the transit of thermal fluctuations. Either by tracking the heat fluctuations by using infrared detectors, tracking localized gas concentrations using infrared light, or tracking particulate fluctuation by the scintillation light through the gas, the time of passage between two sensing points is measured.

These instruments are path monitors but do not have to be installed at an angle as do the ultrasonic instruments. They may be sensitive to stack vibrations and can have problems measuring at low flow rates or at flow conditions where little combustion is taking place and thermal turbulence is not present.

2.2.2.5 Monitoring Flow Using Heat Input

An alternate method for measuring flow is available to gas and oil fired combustion sources that have installed fuel flow meters. If the fuel heat content is known and fuel feed rate is determined using the fuel flow meter, the stack gas flow can be determined from the following expressions:

$$HI = R_f xGCV \quad \textbf{Eq. 2-8}$$

where:

HI = heat input rate (mmBtu/hr) (KW/hr)

R_f = fuel feed rate (scfh or g/hr) (scmh or l/hr)

GCV = mmBtu/scf or Btu/gal (KW/hr/scm or Whr/l)

$$Q_s = F_d \frac{20.9(HI)}{(20.9 - \%O_2)} \quad \textbf{Eq. 2-9}$$

$$Q_s = F_c \frac{100(HI)}{\%CO_2} \qquad \textbf{Eq. 2-10}$$

where:

Q_s = flue gas volumetric flow rate

20.9 = percentage of O_2 in air

F_d = dry F factor (stoichiometric amount of combustion products produced (ft^3) divided by the mmBtu produced per unit of fuel)

F_c = F sub c factor (stoichiometric amount of CO_2 produced divided by mmBtu produced per unit of fuel)

These calculation methods are allowed as specified in Subpart H and Appendices D and E of Part 75 [5,6,7]. They are also used in lieu of flow monitors in many Canadian CEM installations. Other calculation methods can be used to determine flue gas volumetric flow from combustion characteristics, but these are the most common.

These equations are stressed here because they can be used to cross-check flow measurements made by installed flow monitors. In general, flow monitors will be biased high relative to the heat input calculation method, which raises the question as to which method more accurately determines the flue gas flow. In most studies conducted to evaluate this issue, biases in the instrument methods and (more specifically) the Reference Test Method 2 used to calibrate them are eliminated until a closer correspondence with the heat input method is achieved. Differences between the instrument results and the heat input calculations should not exceed 3%.

Because flow monitors measure either at a point or on a line, the volumetric flow measured is not equivalent to the area average determined by Method 2. However, in 2001, the EPA reported that when tested against Method 2, the median relative accuracy for flow monitors was 3%. How is this possible? In practice, a “pre-RATA” is conducted on the flow monitor prior to its certification testing when it is first installed. If the flow monitor data differ from the Method 2 results, either a calibration factor or calibration curve (correcting as a function of load) will be used to adjust all subsequent data. Another technique is to relocate the probe to a point that will represent the average Method 2 results. After these adjustments are made, the certification test is conducted and the flow monitor passes.

2.2.3 Opacity Monitors

As with gas *in situ* path monitors, opacity monitors can be either single-pass or double-pass in design. The double-pass systems are the most common and are used extensively in the U.S. to meet the opacity monitoring requirements of Part 60 and State regulatory programs. Opacity monitor data are used directly for enforcement in some regulatory jurisdictions. In others, they are used to report excess opacity emissions to the State, which may or may not take action. Stack or duct opacity measurements can be related to the stack exit opacity through the equation:

$$Op_x = 1 - (1 - Op_t)^{\ell_x/\ell_t} \qquad \textbf{Eq. 2-11}$$

where:

Op_x = Opacity at the stack exit

Op_t = Opacity at the opacity monitor location

ℓ_x = Stack exit internal diameter

ℓ_t = Opacity monitor optical path inside the stack or duct (2 times the stack diameter for double-pass monitors)

The ratio (ℓ_x/ℓ_t) is known as the path length correction factor (PLCF) and is input into the instrument's control unit before installation. Because a stack's opacity limit is based on the stack exit opacity and corresponds to the opacity, a visible emissions (VE) observer would read the stack exit opacity following the procedures of EPA Test Method 9.

A typical double-pass opacity monitor is shown in Figure 2-21.

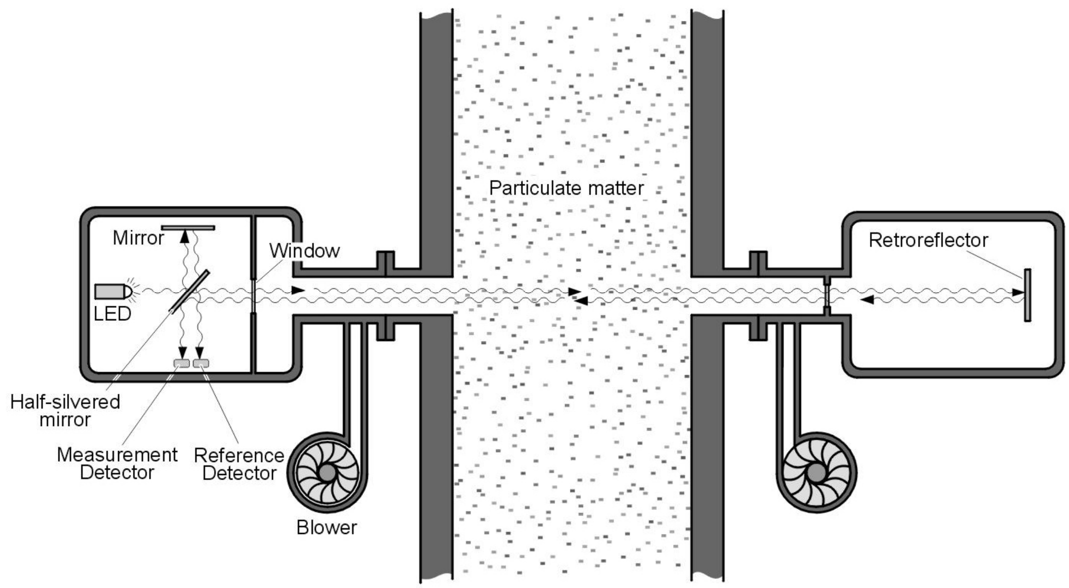

Figure 2-21
Double-Pass Opacity Monitor

Instruments installed today must meet the requirements of ASTM 6216 [8] and EPA Performance Specification 1 of 40 CFR 60 Appendix B [9] and must incorporate certain features. First, they must transmit light in the visible region of the spectrum, they must provide a means of conducting a zero and span check of the active optical and electronic components, and they must incorporate an optical alignment indicator. They must be insensitive to ambient light and meet other optical and electronic requirements.

Because the EPA reference test method for opacity is the visual emissions observer, a relative accuracy test is not conducted to certify the monitor as is the case with gas concentration monitors. An opacity monitor must instead meet the ASTM design specifications and pass a linearity test using certified optical filters and then pass a response time test and a 7-day drift test once installed on the duct or stack.

The opacity monitor shown in Figure 2-21 sends light from a light emitting diode through beam splitters and optical windows, then into the stack. The light is reflected from a mirror (retroreflector) on the opposite side and proceeds back to the transceiver, where the photodetector, I, measures the amount of light returned. The photodetector I_o measures the light intensity initially sent into the flue gas. By taking the ratio of I/I_o, the flue gas transmittance is calculated. The flue gas opacity ($O_t = 1 – T$) is corrected using the path length correction factor to obtain the stack exit opacity O_x.

Calibration is performed by the automatic insertion of a “zero mirror” into the light path of the transceiver. The zero mirror gives a “pseudo-zero” reading, not a true cross-stack zero. However, an iris on the mirror is adjusted in a clean room, prior to installation, so that the pseudo zero will be equivalent to the cross-stack zero. When the zero mirror is in place, a filter of known opacity moves in front to provide an upscale calibration value. When the zero mirror is in place, the instrument should read zero. If the transceiver window is dirty, an upscale value will register; however, electronic drift can also contribute to this value. It is allowed in these instruments to correct for this drift, up to a level of 4% opacity, after which an alarm is to be given, warning that the window should be cleaned.

Optical windows are used to keep the internal optics free of particulate matter. Purge air blowers provide an air curtain to minimize the collection of particulate matter on the windows. The blower uses ambient air that is filtered to remove particles that may be present. Changing the filters and cleaning the windows are two major preventive maintenance activities conducted on opacity monitors. Quality assurance procedures that require quarterly audits using certified optical filters have been proposed by the EPA (Method 203).

The technology of opacity monitoring is quite mature. Opacity monitors should exhibit availabilities of better than 98%. If they do not, it is time to declare the instrument obsolete and purchase a new one (see Section 9). Although opacity monitors are designed to provide data that can be correlated to the stack exit readings of a VE observer, this correlation may not be any better than ±7.5% opacity, depending upon the capability of the observer, observing conditions, and the presence or absence of water droplets in the stack and/or the presence of a steam plume.

2.3 CEM System Control and Data Acquisition and Handling Systems

Continuous emission monitoring systems are designed to perform the daily calibrations, probe blowback, and air cleaning cycles automatically. Blowers, pumps, heaters, power supply, and so on provide inputs to control systems to activate alarm set points. CEM system alarms may then register on control room panels or, more commonly today, on the monitors of the CEM data acquisition system, remote terminals, or the plant distributive control system (DCS).

2.3.1 The CEM System Controller

The type of control system used has often been specified by the user, but in deference to the experience of the CEM integrator, the integrator may incorporate their choice of controller into the system. In the 1990s, programmable logic controllers (PLCs) were the most popular type of control system, but the use of ESC data loggers has replaced or supplemented PLC systems. Others use specially configured microprocessors for the control applications.

The controller serves as the interface between the analyzers and system sensors to provide inputs to the CEM computer—the core of the CEM data acquisition and handling system.

Communication between the PLCs or data loggers is usually by serial communications via RS-232, RS-422, or RS-485 communication protocols. The CEM software then converts the analyzer data into the proper units, averages it, and organizes it into recordkeeping and reporting formats.

Analyzer zero and span calibration checks are conducted daily. The CEM control system should initiate these automatically and the data acquisition system (DAS) should report the drift in both ppm (or % CO_2 or % O_2) and as a percent of span.

The controller provides for system alarms, receiving status lines that indicate CEM system and analyzer failures such as: power loss, sample vacuum loss, instrument/purge air loss, analyzer lamp failure, or sample pressure loss.

2.3.2 The Data Acquisition and Handling System

The data acquisition and handling system (DAHS) receives inputs from the PLC or data logger, the computers being usually IBM compatible PCs. Operating systems are either Windows or Unix based. The functions of the data acquisition and handling system (DAHS) are to display, record, and report data. A typical DAHS is shown in Figure 2-22.

Figure 2-22
Data Acquisition and Handling System for Part 75

2.3.2.1 Displaying Data

Typical CEM DAHS display screens include:

- Menu/overview screen
- Instantaneous emission data screen
- Average emission data (in units of the standard)
- Daily summaries
- Alarm (malfunction and exceedance)
- Calibration drift summary
- Data trending
- Utilities (digital, analog contact summary, and database editor)

The DAHS should incorporate an alarm screen or some other means of making known that the system is in a malfunction condition. Most CEM DAHS systems also have the capability of alarming when emission levels begin approaching or exceeding the emissions standards. These alarm limits are usually a configurable parameter in the DAHS. The system should also have the capability of generating printed alarm summaries.

When a CEM system malfunctions or a unit exceeds the emissions standard, most CEM system DAHS have the capability for the operator to enter a "reasons code" for the malfunction or exceedance. The reasons are usually configurable and are manually keyed into the DAHS when the incident occurs in order to maintain a record for the preparation of the quarterly report.

2.3.2.2 Reporting Data

The DAHS should have the capability of generating reports specific for the CEM system for diagnostic record-keeping purposes, internal plant reporting, and for regulatory reporting. Reports may include emissions data, process data, alarm, and malfunction information. These reports and other CEM data may also be distributed through the appropriate plant communications network. Some typical reports are:

- Daily Calibration Report: the report giving a summary of calibration drift in ppm or % and the calibration drift as a percent of span of the instrument
- Alarm Summary: a summary of all CEM system alarms for any configurable period.
- Daily Summary: a summary of hourly emissions data for the day.
- Excess Emission Report: a report of periods of excess emissions and reasons for excess emissions (Part 60 sources).
- Electronic Data Report (EDR): required under Part 75.

In cases where data are invalid, two scenarios may result:

a) If the unit is regulated under 40 CFR 60 requirements, the invalid data are not submitted, but the number of hours for which data were not obtained are reported in the quarterly excess emissions report submitted to the State, along with the quarterly system availability. Reasons for missing data may also be required to be submitted.

b) If the unit is regulated under an SO_2 or NO_x emissions trading program, data must be substituted for any missing periods. Missing data substitution procedures are defined in the Part 75 Program rules.

All data must be retained by the DAHS, even "bad" data. If bad data are subsequently corrected, the substituted or corrected data must be identified as such with an appropriate code (number, color, and so on). The original "bad" data should also be indicated as such with an appropriate code, but it must not be removed from the database. In other words, the system should have the capability of editing the database without overwriting the original data.

2.2.3.3 Recording Data

Typically, CEM DAHS systems will retain minute data for a few days or weeks and the 15 minute averages for a few weeks or months, depending on whether there is a need to retain this "fine" data for process optimization purposes. This may be extended through the utilization of backup tapes, but eventually, earlier minute-by-minute data will be lost as backup tapes are overwritten. The hourly data, however, is always retained for 3 or 5 years or longer, depending upon the regulatory requirements and company policy.

3 CEM SYSTEM RESPONSIBILITIES

Continuous emission monitoring systems differ from process analyzers in that their operation and performance must meet standards set by the regulations that required them to be installed. These systems are installed because of the EPA Part 75 Acid Rain Program rules, the EPA Part 60 New Source Performance Standards, State permit requirements, or court orders or consent decrees. In any of the cases, performance specifications are established for the CEM system initial certification, a set of rules is given for their continuing operation, and the quality assurance requirements are provided. These rules vary from being relatively forgiving (for example, the Part 60 requirements) to stringent (for example, Part 75). Because of regulatory issues, a continuous emission monitoring system requires more management attention than does the operation of process analyzers.

Operating a CEM system requires knowledge of both technology and regulations. CEM system analyzers must meet certain design specifications, they must undergo a daily calibration check and periodic performance checks, and the data must be recorded and reported in specified formats. The regulations can be quite daunting, particularly those associated with the 40 CFR 75, which are supplemented by a set of guideline documents and interpretive manuals. As a result, responsibilities for a CEM system may be shared between the CEM technician, an environmental engineer, and/or other management/supervisory personnel. Nevertheless, the CEM technician must understand the distinctions between process analyzer systems and the CEM systems and the requirements that they must satisfy.

3.1 The CEM System Management Program

In plant environmental programs, an environmental engineer will often be responsible for interfacing between the corporate office, the plant, and the environmental regulatory agencies. This may be done by someone in the corporate office or in the plant, depending upon the program and the company organization. In Part 75 programs, a “designated representative (DR)” (Acid Rain Program) or “authorized account representative (AAR)” (NO_x Budget Program) must certify that all data submitted to the EPA is correct. The environmental engineer is often the person who provides assurances to the DR or AAR that the data are correct and may occupy a majority of his or her time validating data, assuring compliance with regulations, and reviewing and preparing reports.

The functions of the environmental engineer should not be overstated. In companies that have only one or two operating units, the CEM technician may be the one responsible for providing such assurances to the company DR or AAR. In addition to operating and maintaining the equipment, validating and assuring data quality may consume the balance of a technicians’ time. The point is that the range of responsibilities of a CEM system technician can extend from simply maintenance of the system to the submittal of the quarterly report with the supporting evaluation and validation.

Based on the previous discussion, first consider the responsibilities that the CEM technician might assume:

- Ensures that the CEM, analyzers, and data acquisition system are operating normally at all times
- Assures that all CEM system analyzers meet their daily calibration error (drift) check requirements
- Performs the CEM system weekly checks and records values in accordance with the CEM system weekly checklist
- Reviews all daily CEM printouts weekly
- Performs scheduled preventive maintenance in accordance with procedures given in the QA Manual and the system Operation and Maintenance Manuals
- Performs corrective action as necessary
- Informs the I&C Supervisor when monitoring system problems occur
- Records in the CEM system logbook, performance of preventive maintenance activities, performance audit activities (linearity tests, RATAs, and so on), any adjustments performed, and any observation specific to the system that is not already included on applicable forms
- Records in the CEM system logbook, corrective maintenance performed, a description of the problem requiring corrective maintenance, reasons for the occurrence of the problem, a description of corrective actions taken, and suggestions (if possible) for preventing the problem from reoccurring
- Ensures that all required calibration gases are on hand
- Performs weekly and quarterly backup (on tape) of the CEM system data
- Records all reason and action code entries into the DAHS
- Recommends monitoring/DAHS system changes and upgrades as necessary
- Forwards copies of CEM system daily printouts to the I&C Supervisor for review and sign-off
- Requests approval from I&C Supervisor for service contract assistance
- Maintains spare parts listings and initiates purchases for equipment, calibration gases, spare parts, and supplies
- Supports and assists source testers during monitoring system/analyzer performance evaluations and correlation studies

On the other hand, the environmental engineer's responsibilities may include the following:

- Reviews and verifies monitoring system data for completeness and accuracy

- Reviews all daily CEM system printouts, which is a review of all reason and action code entries on the printouts
- Generates, reviews, and submits the quarterly Acid Rain Program or NO_x Budget Program quarterly Electronic Data Report (EDR) (Part 75 sources)
- Generates, reviews, and submits the quarterly or semiannual Excess Emission Report Summary or Excess Emissions Report (Part 60 affected sources)
- Communicates regulatory issues regarding the Acid Rain/NO_x Budget monitoring program requirement to the designated representative/authorized account representative
- Coordinates training in the QA procedures, regulatory requirements, and corporate policy regarding the Part 75 monitoring program
- Ensures that all checks and audits required by Part 75 are performed (for example, Quarterly linearity tests, RATAs, flow-to-load tests, 5 year tests, and so on)
- Ensures that the plant CEM System QA/QC manual and Monitoring Plan are current and accurate with respect to system design and operation

Depending upon the size of the organization, the technician may perform some, none, or all of the environmental engineering functions, in addition to the operation and maintenance activities. However, other arrangements may have the Unit Operators enter reasons and action codes into the DAHS or may have auxiliary operators or non-CEM technicians perform daily walk through inspections.

CEM systems frequently run more smoothly when one technician is given primary responsibility of the system. Ownership of the system can generate pride in maintaining a system to a high level of performance. However, it may not always be possible to designate a single person or even persons as CEM technicians. In union shops, there may not exist a trade category such as "CEM technician." To single out a person for this function may create problems in defining the job category and then increasing compensation for the added responsibilities.

Also, some union shops require that technicians rotate between assignments, so that all have equal responsibilities in the long run. This creates a problem when running a CEM program because it is difficult to train everyone in the regulatory details of the program. Also, CEM systems tend to generate patterns of maintenance, where little things count and where memory is important. A technician rotating into the CEM system responsibilities may not be aware of these patterns and may not choose the best options when corrective maintenance is required. In general, whether the instrument shop is a union shop or not, someone usually takes more of an interest in the CEM system than do others. This person becomes the point person to ask for direction and/or to provide guidance for CEM system maintenance.

Key Human Performance Point

CEM systems tend to generate patterns of maintenance, where little things count and where memory is important.

However, shared responsibility can lead to gaps in performing the testing, review, and validation that is required in a CEM program. It has been recorded that some plants forgot to perform the quarterly linearity tests; others the flow-to-load tests, and so on. If mandated tests are not performed, questions arise with the regard to the performance of the periodic preventive maintenance activities or the data review and validation.

If an individual is made responsible for the CEM system, a backup person is still needed for periods when vacation or personal leave is taken. In addition to a backup support, other technicians should be trained in the rudiments of maintenance so that they will be able to service the systems when on call during weekends or holidays.

3.2 Technician Skills

An instrument technician maintains, repairs, and overhauls calibrating, measuring, and control instruments. The technician installs and connects instruments to flue gas streams and process and hydraulic, pneumatic, and electrical lines. He or she calibrates, inspects, tests, disassembles, cleans and replaces parts, and reassembles instruments. The instrument technician must understand the principles of operation of the plant instrumentation and the plant quality control procedures necessary to maintain them. Additional skills include the ability to work with microprocessors, programmable logic controllers, and data acquisition systems and their software.

The CEM technician, in addition to the above, must have knowledge of the design and performance specifications required by regulation for the CEM system. He or she must be able to use the software associated with the system, change configurable parameters in the software, correct data in the database, and generate internal and external reports.

Perhaps more important are those skills that underlay technical training. The ability to find the root cause of a problem, find its solution, along with the common sense capabilities of a mechanic in fixing something so that it will work are found in the best technicians. These capabilities combined with the patience to thoroughly document one's work and the initiative to understand EPA monitoring requirements are the qualities that are looked for in a CEM technician.

3.3 Contract Maintenance

An alternative to providing training and allotting time to in-house personnel is to purchase a maintenance contract with the CEM system integrator. A maintenance contract will, at a minimum, provide for quarterly visits, where the system and instruments are checked, consumables replaced, and other preventive maintenance conducted, such as cleaning capillaries of NO_x monitors or flushing sampling lines. A limited number of emergency service calls may be included in the contract or they may be billed separately. Maintenance contracts can relieve the burden of performing preventive maintenance from the plant technician and provide knowledgeable support when problems occur and corrective maintenance is required.

The success of a contract maintenance program depends upon both the responsiveness and the capabilities of the technicians sent out to provide the service. Vendor service technicians share their time between commissioning new systems and responding to service calls and may be unavailable when needed. It is also difficult for CEM system vendors to retain service technicians, because of the demands of constant travel. However, this problem can be mitigated if the vendor has enough personnel to provide regional service.

Another option is to contract with independent CEM service technicians. These tend to be very qualified individuals who gained experience with a CEM system vendor and may have formed their own business based on a core of clients impressed with their work. The problem here is that such individuals tend to be in demand and may be selective in contracting with new clients.

The risk with contract maintenance is that in depending upon the skills of outside contractors, the skills of in-house staff may not become developed. If a CEM system should fail and the contractor is not available immediately, the CEM system may suffer downtime. Responsibility shifts to the contractor, and although the contractor may provide good service, he cannot guarantee the performance of the system without the in-house staff conducting routine quality control checks. Problems cannot be resolved until it is known that they exist. A cooperative effort between plant personnel and the contractor is necessary if the system is to meet its performance requirements and operate with high availability. There are many cases where this has been successfully achieved.

3.4 Options for Shared Responsibility

There are obviously a number of ways that CEM programs can be managed. The degree of management attention to the monitoring program will be dependent upon the attention given by the regulating agency to the submitted reports. In the trading programs, where electronic data reports (EDRs) undergo EPA computerized quality control checks and where allowances are bankable commodities, corporate management provides the resources for the CEM programs to meet or exceed EPA requirements. In the Part 60, New Source Performance Standard programs, where excess emissions reports are submitted to the State, it is not unusual to receive little feedback. Here, incentives to upgrade the system or exceed minimum requirements are not as commanding.

Depending upon the perceived importance of the CEM program, responsibility may be shared to ensure its successful operation. From corporate oversight to routine inspection, a hierarchy of activities can be established to ensure that all procedures are followed, that the data are valid, that the reports are accurate and complete, and that resources are available for everyone to do their job. In the end, who performs the activities is not important; the end result is what matters most. The following diagram displays how some of the functions necessary for running a successful CEM program may be assigned to different personnel.

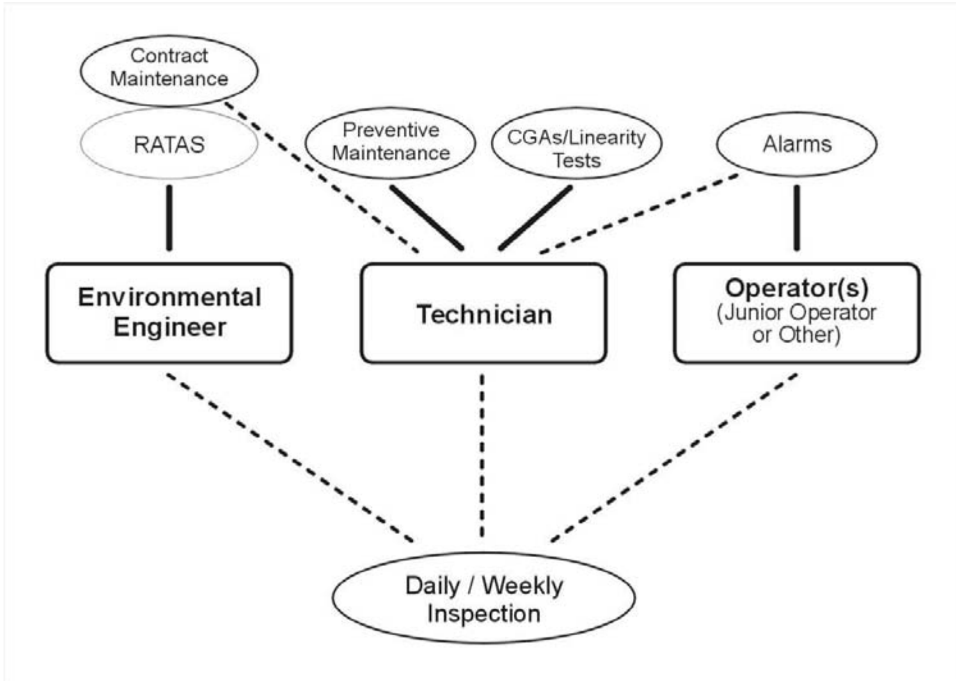

Figure 3-1
Options for Assigned Responsibilities in a CEM Program

The areas where assigned responsibilities may vary most are those of the CEM technician and the environmental engineer coordinating the CEM program. The more responsibilities that the technician (or technicians) can assume for validating the data and the EDRs, the more time can be made available to the engineer for meeting his or her other responsibilities. Assuming more responsibility for a CEM program is not always unwelcome for the technician. The work can be higher profile than other maintenance assignments, and the challenge of achieving higher levels of system performance is one that some readily accept.

However, one can become too comfortable in these responsibilities. Working in the private office of an air-conditioned CEM shelter can be easier than fixing blown circuits or failed pumps in the plant. Depending upon the complexity of the system, one can be convincing that the activities of inspection, maintenance, and documentation may constitute a full-time job. Indeed this may be true, particularly for an older CEM system or one that was poorly designed. To maintain high availability and acceptable performance for such a system, dedicated technicians may be necessary. It has been proven often that even for the most poorly designed CEM systems, which good performance can be obtained if enough resources and manpower are applied. But this in effect is what distinguishes good CEM systems from poor CEM systems—the level of effort and resources necessary to achieve acceptable performance.

Key O&M Cost Point

This in effect is what distinguishes good CEM systems from poor CEM systems—the level of effort and resources necessary to achieve acceptable performance.

EPRI [2, Table 4-1] estimates that 2 man-days per week should be allocated for the maintenance and operation of a CEM system. This number was determined from the experience of seven utilities, but was computed by summing all of the hours dedicated to the CEM system over the year and dividing by 52. This over-weights the hours spent on CEM system during the week because several activities such as overseeing RATAs and preparing EDRs may occupy several days at a time. Also, some activities may be conducted by others. For example, the environmental engineer may take responsibility for reviewing the data and submitting the RATA, or a mechanic or auxiliary unit operator may conduct the daily inspection.

To illustrate the difficulty in generalizing such estimates, two scenarios are provided below in Table 3-1.

Table 3-1
CEM System Manpower Estimates

	Minimum Scenario	Maximum Scenario
Daily Calibration Checks	-	1 hr/day
Daily CEM System Checks	1 hr/day	1 hr/day
Linearity Tests	6 hrs/qtr	8 hrs/qtr
Annual RATA	32 hrs/year	40 hrs/qtr
Preventive Maintenance	8 hrs/qtr	8 hrs/wk
Corrective Maintenance	48 hrs/yr	8 hrs/wk
Documentation/Evaluation/ Training	1 hr/wk	4 hrs/wk
EDR Review	8 hrs/qtr	0.5 hrs/day 8 hrs/qtr
System Upgrades (proactive maintenance)	40 hrs/5 yrs	40 hrs/5yrs
Total Hours/Year	593	2230
Average Hours/Week	11	43

3.4.1 Minimum Scenario

The minimum scenario assumes that the CEM system has been designed correctly, that all of the bugs have been worked out of the system, and that it has been certified and functions with few failures, but still requires periodic preventive maintenance. Because the system has been well designed, it is not necessary to watch the daily calibration error cycle, but nevertheless, the calibration error results, possible alarms, and other diagnostic parameters are checked in a daily inspection. Preventive maintenance is assumed to be routine, but unscheduled maintenance events may occur three or four times per year, requiring six days for troubleshooting and repairs.

The scenario gives time estimates for only one system, so more effort may be required if more units are monitored.

It is also assumed that the DAHS software is well designed and that a minimum number of problems occur in preparing the quarterly EDR or Part 60 excess emission reports. It also assumes for Part 75 reports, that the EDR preparer is familiar with the use of EPA's Monitor Data Checking (MDC) program and applies it to review the data prior to submittal.

Note that in the minimum scenario, if someone other than the CEM technician conducts the EDR review and others conduct the routine daily inspections, the total hours per year decrease to 196, to give an average technician labor effort of 4 hours per week.

Admittedly, there are a number of assumptions in this scenario. It assumes a relatively perfect, well running operation, where the regulations are well understood, the quality assurance program is fully implemented, and not much goes wrong. Here, the technician is knowledgeable and performs his or her work routinely and efficiently.

3.4.2 Maximum Scenario

In this maximum scenario, the CEM system is well designed and operates well. It is operated and maintained by a full-time CEM technician who has been given responsibility for the system, generating the EDR, and remaining current with the CEM regulatory requirements. The technician is present during each daily calibration check, performs the daily inspection, checks over the data daily, optimizes the system operation before linearity tests and RATAs, and documents thoroughly the performance of the system. Skills are maintained through training classes and review of pertinent literature.

Although the preventive and corrective maintenance time estimates may seem excessive, much of this time is spent thinking about potential solutions to problems and fine tuning the operation. Time spent conducting predictive maintenance by trending data or evaluating analyzer and system diagnostics may be counted as "preventive" or "corrective."

With this level of attention, the system is operating in peak form and the technician maintains pride of ownership in the system. Although few maintenance problems may actually occur, the majority of the technician's time is spent in either planned and scheduled activities, the evaluation of options for improving the system, or documenting activities conducted on the systems to provide a defensible monitoring program. The majority of the time is not spent in fixing things but in prevention, planning, and evaluation.

In many ways, this is an ideal way of managing the operation of a CEM system, but in contrast to the minimum scenario, it is less efficient. It requires a significant commitment on the part of management for the operation of the system. Here, the job expands to fill the time, but this is not necessarily a negative point if the time is spent in optimizing the system performance as well as the skills of the technician.

An alternate version of this scenario requires a full-time technician to maintain the CEM system in order to prevent it from breaking down. Here, the CEM system may not have been well designed for the application or may not be fully debugged for optimal operation. This may result in more frequent failures and more time necessary to fix recurring, unresolved problems. Or, if the problems are known, the maintenance may be primarily preventive, requiring extraordinary effort to prevent system failures. The time necessary for documentation in logbooks, inspection forms, and maintenance request forms will also increase as the number of maintenance activities increases.

Hopefully in such an alternate scenario, the greater preventive maintenance demands should decrease the amount of time necessary to fix things, but the preventive maintenance may consist of fixing parts and components so that failures will not occur. This may include frequent pump reconditioning, filter and trap change-outs, probe washing, and so on. In fact, poorly designed systems have been found to operate within precision and accuracy standards with high availability when maintained by dedicated, full-time technicians. In this scenario, a commitment is made by both management and technicians for the system to meet the quality assurance objectives at all costs. The problem, however, may be that the costs are high and unsupportable. When this scenario occurs, an evaluation of the monitoring program should be made with regard to the fitness of the system for its use. It is often better to declare a system obsolete and purchase a new system than to continually struggle to maintain its performance (see Section 9).

Key O&M Cost Point

When CEM system O&M costs and performance become unreasonable, it is often better to declare a system obsolete and purchase a replacement system.

4
DAILY CALIBRATION CHECKS

The daily calibration check has become one of the central activities of the CEM technician's working day. It is so important that some technicians make a point of being present when the CEM system is undergoing the automatic, daily check. Others will check the daily calibration check results as soon as they arrive for work. During weekends or holidays, shift operations will review the calibration data and will call in a technician if problems are noted. Daily calibration check results are sent to supervisors, checked by the environmental engineer on his CEM RTU, and sometimes even reviewed by the plant manager. Such review has become so important because if the daily calibration checks indicate that an analyzer has drifted either out of tolerance or out of control, something has to be done. This section discusses, in depth, the essential activity of daily calibration.

One of the primary features that distinguish CEM systems from process monitoring systems is that CEM systems are required to undergo daily calibration checks. They must pass through an initial certification process and then their performance must be evaluated periodically. These activities are not required of instrumentation systems installed for process control, where the process analyzers are typically operated and maintained at levels appropriate to their application. However, in regulatory applications, data must be comparable from plant to plant so that emissions limits and standards can be applied fairly. In addition, data must be as close to truth as possible so that, from the perspective of public health and welfare, pollutant emissions are not under-regulated and from the business perspective, pollutant emissions are not over-regulated.

The *daily* calibration check is a procedure that is deeply ingrained in U.S. emission monitoring regulation. Daily checks using calibration gases, gas cells, or filters are allowed for these checks in Part 60 requirements, whereas in the Part 75 trading programs, gases traceable to National Institute of Standards and Technology (NIST) standard reference materials (SRMs) are mandated. Instruments calibrated to NIST traceable gases are referenced to standards that are as accurately determined as possible. Such accuracy is essential in supporting emissions trading programs, where an error of only a few ppm in an emissions measurement can mean many dollars. But there are other reasons for requiring daily calibration checks, and litigation is one of the more important ones. If CEM data are used to support enforcement cases, or to provide a defense in an enforcement case, the quality of the data is one of the first issues of questioning. If it can be shown that a monitoring system's daily calibration checks and performance tests meet applicable standards, the data are credible in court. The credibility of data either in trading-type or enforcement-type regulatory programs is therefore very important to a regulatory agency, and the daily calibration check is one of the primary supports for that credibility.

Although CEM system daily calibration checks require both time and resources, the CEM technician benefits directly from the results. The daily data gives an indication of the status of the system. It can show trends in performance. It can be an indication of instrument or system malfunction. The fact that the check is conducted daily implies that attention is paid to the system daily, so that maintenance can be performed expeditiously to minimize system downtime and maximize data quality. Although many instrumentation systems today can operate for weeks or even months without exhibiting calibration drift or a failure in performance, problems will still occur. The daily calibration check provides one of the best tools available for warning of either a developing or an existing problem.

In a calibration check, zero gas is let into the system until the flue gas is flushed from the system and analyzer, and a stable reading is obtained (see Figure 4-1).

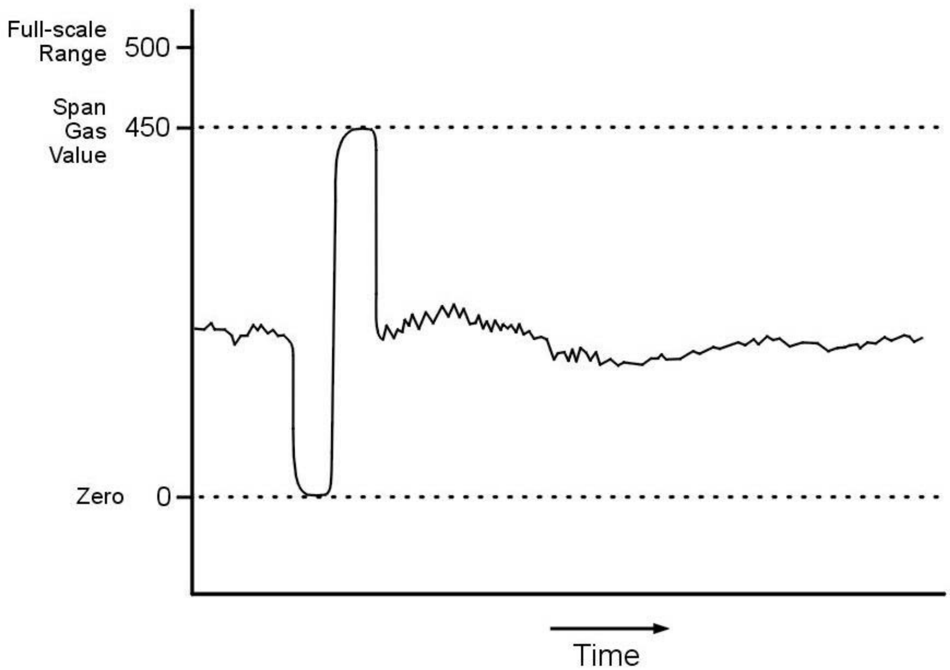

Figure 4-1
A Calibration Check Sequence

The calibration gas is then injected into the system and continues to flow until the zero gas is flushed from the system and the analyzer, and then a stable reading is again obtained. A calibration check reading is taken by the DAHS and then the flue gas is returned to the system. The system is purged of calibration gas for a period programmed into the controller, and then, at the end of this period, the DAHS again records emissions data. If either the zero or up-scale calibration check indicates that the system exceeds drift limits specified in the CEM system quality control procedures or out-of-control limits specified by the EPA, the instrument(s) must be recalibrated.

This calibration check sequence should take less than 30 minutes. Taking longer may result in not having enough data to report a "valid hour" to EPA and result in having to report an hour of missing data for the hour of the calibration period.

Key O&M Cost Point

Taking longer than 30 minutes to perform a calibration check could result in having to report an hour of missing data to the EPA.

4.1 Some Essential Definitions

A primary responsibility of an instrument technician is to calibrate instruments—an activity that requires both skill and attention to detail. A discussion of instrument calibration should therefore appear to be relatively straightforward. However, communication between technicians, supervisors, management, and inspectors can sometimes be a problem because the basic definitions associated with "calibration" have often taken on new meanings in the world of CEM systems. For example, the request to "calibrate the instrument" may be either a request to *check* the calibration of the instrument or to *adjust* the calibration of the instrument. More information is usually necessary to understand whether a check or an adjustment is to be performed.

Key Technical Point

When requested to calibrate the instrument, the technician should know whether to check or to adjust the CEM instruments.

First, regular industry's understanding about the meaning of span, range, and calibration drift is not the same as the regulatory meanings. One must realize that previous interpretations of these words must give way to the EPA definitions. It is somewhat like learning a new language—in order to be conversant with rules of Part 60 and Part 75; one must speak the language used in the rules.

4.1.1 ASTM Definitions for Ambient Air Analyzers

Full-scale: the maximum measuring limit for a given range of an analyzer

Range: the concentration region between the minimum and maximum measurable limits

Span drift: the change in analyzer output over a stated time period, usually 24 hours of unadjusted continuous operation, when the input concentration is at a constant, stated upscale value

Zero drift: the change in analyzer output over a stated time period of unadjusted continuous operation when the input concentration is zero; usually expressed as a percentage change of full scale over a 24-hour operational period

Noise: random deviations from a mean output not caused by sample concentration changes

4.1.2 Definitions from 40 CFR 60 Appendix F (Quality Assurance Procedures)

Span value: the upper limit of a gas concentration measurement range that is specified for affected source categories in the applicable subpart of the regulation
(In Part 60 Appendix A Test Method 6C, "span" is the upper limit of the gas concentration displayed on the data recorder.)

Zero, low-level, and high-level values: the CEMS response values related to the source-specific span value. Determination of zero, low-level, and high level values is defined in Performance Specification 1 of Part 60 Appendix B [9]

Calibration drift (CD): the difference in the CEMS output reading from a reference value after a period of operation during which no unscheduled maintenance, repair, or adjustment took place. The reference value may be supplied by a cylinder gas, gas cell, or optical filter and need not be certified.

4.1.3 Definitions from 40 CFR 75

Span: the highest pollutant or diluent concentration or flow rate that a monitor component is required to be capable of measuring under Part 75.

Calibration error: the difference between:

1) The response of gaseous monitor to a calibration gas and the known concentration of the calibration gas

2) The response of a flow monitor to a reference signal and the known value of the reference signal

3) The response of a continuous opacity monitoring system to an attenuation filter and the known value of the filter after a stated period of operation during which no unscheduled maintenance, repair, or adjustment took place

Measurement range: a value selected such that:

1) It is high enough to prevent full-scale exceedances from occurring

2) It is low enough to ensure good measurement accuracy and to maintain a high signal-to-noise ratio

3) During typical unit operation, the readings obtained are to the extent practicable, between 20.0% and 80.0% of full-scale range of the instrument

Reference value or reference signal: the known concentration of a calibration gas, the known value of an electronic calibration signal, or the known value of any other measurement standard approved by the Administrator, assumed to be the true value for the pollutant or diluent concentration or volumetric flow being measured.

The definitions apply to the instrument or system application. The ASTM definitions are the most general and were written for ambient air monitor applications, although they could just as easily refer to process analyzers or CEM systems. The EPA Part 60 definitions apply to sources that are regulated under the 40 CFR 60 New Source Performance Standards, or under State permits, where States have adopted by reference, Part 60 procedures (which are practically all the States). The Part 75 definitions are the most prescriptive, and differ from those previously accepted in the field of instrumentation. Part of the reason for doing this was to establish uniform procedures for setting the instrument range and selecting calibration gases. It was also desired to avoid over-ranging of the instruments in the case of emission upsets, while avoiding measuring in the noise level during normal operation.

4.1.3.1 Range

Consider first, the definition of "range." The ASTM definition of range is the "...region between the minimum and maximum measurable limits." In Part 60 sources, the upper end of the range is called the "span," and the span is defined in the Subpart of Part 60 that regulates the effected source category. For example, the span value for an SO_2 analyzer required for a fossil-fuel-fired steam generator regulated under 40 CFR 60 Subpart D is 1500 ppm if it burns coal.

On the other hand, Part 75 qualifies the upper end of the range to have a value such that the majority of the measurements taken during normal operations fall within 20% to 80% of this value. In Part 75, this value **is not** the span value. The Part 75 span value is something completely different from a Part 60 span value.

Another term that may be encountered for the upper limit of the range is the "full scale value." In any case, this upper value is the last value given on the meter, the end of the scale, where if the measurements go higher, the instrument is said to be off-scale or out of range.

The selection of the range value in Part 75 systems is important, because if an SO_2, NO_x, or flow monitor goes off-scale, the data is "missing" and hourly data must be substituted that have a value that is 200% of the full-scale range.

4.1.3.2 Span

The term "span" is the most confusing in the field of gas monitoring. In Part 60, it has been defined as the upper end of the measurement range, a terminology that is consistent with most instrumentation practice. Used as a verb, "spanning an instrument" means to set the range of the instrument by adjusting its calibration using zero and span gases. A "span gas" is a cylinder gas, having a concentration usually at the upper end of the range (for example, > 80% of the range).

The term "span value" used in Part 60 affected sources means the full-scale range value, that is, the upper limit of the range.

The "span value" used in Part 75 has, however, a different meaning. The "span value" here is a calculated parameter, based upon the "maximum potential concentration (MPC)" or "maximum expected concentration (MEC)" from which one determines the concentrations of the calibration gases required to be used for the daily calibration error and quarterly linearity tests.

For SO_2 analyzers, the maximum potential concentration is calculated from the fuel sulfur content using Eq. A-1a of 40 CFR 75 Appendix A §2.1.1.1 [10] or from a minimum of 720 hours of quality assured data obtained while the unit is burning the highest sulfur fuel or fuel blend that is to be combusted.

The MEC is calculated for units with installed SO_2 scrubbing systems and is calculated from the MPC and the design removal efficiency.

For NO_x analyzers, the maximum potential concentration is dependent upon the type of boiler and type of fuel burned. MPCs are given in Tables 2-1 and 2-2 in 40 CFR 75 Appendix A §2.1.2.1 [10].

Flow monitor "calibration span value," that is, the value at which the instrument calibration is to be checked, is determined from Eq. A-3a or A-3b of 40 CFR 75 Appendix A §2.1.4.1 [10]. These equations are based upon F factor calculations and the value of the maximum heat input.

To calculate the Part 75 span value, the MPC or MEC is multiplied by a factor from 1.00 to 1.25 to account for a possible emissions excursion and then rounded up to the next highest multiple of 100 or ,if the SO_2 span is ≤ 500 ppm, it can be rounded up to the next highest multiple of 10. The resultant value is then used to determine the concentrations of the calibration gases required for the daily calibration error checks and the quarterly linearity tests.

The value of the Part 75 "full-scale" range value is then selected to be either equal to or greater than the span value provided that the data obtained during normal unit operation fall within 20 to 80% of the range. To simplify everything, if possible, it is best to make this range value equal to the span value.

4.1.3.3 Valid Hour

The introduction to this section alluded to the term "valid hour." In the General Provisions of Part 60, Part 60 affected sources "must complete a minimum of one cycle of operation (sampling, analyzing, and data recording) for each successive 15-minute period" [40 CFR 60.13(e)(2)] [11]. Also [in 40 CFR 60.13(h)] [11], "for continuous emission monitoring systems other than opacity, 1-hour averages shall be computed from four or more data points equally spaced over each 1-hour period" [1]. If strictly interpreted, this does not give much time to conduct a calibration drift check. However, these provisions can be modified in the Subparts of Part 60, where, for example, in Subpart Da, only two data points per hour are necessary to constitute a valid hour. Many State agencies consider that as long as one data point is obtained in each quarter of the hour, the hour will be valid. In this interpretation, one could conduct a calibration check from the 46th minute of an hour to the 14th minute of the following hour, for a total of 28 minutes, and not invalidate either hour. Some states do, however, have a problem with the words "equally spaced" and do not allow this interpretation. Others, however, prefer not to invalidate the otherwise acceptable 45 minutes of data obtained during each of the two hours. When in question, state regulators should be contacted for their policy regarding these rules.

For Part 75 affected CEM systems, the General Operating Requirements of 40 CFR 75.10 (d)(1) [12] state that "hourly averages shall be computed using at least one data point in each fifteen minute quadrant of an hour" [13] so, "an hourly average may be computed from at least two data points separated by a minimum of 15 minutes.....if data are unavailable as a result of the performance of calibration, quality assurance, or preventive maintenance activities..."

4.1.4 Calibration Drift and Calibration Error

4.1.4.1 Part 60 Calibration Drift

The Part 60 definition of calibration drift (CD) is the difference in an analyzer output reading from a reference value after a period of operation during which no unscheduled maintenance, repair, or adjustment took place. This reference value can be that of a cylinder gas, an optical filter, or a gas-filled cell. The reference material is not required to be traceable to any standard reference material; the reason for this being that the drift test is meant to check the day-to-day drift of the instrument and not its absolute calibration.

When a CEM system is initially certified under the Part 60 Appendix B Performance Specifications, it must undergo a seven-day calibration drift test [6]. For each of seven days, it must not drift by more than 2.5% of the Part 60 span value (for SO_2 and NO_x analyzers). If it fails, one must start over and continue until it passes. In general, failure to meet this drift requirement implies that there are startup problems, either with the CEM system or the analyzer, which must be corrected before the system can provide data acceptable to the regulating agency. The drift performance specification differs, depending upon the type of analyzer. The drift specification is 2.5% for SO_2 and NO_x analyzers, 0.5% O_2 or 0.5% CO_2 for the diluent analyzers, 5.0% or 3.0% for CO analyzers, and 5.0% for H_2S analyzers.

After the system is certified, the zero and span drift of each analyzer must be checked every 24 hours. If, in a daily zero and span calibration drift check, an analyzer should drift by more than twice the value of the drift performance specification (2×2.5% = 5.0% for SO_2 and NO_x analyzers), the EPA requires that the analyzer be adjusted [see 40 CFR 60.13(d)(1) and 40 CFR 60 Appendix F §4.1][12,14, respectively].

Furthermore, for Part 60 units that are affected by the CEM quality assurance requirements of 40 CFR 60 Appendix F (as required by the Part 60 Subpart, operating permit, consent decree, or other), the CEM system is said to be out-of-control if the calibration drift should be greater than four times the drift specifications (> 10% for SO_2 and NO_x analyzers) or greater than twice the drift specification for five consecutive days. Out-of-control data are not acceptable for regulatory reporting, and the CEM system is essentially unavailable for monitoring emissions until the problem is resolved.

The Appendix F out-of-control criteria, with respect to today's instrumentation, are quite generous. If a SO_2 analyzer daily calibration drift check exceeds 5.0% for five consecutive days, this means that the analyzer had to be adjusted for five days running. After the second or third day, the CEM operator should have been aware that either a problem exists or that one is developing. A drift of 10% span certainly indicates a major problem has developed. The out-of-control period extends back to the last good calibration conducted 24 hours earlier.

4.1.4.2 Part 75 Calibration Error

For CEM systems installed to meet the requirements of Part 75, the term calibration "error" is used instead of calibration "drift" when one conducts the daily calibration check. The term "error" is used because calibration gases traceable to NIST standards are required when performing the check. The traceability requirement establishes a link from the analyzer back to NIST standard reference materials (SRMs). If one can link all Part 75 CEM systems back to these SRMs, then arguments can be made about the comparability and accuracy of the data generated by these systems.

The Part 75 calibration error requirements are both more stringent and more rational than the calibration drift requirements of Part 60. In Part 75:

- Only certified, NIST traceable cylinder gases may be used to check the daily calibration
- The calibration gas must pass through all filters, scrubbers, conditioners, and other monitor components used during normal sampling and through as much of the sampling probe as is practical (this requirement is not prescribed in Part 60)
- Calibration error criteria are given as a percentage of the "span value," which may or may not be the upper value of the range

The initial calibration error certification procedure again requires that the calibration error (drift) be determined for each of seven days. The drift must be less than 2.5% of span for <u>each</u> of the seven days ($\leq$ 0.5% O_2 or $\leq$ 0.5% CO_2 for diluent monitors). The daily calibration errors (drifts) are <u>not</u> averaged to make one seven day drift. Part 75 does, however, allow some options. If the Part 75 "span value" (Note: this may not be the full-scale range value), is less than 200 ppm, calibration error results are also acceptable if the absolute value of the difference between the monitor response and the reference value is $\leq$ 5 ppm.

After the CEM system is certified, the daily calibration error is expected to be less than $\leq$ 2.5% of the span of the instrument. EPA, in Part 75, <u>recommends</u> that the analyzer be adjusted if the daily instrument calibration error exceeds 2.5% (that is, the value of the calibration error performance specification) [40 CFR 75 Appendix B §2.1.3 (b)]. This is not a requirement, so an instrument is allowed to drift beyond this level, without immediate adjustment. However, if the daily SO_2 or NO_x analyzer calibration error exceeds 5.0% or an O_2 or CO_2 analyzer daily calibration error exceeds 1.0% O_2 or 1.0% CO_2, the analyzers is out-of-control [40 CFR 75 Appendix B §2.1.4(b)]. This differs from Part 60 CEM systems, where a daily drift of 5.0% is an action limit for recalibration, not an out-of-control limit. In Part 75, any day where the calibration error exceeds twice the performance specification, the analyzer is out-of-control.

4.1.4.3 Importance of the Daily Calibration Error (Drift) Test

As discussed earlier, the daily calibration drift or error check is central in the normal operation of a CEM system. Most technicians will set a "tolerance" or warning limit below the out-of-control limit so that some action can be taken before missing data might result. A tolerance limit of 2.5% of span is often chosen, which is tight for both Part 60 and Part 75 analyzers. At such a level, variations in atmospheric temperature, shelter temperature, or power fluctuations may generate an excessive number of alarm conditions.

One solution to this is to raise the tolerance level to a compromise value, such as 3.5% of span. A Part 60 analyzer is required to be recalibrated only when the calibration drift exceeds 5.0% of the full-scale range value. Part 75 recommends that adjustments be made when the calibration error exceeds 2.5% of the Part 75 "span value"; however, this is not a requirement. For Part 75 systems, adjustments should be made before calibration errors of 5.0% are reached; otherwise, the system will be out-of-control. Another solution is to investigate the cause or causes of the instrument drift and eliminate them.

An argument may be made that the best way to operate the system is to have as little drift or calibration error as possible and to recalibrate the system even if it drifts (for example, above 2.0% of span). Such a criterion for recalibration may be excessive for the operation of the system. Random fluctuations may be causing the drift, and frequent daily calibration adjustments may be merely an exercise in chasing noise from one day to the next. Frequent recalibrations are also expensive, both in time and calibration gas usage. Part 75 requires that after each calibration adjustment, an additional calibration error test be conducted [40 CFR 75 Appendix B §2.1.3 (b)] (U.S. EPA 2003i) to verify that the adjustment was made properly [15,6, respectively]. A simple calibration adjustment after a daily calibration error test, therefore, means that 3 calibration procedures are conducted in one day instead of one.

In some CEM systems, the data acquisition system will make adjustments to the data to correct for the daily calibration error. A correction factor will be multiplied times all subsequent data until the next calibration error test. A problem can occur here if the correction factor corrects back to the response from the previous day or to the value of the calibration gas cylinder. If the previous day's response was itself corrected, one could cascade corrections to a point where the system would be out of control.

4.1.5 Calibration Gases

Calibration gases are integral in EPA's quality assurance program for CEM systems. The quality of calibration gases themselves is specified by the traceability protocol "EPA Traceability Protocol for Assay and Certification of Gaseous Calibration Standards" [16]. Gases developed under this protocol are termed "protocol gases" and are required in Part 75 applications. They are not required for the daily calibration drift checks of Part 60 systems, but NIST traceable gases are required for use in the Part 60 Appendix F quarterly cylinder gas audits (CGAs). A "traceable" standard is one that has been compared and certified, either directly or indirectly by not more than one intermediate standard to a primary NIST standard reference material (SRM).

Standard reference material (SRM): a calibration gas mixture issued and certified by NIST as having specific known chemical or physical property values.

Gas manufacturer's intermediate standard (GMIS): a compressed gas calibration standard that has been assayed and certified by direct comparison to a standard reference material (SRM), an SRM-equivalent PRM, a NIST/EPA-approved certified reference material (CRM), or a NIST traceable reference material (NTRM), in accordance with Section 2.1.2.1 of the "EPA Traceability Protocol for Assay and Certification of Gaseous Calibration Standards" [16].

SRMs are essentially the “gold” standards to which intermediate standards and protocol gases can be traced. Gases considered equivalent to SRMs are manufactured in the Netherlands by the Netherlands Measurement Institute (NMI) and are called SRM-equivalent Primary Reference Materials (PRMs).

The Gas Manufacturer’s Intermediate Standard (GMIS) is an intermediate reference standard that has been compared directly to an SRM and can be used by gas manufacturer’s to prepare protocol gases. Such intermediate standards are necessary because of the cost and limited supply of the SRMs. The GMIS is assayed against an SRM three separate times over a period of three months [16]. The GMIS must have a 95^{th}% uncertainty of less than 1.0% of the mean concentration.

4.1.5.1 Protocol Gases

Protocol gases are prepared by gas manufacturers using either procedure G1 or G2 given in the EPA traceablity protocol. The G1 procedure involves the direct comparison of the candidate gas mixture to reference standards without dilution. G2 is the indirect comparison of the candidate gas to reference standards with dilution. Today, a number of gas vendors use Fourier transform infrared spectrometers calibrated with SRMs or GMISs to perform this comparison. The calibration procedures, linearity response, adjustment procedures, and uncertainty calculation procedures are all strictly defined in Procedures G1 and G2. Protocol gases must be certified by the vendor to be within 2.0% of the concentration specified on the label.

A certificate is required for protocol gases and must be retained by the user. Typically, the certificate will be pasted on the cylinder and a separate copy will be provided for filing. The certificate must include the following information:

1. Cylinder identification number
2. Certified concentration
3. Balance gas in the mixture
4. Cylinder pressure at the time of certification
5. Assay/certification date
6. Certification expiration date
7. Reference standard identification (standard number, cylinder number, and concentration)
8. Statement that the assay/certification conforms to EPA protocol guidelines
9. Analytical method used to perform the assay
10. Laboratory identification of the producer
11. Chronological record of all certifications for the standard
12. Statement that certification was corrected for interferences (if applicable)
13. An estimate of the total uncertainty of the assay

For protocol gases, certifications are good from 12 to 36 months, depending upon the gas mixture. However, if the cylinder pressure falls below 150 psig (1034 kPa), the concentration may change and the cylinder should not be used. Preparing a protocol gas requires a minimum of two weeks, because two assays, two weeks apart, are required to check the stability of the mixture. Although gas vendors may have some mixtures in stock, they are usually custom blended and must be prepared upon receipt of an order. If cylinder gas pressures are not tracked and gases are not ordered on a timely basis, it is possible that cylinder gases appropriate for the system will not be available for the daily calibration checks. If the daily checks are not conducted, subsequent data will not be quality assured, and in Part 75 systems, such data will be viewed as missing.

Key Technical Point

If protocol gas has been stored between 12 to 36 months and/or the cylinder pressure falls below 150 psig (1034 kPa), the concentration may change and the cylinder should not be used.

Key Human Performance Point

If cylinder gas pressures are not tracked and gases are not ordered on a timely basis, it is possible that cylinder gases appropriate for the system will not be available for the daily calibration checks.

Traditionally, “single-blend” gases have been used to calibrate and check the calibrations of analyzers. Because of the costs and time that it takes for some systems to undergo a calibration check, the use of “multiblend” gases has become a common practice. Typically, in the Part 75 Acid Rain Program, blends of SO_2, NO, and CO_2 are used in nitrogen so that all three analyzers used in such systems can undergo a calibration check at the same time. It should be noted, however, that the CO_2 concentration in these blends may be on the order of 12% to 15%. Because CO_2 is a heavier gas (molecular weight 44) than nitrogen (molecular weight 28), the density of a CO_2 containing multiblend cylinder gas will be greater than one not containing CO_2. This change in density will affect the dilution ratio in the dilution probe.

For example, consider that an NO analyzer is calibrated initially using a cylinder gas containing a blend of 200 ppm NO in nitrogen. If gas from a multiblend gas containing 200 ppm NO, 15% CO_2, and balance nitrogen was sent through the system, the dilution ratio would increase and the analyzer would read higher than 200 ppm. This can be a problem when conducting linearity tests, if gas cylinders containing just SO_2 or NO in nitrogen are used on a CEM system calibrated with a multiblend gas containing CO_2 (or vice versa). Linearity tests have failed because of this reason; however, the effect can be corrected if the molecular weights of the two different gas mixtures are calculated.

The effect of CO_2 on the dilution ratio of dilution systems obviously extends to the actual flue gas emission measurements. Most combustion source flue gases will contain CO_2 on the order of 8%–12%. If the dilution system analyzers are initially calibrated with double blends of SO_2 or NO in nitrogen, without CO_2, the actual flue gas measurements will be incorrect because of the density effect. For this reason, dilution systems should be calibrated using multiblend gases containing CO_2 at a concentration level close to that of the flue gas CO_2 concentrations.

4.1.5.2 Calibration Gas Quality

Although certified gases are to have gas concentrations within stated levels of accuracy, they sometimes are not as accurate as indicated on the certificate. With over a dozen commercial gas vendors, the quality of the laboratories, quality control procedures, and documentation can vary. There have been instances where cylinder gas concentrations differed by more than 10% from the mean concentration given on the bottle. The EPA initiated a series of blind audits of certified gases in the 1980s. In these audits, the gas cylinders were purchased by a consultant or EPA contractor and then delivered to the EPA for analysis by an independent laboratory. The results were published and provide a means of evaluating the performance of the gas vendors in adhering to the EPA protocols.

The quality of protocol gases is not a trivial issue. One may simply assume that if a cylinder comes with a certification statement, the gas is accurate to within the 1.0% to 2.0% stated on the certificate. This is not necessarily true, because users have experienced inaccuracies greater than 2.0%. For this reason, sufficient gas should be retained in a cylinder to crosscheck any new cylinders placed into the system. The quality assurance manual should include a procedure for crosschecking the new cylinder against the old one and rejecting the new cylinder if it is out of tolerance.

Key Technical Point

Crosschecking new gas cylinders against the old cylinders and rejecting the new cylinder if it is out of tolerance should be part of the CEM QA Manual.

Similar crosschecks should be conducted before relative accuracy tests are conducted by source testing companies. The source testing companies will be using their own calibration gases, so before the test, either the CEM system calibration gases should be checked against the source testing company's analyzers or the source tester's calibration gases should be checked against the CEM system analyzers. Any discrepancy can then be taken into account when evaluating the relative accuracy test results. Some may feel that better relative accuracy test results can be obtained if the same set of calibration gases is used to calibrate both the CEM system and the source testing company's analyzers. Because there is no certainty that one gas is more accurate than the other, this is not considered good scientific practice.

When replacing cylinder gases, it is of course necessary to reconfigure the DAHS with the new gas concentration values of the replacement cylinder. Although this is certainly obvious, time constraints, a call-out for emergency repairs, or merely forgetfulness may prevent this from being done immediately after the cylinder is exchanged. If not done, on the next calibration error check, the DAHS will compute the calibration error from the previous cylinder value, and the analyzer, or analyzers, may appear to be out-of-control if the concentration values of the two cylinders differ significantly.

Key Human Performance Point

When replacing cylinder gases, remember to reconfigure the DAHS with the new gas concentration values of the replacement cylinder. If not, the DAHS will compute the calibration error from the previous cylinder value, and the analyzer, or analyzers, may appear to be out-of-control.

4.1.5.3 Zero Air

Zero air or a low-level gas is necessary to check the lower end of the range of an analyzer. A calibration gas having a value from 0% to 20% of span can be used for this purpose, but usually a cylinder of zero gas, or in the case of dilution systems, the dilution air is used for the zero air. The various options for zero air allowed by EPA for Part 75 affected systems are given.

Zero air material means either:

1) A calibration gas certified by the gas vendor not to contain concentrations of SO_2, NO_x, or total hydrocarbons above 0.1 parts per million (ppm), a concentration of CO above 1 ppm, or a concentration of CO_2 above 400 ppm

2) Ambient air, conditioned and purified by a CEMS for which the CEMS manufacturer or vendor certifies that the particular CEMS model produces conditioned gas that does not contain concentrations of SO_2, NO_x, or total hydrocarbons above 0.2 ppm, a concentration of CO_2 above 1 ppm, or a concentration of CO_2 above 400 ppm

3) For dilution-type CEMS, conditioned and purified ambient air provided by a conditioning system concurrently supplying dilution air to the CEMS

4) A mixture certified by the supplier of the mixture that the concentration of the component being zeroed is less than or equal to the applicable concentration specified in paragraph (1) of this definition and that the mixture's other components do not interfere with the CEM readings.

When using dilution air for zero air, one should periodically check the zero of the system with a cylinder of certified zero air. If dilution air is used only, failures in the air-cleanup system may pass through contaminants to the analyzers. The contaminants may go undetected if this pass-through is interpreted as instrument drift or a change in the dilution ratio. A periodic check with a zero gas cylinder can be used to "reset" the system if such corrections have been made.

4.1.6 Implications of the Calibration Check

The zero-span calibration check assumes a linear relationship of the instrument over its range. In some cases, an instrument's response may not increase linearly with increasing concentration. However, in current instruments, a nonlinear response is usually corrected in the internal microprocessor to provide a linear output. Given a linear response, the effect of calibration drift is illustrated in Figure 4-2.

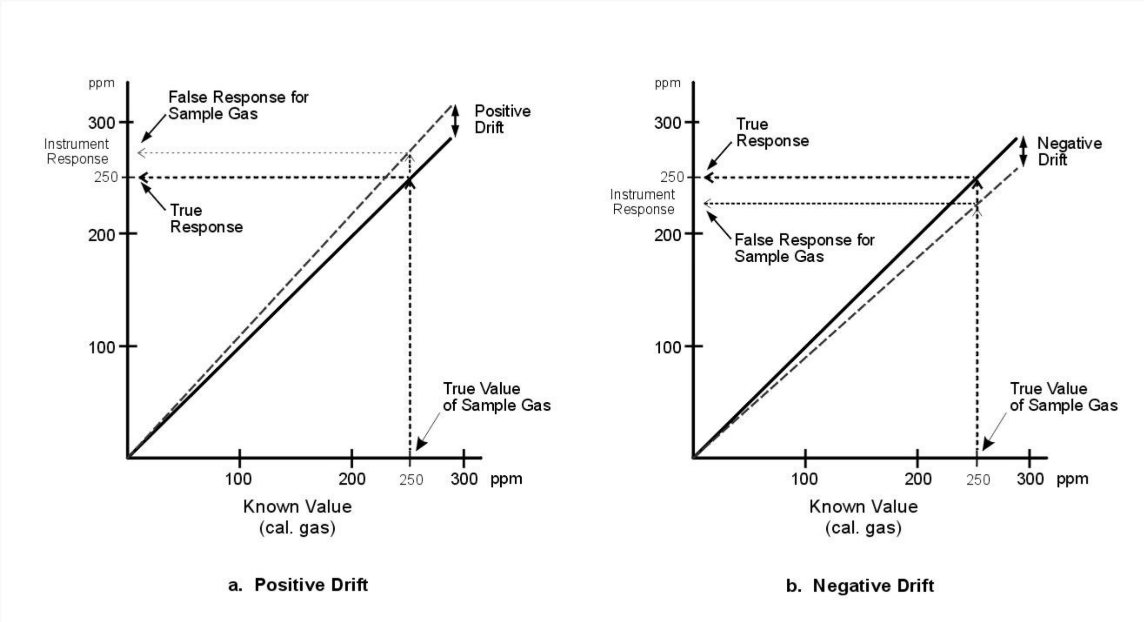

Figure 4-2
Effects of Calibration Drift on Emissions Data

In Figures 4-2a and 4-2b, the instrument response is plotted as a function of "true" value. In Figure 4-2a, the instrument has drifted in a positive direction when the instrument's calibration error was checked using a zero and high-level calibration gas. In the example, the instrument read higher than 450 ppm when the system was checked with a 450 ppm calibration gas. The instrument exhibited no drift using a zero gas. Note from the dotted line that if true flue gas concentration is 300 ppm, the instrument response would be higher than if the instrument was in calibration.

In Figure 4-2b, the instrument has drifted in a negative direction when the instrument's calibration error was checked using a zero and high-level calibration gas. In the example, the instrument read lower than 450 ppm when the system was checked with a 450 ppm calibration gas. The instrument again exhibited no drift using a zero gas. Note from the dotted line that if true flue gas concentration is 300 ppm, the instrument response would be lower than if the instrument was in calibration.

Other scenarios can be considered, for example, where the zero and upscale calibration checks drift equally in the same direction, one negatively and one positively, and so on. Calibration adjustments can minimize the error in the measurements, but again, adjustments should not be made for small percentage changes in drift. If the drift is due merely to system or analyzer "noise," the errors should be equally positive and negative and will average to zero.

4.1.7 Daily Calibration Checks for Flow Monitors and Opacity Monitors

The daily calibration drift or calibration error checks give the day-to-day drift for the gas analyzers. Flow monitors and opacity monitors also undergo daily calibration checks, but these are performed internally, without the use of independent reference standards.

4.1.7.1 Opacity Monitors

Opacity monitors use an internal reference filter, which may be as simple as a metal grid or as complex as a liquid crystal window that can close "shutters" to give 16 different opacity readings. These internal devices are not certified by an independent body; however, opacity monitors must undergo a "calibration error" check using three certified filters before the instrument is installed. These filters are independent of the actual monitor, thus allowing the performance of the instrument to be traceable to NIST traceable standards. The internal filter then indicates the drift of the instrument from that original calibration error check.

In double-pass opacity monitor systems, the daily calibration check is conducted on the transceiver assembly only. The checks monitor the active optical and electronic components of the system but do not typically check the retroreflector or the alignment of the system. Drift in opacity monitors is usually due to dirt accumulation on the transceiver optical window or system electronic drift. This combined drift can be automatically corrected by the instrument, but a warning must be given if the correction exceeds 4% opacity. Exceeding a 4% opacity drift correction usually requires a visit to the monitor and a window cleaning.

Opacity monitoring is a mature technology and little drift is normally observed either in the zero or the span for properly designed and installed instruments. Most problems occur with alignment after shutdown and startup, lightning strikes, or particulate fouling when the air blower system fails or cannot compensate for high particulate loads.

4.1.7.2 Flow Monitors

Flow monitor daily calibration checks do not use independent standards for daily calibration. The zero and span checks designed for these monitors usually check only the transducers or part of the electronic circuit. Because the flow is measured *in situ*, using some type of sensor, there is no practical method for checking the system with some type of reference standard. The flow-to-load ratio test or gross heat rate to load test provide the best means of evaluating the day-to-day performance of these systems, but these tests are performance indicators and not calibration techniques. These tests will be discussed in more detail.

The daily zero and span checks of differential pressure type flow monitors check the zero response and an upscale response of the instrument pressure transducer. Typically, solenoids close off the tubing extending from the impact and wake pressure ports of the monitor. The two lines are opened to the atmosphere or the same pressure to give a net differential pressure of zero across the transducer. Closing the lines and pressurizing one side can then give an upscale reading on the transducer. These calibration checks do require sometimes relatively complicated plumbing schemes, which use a number of solenoids to switch between the different pressure lines during the sequences.

The ultrasonic flow monitors perform a zero and span calibration by manipulating the transducer signals. If the time that it takes for sound to reach the upstream transducer from the downstream transducer is substituted electronically for the time that it takes sound to reach the downstream transducer from the upstream transducer, the instrument will see two identical times to give a zero signal. Also, if a known delay is introduced into one of the signals, an upscale calibration signal can be generated. Again, these techniques are internal to the instrument and do not represent reference measurements that are independent of the system.

Checks on a thermal sensing flow monitoring system are set up from an initial calibration of the instrument as a function of electric power versus gas velocity. Wind tunnel testing may be used to generate this calibration function. Calibration signals corresponding to this function are then generated electronically to be sensed by the instrument as zero and span readings.

These calibration techniques obviously have limited usefulness, and the daily zero and span responses will show little variation unless a major problem develops with the processing end of the instrument. Most problems in these systems occur, however, in the probe sensor, which is not checked by these zero and span techniques.

4.1.8 Quality Control Charts

A quality control chart can be used to assess the ongoing performance of the CEM system analyzers. The zero and calibration drift/error data can be plotted over time to produce a trend plot of the calibration check results (see Figure 4-3).

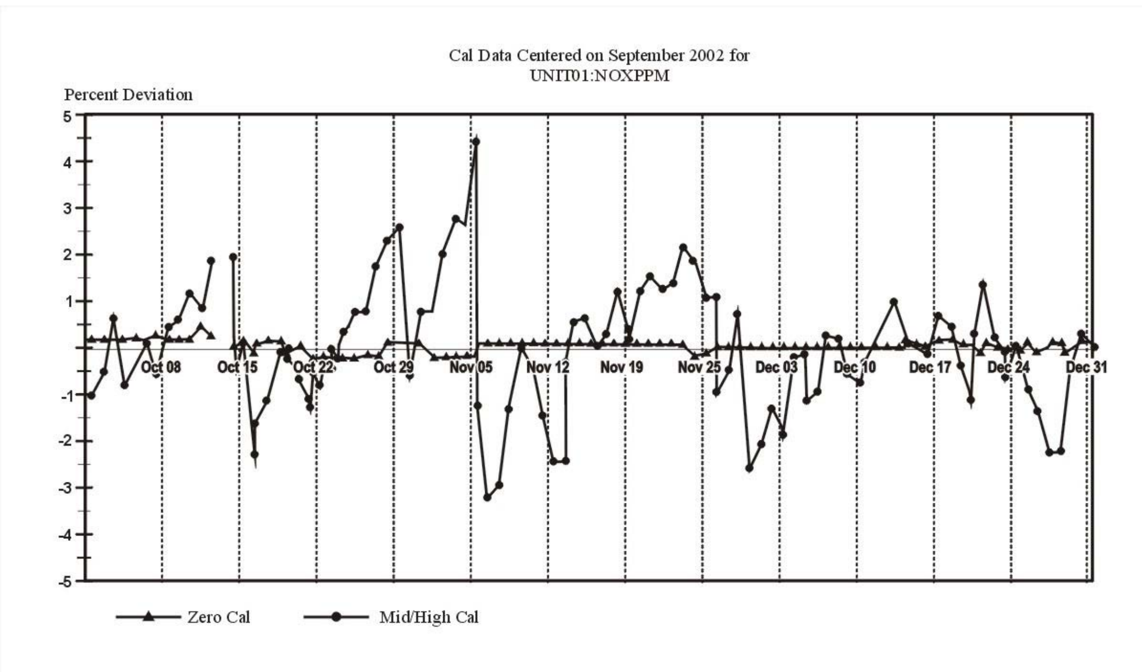

Figure 4-3
A Typical Quality Control Chart for Zero and Span Calibration Drift/Error

The drift can be plotted against time as a percentage of the span value or merely as the difference between the instrument response and the reference value. A typical chart should indicate a more or less random pattern over the time period examined. Such charts can be prepared manually; however, most CEM data acquisition systems can generate them automatically, either over fixed time periods or over a user-specified time period.

Quality controls are useful in detecting nonrandom patterns in the daily calibration checks. They provide a record of the system performance over an extended period of time and will give an indication of system or analyzer degradation as well as give evidence of system or analyzer malfunctions. They are one of the best evaluation tools for the corporate auditor or agency inspector because the charts will indicate when the system is out-of-control or when it is unstable. After determining the dates when such problems occur, the auditor can focus on the CEM logbook and data records to assess how the problems were resolved.

Quality control charts can also be one of the best evaluation tools for the CEM system technician. However, there is often too much focus on whether an analyzer passes or fails the daily calibration drift or error check and too little focus on the day-to-day changes in the drift. By taking the time to generate the quality control plot, the technician can assess whether the system is biased relative to the reference gases, whether the system performance is degrading, or whether it is improving before or after maintenance. The charts in Figure 4-4 illustrate some possible trends that may occur.

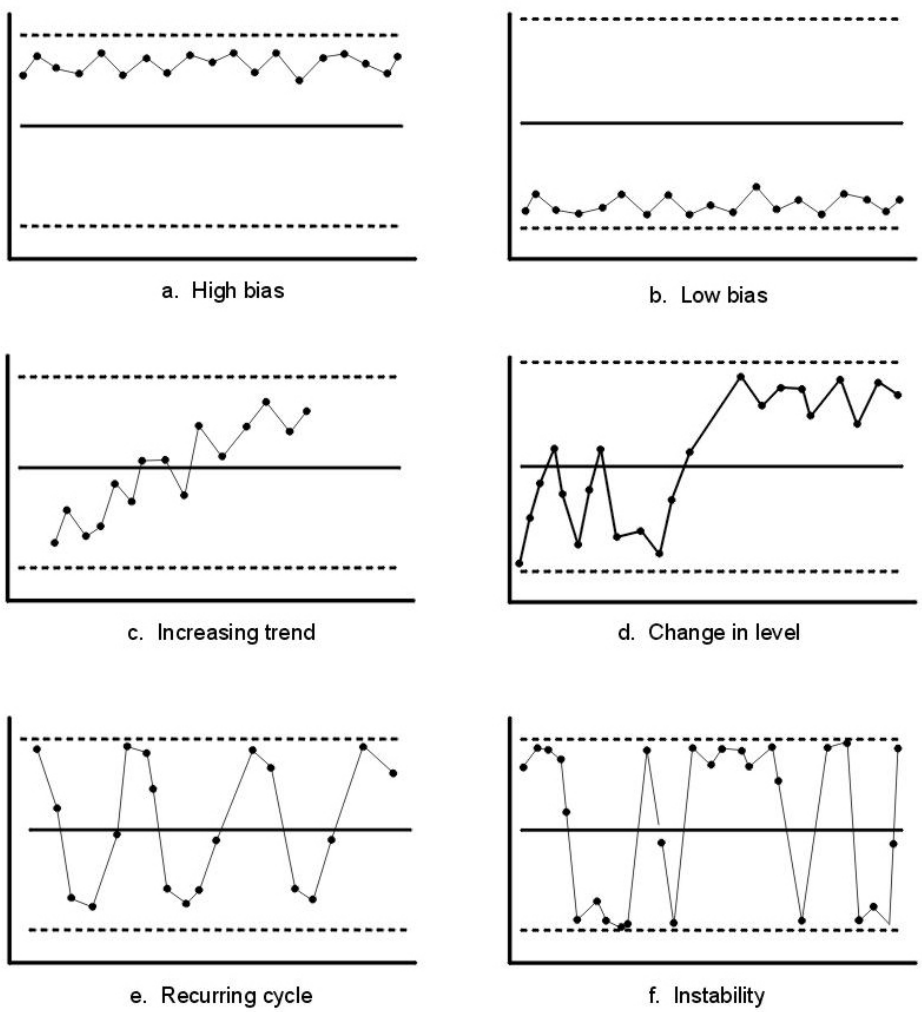

Figure 4-4
Quality Control Chart Examples

Figure 4-4 depicts the following characteristics:

a. The trend is consistently above zero, indicating that the data are biased high relative to the reference value.

b. The trend is consistently below zero, indicating that the data are biased low relative to the reference value.

c. An increasing (or decreasing) trend in calibration drift, indicating a degradation in performance that, if continued, will lead to an out-of-control condition.

d. A change in level, indicating a change in the system or analyzer.

e. A recurring cycle, indicating a correlation between instrument drift and some periodic external factor.

f. Large swings in day-to-day drift, indicating instability in the system or analyzer or problems in performing the calibration checks in a consistent manner.

Items d, e, and f are the most indicative of the occurrence of CEM system problems that will require corrective maintenance. They may be due to an unstable lamp or detector, an erratic circuit board, or other physical problem in the system. Items a, b, and c indicate biases that one may or may not choose to eliminate or an annoying correlation with some agent that has not been or is difficult to identify. Prior to the Acid Rain Program, problems such as these were often ignored because CEM systems could still meet the relatively less stringent performance specifications. However, with the advent of trading allowances, where pounds of pollutant have some monetary value, it has been advantageous to eliminate small biases.

The most typical correlation between CEM system drift and external factors is found in dilution systems. It has been noted that the dilution ratio is affected by the gas density, which is affected by the temperature, pressure, and molecular weight of the gas at the probe. Changes in atmospheric pressure can affect the dilution ratio and the calibration drift/error from one day to the next. CEM system technicians must frequently recalibrate their dilution systems after a storm passes the plant. Figure 4-5, taken from actual plant data, illustrates the correlation between instrument drift and atmospheric pressure.

Key O&M Cost Point

CEM system technicians must frequently recalibrate their dilution systems after a storm passes the plant.

Key Technical Point

CEM system technicians must frequently recalibrate their dilution systems after a storm passes the plant.

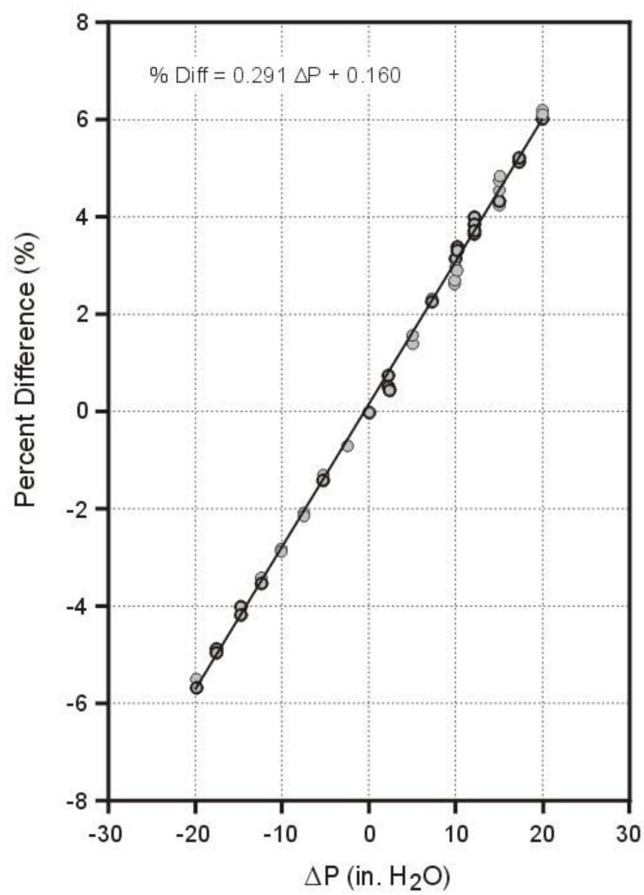

Figure 4-5
Correlation between Calibration Error and Atmospheric Pressure in a Dilution Probe

A change of 3.45 in. (8.8 cm) of water pressure in the total stack pressure (stack pressure + barometric pressure) will cause a 1% error in the measurements made by an EPM dilution probe. This may vary with other dilution-type probes, but all are affected. The error can be corrected by incorporating a correction factor or algorithm in the DAHS or by incorporating a device in the dilution air line that changes the dilution air flow rate in step with barometric pressure changes measured by a suitable pressure transducer. Flue gas temperature changes can also affect the dilution probe system on the order of 1% error for each 50°F (10°C) change in temperature, when the temperature changes from that at the time of the initial calibration of the system.

A good quality control practice is to generate quality control charts monthly (for both zero and upscale calibration drift/error) for every analyzer in the CEM system, including the opacity and flow monitors. Quarterly, the monthly quality control charts should be compared to note any trends or variation in the chart patterns. If the plant has more than one monitoring system, the control charts between the different NO_x or SO_2 or other analyzers can be compared to assess which analyzers have the lowest drift and greatest stability. The next exercise is to determine how the other analyzer or analyzers can be brought to the same level of performance.

In an overall corporate QA program, quality control charts from one plant can be compared to the charts of another. This is a tool for assessing the overall performance of one plant over another. Such an assessment may determine that one plant has established procedures that lead to better performance. These procedures can then be shared between the plants to improve the emissions reporting programs of the company.

4.2 Practical Issues

Performing daily calibration checks on CEM systems requires working with gas cylinders on a routine basis. No matter how automated a system is, gas cylinders will still have to be switched out, new cylinders purchased, and old ones sent back. Records have to be maintained and changes have to be made in the DAHS upon each cylinder replacement. These activities cannot be avoided and can take more time than necessary if not approached systematically. Some practical notes from experience are offered that may assist in these efforts.

4.2.1 Safety

Compressed gas cylinders are delivered at pressure of around 1900 psi (13,100 kPa). If the main cylinder valve is knocked off, the cylinder becomes a rocket and cause considerable damage. Safety procedures should be established to avoid any such mishap. Established safety procedures for cylinder gas are:

- Use a cylinder cart when transporting cylinders
- Always chain a cylinder when stored or when hooked up with the CEM system
- Never roll a cylinder
- Never drop a cylinder

4.2.2 Gas Regulators

Gas regulators are specific to the gas being used. In fact, gas cylinders will have left-handed and right-handed threads to avoid using incorrect regulators for corrosive or toxic gases. Never exchange fittings on a regulator to compromise this check.

4.2.3 Pig Tails

To minimize the number of regulators, a manifold can be constructed so that a simple fitting can be connected to the gas cylinders. This provides for easier change out of cylinders and less wear and tear on the regulators, which do suffer from frequent connections and disconnections from the cylinders.

4.2.4 Pressure Transducers

Some CEM systems are not visited or inspected each day. If attention is not paid to the cylinder gas pressures, it is possible that a cylinder can run out of gas. Pressure transducers can be fitted in pressure manifolds to provide an electronic signal to the DAHS and CEM system RTU to monitor these pressures. This system feature is particularly useful when cylinder gases are at elevated stack locations.

4.2.5 Ambient Conditions

Cylinders installed in the system with regulators attached should not be exposed to rain, snow, ice, or corrosive plant gases. The cylinders should be protected either with a weather cover or in a cabinet if they are to be installed outside of the CEM shelter. Installing the active cylinders in the CEM shelter may be preferable to some; however, plant safety procedures may not allow the installation of gas cylinders in a confined space. If they are installed in the shelter, it is prudent to monitor the shelter atmosphere using toxic gas sensors. These sensors provide a meter readout on the outside of the shelter to provide a safety assessment before entering the shelter.

Gas cylinders located outside may exhibit concentration stratification, and CO_2 may begin to condense when ambient temperatures decrease below -10°F (-23.3°C). One technique that has been used to minimize these effects is to set a small heating pad under one-half of the cylinder base. The other side being cold, a circulation will develop in the cylinder to inhibit stratification. Nevertheless, a better solution would be to move the cylinders to a warmer location.

Key O&M Cost Point

To minimize cost associated with gas cylinders, it is essential that responsibility be given to some individual for the gas cylinder program.

4.2.6 Demurrage Charges

Gas vendors charge a rental fee (demurrage) for use of the gas cylinders. Although the monthly fee per cylinder is relatively small, the charges add up when one considers the number of cylinders that are necessary for calibration error and linearity tests. Gas vendors expect that plant personnel will forget to return gas cylinders, keep poor records, and otherwise mismanage accounting for cylinder gases. To minimize these costs, it is essential that responsibility be given to some individual for the gas cylinder program or that safeguards are instituted in a plant procurement program to avoid unnecessary charges.

4.2.7 Changing Gas Vendors

Key Human Performance Point

When changing gas vendors, their technical capabilities, response capability, and performance in the EPA's gas audit program should be part of the selection process—not just cost.

A common problem that occurs with certified cylinder gases is that the engineering or instrumentation departments identify a reliable gas supplier and become accustomed to working with them without problem. However, in a plant's efforts to reduce costs, the contracts department broadcasts a bid request and identifies other gas suppliers that can supply gases at reduced cost. Once a new vendor is chosen, the technicians must work with the new vendor. This can certainly be problematic if the new vendor is a provider of welding grade gases rather than protocol gases. If gas vendors are to be changed, it is recommended that the selection process of the new vendor consider technical capabilities, response capability, and performance in EPA's gas audit program—not just cost.

5
PERFORMANCE AUDITS

A *performance audit* is a quantitative evaluation that provides an independent assessment of the monitoring system. Performance audits that are conducted on CEM systems are typically the same tests used for their original certification; however, other tests such as opacity monitor filter audits and the flow monitor flow-to-load ratio test are also used for validating the operation of CEM systems. This section assumes that the CEM system has been originally certified and that the first-time issues such as sampling location, gas and flow stratification, and system setup have been more or less resolved. Because the system has already passed a certification test, the purpose of conducting the performance tests discussed here is to assess whether the system continues to meet the specifications to which it was originally certified.

In the continuing operation of a CEM system, problems can develop that are not indicated by the daily calibration drift/error check, instrument diagnostics, or fault sensors installed in the system. A good CEM systems integrator can design warning or alarm sensors into a system that can alert the operator to many of the obvious faults. It is relatively easy to provide alarms for failed pumps or blowers, condensate breakthrough, or power failures. Leaks, pollutant scavenging by filtered particulate matter, failed NO_2 converters, and so forth are not as easily identified by the daily calibration checks. This is one of the reasons why most regulatory programs now require an annual repeat of the relative accuracy test audit, a test that is completely independent of the installed CEM system and gives an objective evaluation of its performance. Other tests, such as the Part 60 quarterly cylinder gas audit or the Part 75 linearity test, are not as independent but they do offer an incentive to check up and tune up the system prior to their being done.

The following tests are used to evaluate the performance of CEM systems and the data that they generate.

1. Relative Accuracy Test Audit

2 Abbreviated Relative Accuracy Tests

3. Linearity Test/Cylinder Gas Audit

4. Opacity Monitor Filter Audit

5. Flow Monitor Flow-to-Load Test

6. Fuel Flow Monitor Flow-to-Load Test

7. Mass Balance/Predictive Emission Monitoring System Correlations

When satisfactorily completed, these tests provide some assurance that the monitoring data are accurate. By conducting an opacity monitor filter audit, the unit operator may have more assurance that the opacity exceedance alarm is indeed correct and the problem is indeed the electrostatic precipitator. The designated representative or authorized account representative is more confident when certifying that the quarterly electronic data report is accurate and complete. But perhaps most importantly, the CEM system technician is confident that the CEM instrumentation is working well and can assure the I&C supervisor that the operation and maintenance program has been effective.

5.1 The Relative Accuracy Test Audit

The relative accuracy test audit is conducted annually for CEM systems regulated under 40 CFR 60 Appendix F or semiannually or annually for CEM systems regulated under Appendix B of 40 CFR 75 [14]. The Part 75 semiannual requirement is for those systems or that part of the system whose last relative accuracy results were between 7.5% and 10.0%. If the results of the last test were less than 7.5%, only one test per year is required, providing an incentive to maintain the system or, at least, to optimize the performance of the system prior to the test.

Key Technical Point

The Part 75 semiannual requirement is for those systems or that part of the system whose last relative accuracy results were between 7.5% and 10.0%. If the results of the last test were less than 7.5%, only one test per year is required, providing an incentive to maintain the system or, at least, to optimize the performance of the system prior to the test.

5.1.1 Relative Accuracy

The relative accuracy is determined by comparing the CEM system data to that obtained by an independent test apparatus. The test apparatus may be operated either by a source testing company or the company that owns the CEM system. For SO_2 relative accuracy testing, the apparatus is defined in Appendix A in 40 CFR 60 Appendix B, Test Method 6C [11]. For NO_x, Method 7E is applied, and Method 3A is used for testing CO_2 and O_2 analyzers. EPA manual wet chemical test methods may be used for Part 60 applications but are not advised for Part 75 affected units. The relative accuracy is expressed as follows:

$$RA = \frac{\left|\bar{d}\right| + |cc|}{\overline{RM}} + 100 \qquad \textbf{Eq. 5-1}$$

where:

RA = relative accuracy

$\left|\bar{d}\right|$ = mean difference

$|cc|$ = confidence coefficient

$\overline{RM}$ = arithmetic mean of the reference method values

The mean difference is the average of a minimum of nine runs where the data are compared:

$$\left|\overline{d}\right| = \sum_i d_i = \sum_i RM_i - CEM_i \qquad \textbf{Eq. 5-2}$$

Note that when taking the sum, the plus or minus sign for each run is kept, so if in one run the difference was +10 ppm and the next run it was -10, the sum would be 0. The absolute value is only taken after the summation. The mean difference gives an estimate of the systematic error in the system. If the difference is large between the CEM system and the source tester, it may be due to a problem either in the CEM equipment or the source test equipment. In either case, it is recommended that the cause of the bias be identified and, if possible, eliminated [3].

The confidence coefficient is a statistical expression that provides an estimate of how well the tests were conducted and of how well the results were reproduced from test to test. The confidence coefficient is equal to:

$$cc = t_{0.025}\frac{S_d}{\sqrt{n}} \qquad \textbf{Eq. 5-3}$$

where:

$t_{0.025}$ = t value from the t test corresponding to the probability that a measured value will be biased by 2.54% at the 95% level of confidence

n = number of runs

$$S_d = \text{standard deviation} = \left\{\left[\sum (d_i)^2 - \left(\frac{1}{n}\right)\left(\sum d_i\right)^2\right] \Big/ (n-1)\right\}^{1/2} \qquad \textbf{Eq. 5-4}$$

The confidence coefficient represents the largest variation in $\left|\overline{d}\right|$ that would be expected 97.5% of the time.

5.1.2 Bias

Key O&M Cost Point

Low bias is not permitted in allowance trading programs, because the low bias would result in reporting emissions in tons per year that would be lower than true.

For Part 75 systems, an additional calculation is made to determine if the CEM system is biased low relative to the reference test method. Low bias is not permitted in allowance trading programs, because the low bias would result in reporting emissions in tons per year that would be lower than true. To correct such a situation, one may either identify the cause of the bias and remove it, or apply a bias adjustment factor (BAF) that corrects all data after the relative accuracy test upward to correspond to the reference test data.

A CEM system or analyzer is said to be biased low if:

$$\bar{d} - |cc| > 0 \qquad \textbf{Eq. 5-5}$$

or

$$\overline{(RM - CEM)} - |cc| > 0$$

Note that there is no absolute value above the $\bar{d}$. What this means is if the CEM system reads higher than the reference method (RM - CEM) it will be negative and the system will pass the bias test. If the bias test is passed, a bias correction is not permitted to be applied. This results in paying a penalty by reporting higher emissions than true (that is, compared to the reference method) and a loss in allowances. In fact, there is no merit in "passing" the bias test, because it is better to "fail" it and then correct up to the reference method value. If the bias test is failed, the correction is made by applying a bias adjustment factor (BAF) to all subsequent data, where the BAF is expressed as:

$$BAF = 1 + \frac{|\bar{d}|}{\overline{CEM}} \qquad \textbf{Eq. 5-6}$$

where:

$\overline{CEM}$ = mean of the data values provided by the monitor during the relative accuracy test

The bias adjustment factor is then applied to all subsequent data until the next RATA. The data are corrected by using the following equation:

$$CEM_j^{adjusted} = CEM_j^{unadjusted} \times BAF \qquad \textbf{Eq. 5-7}$$

where:

$CEM_i^{adjusted}$ = data value adjusted for bias at time j

$CEM_i^{unadjusted}$ = measurement provide by the monitor at time j

Bias, when not corrected, is commonly about 3% to 4% of the CEM system measurement values. The option to eliminate the cause of the bias always stands; however, in the case of a negatively biased CEM system, it may be easier to accept the bias adjustment factor. In the case of positively biased systems, where potential losses in allowances may result, it may be worthwhile to initiate a study to determine the cause or causes. Biases in flow monitors are particularly prevalent and are generally positive. Flow measurements have the same importance as concentration measurements in the calculation of the pollutant mass rate reported in trading programs. The pollutant mass rate is expressed as:

$$pmr = c_s Q_s = k c_s A v_s \qquad \textbf{Eq. 5-8}$$

where:

pmr = pollutant mass rate (lbs/hr)

c_s = pollutant concentration (ppm, lbs/ft^3)

Q_s = flue gas volumetric flow rate (ft^3/hr)

A = stack, duct cross-sectional area at the flow monitor measurement location (ft^2)

v_s = flue gas velocity as measured by the flow monitor (ft/sec, ft/hr)

k = units conversion

If the flow monitor bias adjustment is greater than 3% or 4%, it is recommended that Test Methods 2F or 2G be used in the RATA instead of Test Method 2. These methods are better at characterizing swirling (cyclonic) flow than is the less sophisticated Test Method 2. Also, in circular stacks or ducts, corrections may be made for the fact that the velocity goes to zero at the wall. This wall “effect” can be corrected by applying Method 2H. A method for correcting for wall effects in rectangular ducts or stacks has not been promulgated, although the effect exhibits a greater positive error in rectangular flues than in circular ones.

5.1.3 Conducting the Relative Accuracy Test Audit

Independent source testing firms normally conduct the relative accuracy tests, although some utilities maintain their own in-house testing teams. The source testing business is not regulated nationally, although a few states (for example, Louisiana and California) have initiated source testing company certification programs. In other states, where no certification programs exist, it is possible to contract with source testers that have neither the experience nor the equipment to perform a relative accuracy test properly. Because the tests are expensive and are critical for determining whether a CEM system is in control or out-of-control, source testing firms should be selected carefully.

Key O&M Cost Point

Because the tests are expensive and are critical for determining whether a CEM system is in control or out-of-control, source testing firms should be selected carefully.

One condition of a contract with a source testing firm should be that a test plan be submitted for the period of testing. This is a normal quality assurance procedure and some States require that test plans be submitted prior to the test. A professional testing company should not hesitate to supply such a plan, since the plan should be part of a normal paperwork package. A typical test plan should include many of the discussions in the following sections.

5.2 Source Test Plan

- Project description
- Project organization, personnel, and responsibility for the test
- QA objectives for measurement data in terms of precision, accuracy, completeness, representativeness, and comparability
- Test requirements—access, ports, power
- Sample procedures
- Special procedures or exceptions to the EPA Test Methods
- Sample custody procedures (if samples are taken)
- Calibration procedures and frequency
- Laboratory analytical procedures (if any)
- Safety policy and procedures
- Data reduction, validation, and reporting procedures
- Internal quality control checks
- Reports

The test plan should be reviewed by the agency and by the plant or corporate environmental engineer, I&C supervisor, and CEM technicians prior to the test. Any deviations to the EPA Test Methods should be discussed and approved by the agency before the test.

A frequent question raised regarding the relative accuracy test is why the instrumented test methods (Methods 3A, 6C, or 7E) conducted by the source tester should be regarded as the reference method or why should the source test data be any better than the CEM data? The reason for this is that the source tester does more than the CEM system. The test method requires that the sample be taken at more than one location (a complete traverse is required in a flow monitor certification) and that, for gases, the source tester analyzer calibration be checked after each of the nine or more runs conducted during the test. Sampling system bias must be corrected in each run of the test. In contrast, the CEM system commonly samples at only one point or, in the case of path *in situ* systems, on a sampling line, and a calibration check (and/or adjustment) is conducted prior to the test only.

The source test should be observed by someone at the plant and by an agency observer. The presence of an agency observer is particularly helpful in that it provides extra assurance that the source test procedures will be conducted properly. In particular, the source test bias check required after each run should be noted as being performed and passing test method criteria.

A relative accuracy calculation should be conducted on-site and as the test proceeds. The equations necessary for the calculation of the relative accuracy have been given in earlier subsections. Table 5-1 can assist in performing these calculations. Table 5-1 is useful either in calculating the relative accuracy manually or in programming a hand-held calculator or portable computer.

Table 5-1
Relative Accuracy Calculation Sheet

Relative Accuracy Test—Data Table

Tester____________________ **Date**_______________

Run No.	Time	RM_i	CEM_i	d_i $(RM_i - CEM_i)$	$(d_i)^2$
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
Sums (Σ)		$\Sigma RM_i =$	$\Sigma CEM_i =$	$\Sigma d_i =$	$\Sigma (d_i)^2 =$
Averages (Σ/n)		$\overline{RM} =$	$\overline{CEM} =$	$\overline{d} =$	—

Mean Difference $\quad |\overline{d}| = \left| \sum \frac{d_i}{n} \right| =$ _______________

Standard Deviation $\quad S_d = \sqrt{\frac{\sum (d_i)^2 - \frac{1}{n}\left(\sum d_i\right)^2}{n-1}} =$ _______________

Confidence Coefficient $\quad cc = t_{0.025} \frac{S_d}{\sqrt{n}} =$ _______________

Relative Accuracy $RA = \frac{|\overline{d}| + |cc|}{\overline{RM}} \times 100$ = ________________

Calculate the Bias $\overline{d} - |cc|$ = ________________

If the Bias is greater than zero, calculate the Bias Adjustment Factor (BAF).

Bias Adjustment Factor $BAF = 1 + \frac{|\overline{d}|}{\overline{CEM}}$ = ________________

Errors in the source test calculations are more common than one should expect. For this reason, it is important that the final source test report be reviewed for errors. It is best that the relative accuracy be recalculated from the original field data to ensure that all calculations were performed correctly. It should not be assumed that the software used to calculate the relative accuracy is necessarily correct. Some common problems in the reports are:

- Assuming dilution probe measures dry instead of wet
- Round-off errors (particularly when calculating relative accuracy in lbs/mmBtu)
- Taking absolute value of each d_i instead of $\overline{d}$
- Use of incorrect formula for the standard deviation, S_d

Exceeding a 10% or 20% relative accuracy specification for a system or monitor is a serious problem that will require identifying the cause of the failure, correcting the problem, and re-testing. In the interim, the system will be out-of-control and any data generated are unacceptable for emissions reporting. CEM system downtime will then accumulate until a successful RATA is completed. Possible reasons for the failure of a RATA are given as follows:

- Flue gas location/stratification problems (should have been resolved at the time of original certification)
- DAHS problems (should have been resolved by the time of original certification)
- System design/operational problems (should have been resolved by the time of original certification)
- Interferences by other flue gases in CEM system (should have been caught at time of original certification)
- Interference by other flue gases in source tester's equipment
- Loss of pollutant in chiller condensate, on sample tube walls, on filters (in source tester's equipment or CEM system—a particular problem at low concentrations)
- Leaks or ambient air incursion in source tester's apparatus or CEM system
- Incorrect calibration gas values (either CEM system or source tester's)
- Improper calibration methods/failure to calibrate

- Time share sampling issues and variability in flue gas concentrations (for example, comparing a 5 minute CEM time share system data with continuous source tester data)
- Failure to correlate sampling times account for lag in system response times for fluctuating sources
- Failure to correct source tester dry system measurements to a wet basis for dilution or hot-wet CEM system evaluations
- Incorrect correction factor or algorithm applied to flow monitor data for flow monitors
- Correction factor or algorithm is no longer valid for flow monitor data due to changed flow conditions or monitor characteristics for flow monitors
- Incorrect calculation procedures
- Incorrect or inconsistent source testing procedures

5.2.1 Abbreviated Relative Accuracy Tests

Part 60 systems that are required to meet the quality assurance procedures of Appendix F are required to conduct a cylinder gas audit for three out of four quarters of the year (a cylinder gas audit is not required in the quarter in which the annual relative accuracy test audit is conducted).

Because most path *in situ* systems cannot be tested with independent cylinder gases, the abbreviated RATA, called the relative accuracy audit (RAA), can be conducted instead of the RATA.

Also, on occasions where certification testing or retesting is not required, a check of flue gas concentrations completely independent of the CEM system may be desired. This may be necessary to check the performance of a path *in situ* system, a predictive emission monitoring system, or even an extractive system that has been exhibiting unusual behavior. In such cases, a portable monitoring system may be useful. By conducting one short run or many with these convenient devices, useful information can be obtained on a CEM system's performance.

5.2.1.1 The Relative Accuracy Audit

The RAA is a minimum three-run relative accuracy test audit, where the relative accuracy is calculated without the confidence coefficient as the relative difference between the mean of the three reference method values and the mean of the three CEM system value is:

$$RA_{RAA} = \frac{\overline{RM} - \overline{CEM}}{\overline{RM}} \times 100$$ **Eq. 5-9**

where:

The relative accuracy performance specification is changed from 20% of the mean reference value to 15%.

Although the RAA was intended to be a lower cost alternative to conducting a RATA, in practice, the costs associated with travel, equipment preparation, and test preparations are not reduced. Because these constitute the majority of the costs for a source tests, the difference in cost between a three-run and a nine-run RATA is not great. Consequently, this test is rarely performed.

Key O&M Cost Point

The RAA was intended to be a lower cost alternative to conducting a RATA. The difference in cost between a three-run and a nine-run RATA is not great. Consequently, this test is rarely performed.

5.2.1.2 Use of Portable Monitors

Other abbreviated relative accuracy tests can be conducted for diagnostic purposes or quality assurance purposes. Portable source test multi-gas analyzers using the same type of sensors used in installed CEM systems are now commercially available at costs of less than $25,000. Electrochemical cell "combustion" analyzers that can measure SO_2, NO_x, CO, and O_2 are available at costs less than $15,000. The electrochemical combustion analyzers have shown performance equivalent to chemiluminescence analyzers for the measurement of NO_x in gas-fired boilers and turbines and an ASTM test method and EPA conditional test method have been published for their application.

Portable analyzers can provide a "reality" check on installed CEM system data by providing an independent assessment of the flue gas concentrations. They can be calibrated with protocol gases and portable systems using chemiluminescence or other electro-optical sensing systems can even be approved as backup CEM systems for application in the Acid Rain Program. The portable analyzers are ideal for checking the performance of path *in situ* systems that cannot accept calibration gases and the predictive emission monitoring (PEMs) systems that are difficult to quality assure.

When using portable monitors for diagnostic purposes, the tests can be as simple or elaborate as one may wish to design. A single point and a single measurement may suffice to provide assurance that the CEM system is operating properly. Or, a side-by-side measurement conducted over an extended period of time may provide more validation. Also, in applications where gas stratification may be a problem, a gas stratification test can be conducted relatively quickly if a suitable probe is connected to the portable system.

Also, the portable systems can serve as a third party audit device during a RATA. If questions arise between source tester data versus the CEM data, information from the portable system may be able to resolve them.

Portable monitoring systems have exhibited significant developments over the past 10 years and their use for CEM system diagnostics is recommended. One must however be careful in the choice of systems. The electrochemical systems tend to have ranges that are not suitable for many applications. Questions of temperature and cell stability must also be addressed before purchase. The quality of these systems is also dependent upon the probe and conditioning system design, which may have to be purchased separately. The probe and moisture removal system should be designed to obtain representative samples for analysis in the particular application.

5.2.2 Audits Using Protocol Gases

Audits using protocol gases are required in the quality assurance requirements of both Part 60 and Part 75. Both specify that audit gases traceable to NIST standards be injected at the sampling probe to check as much of the CEM system as possible. The NIST traceable protocol gases may also be used for diagnostic checks, to cross-check calibration gases, or to provide an extra validation that a maintenance procedure has been conducted properly.

The required audits of Part 60 and Part 75 specify that the audit gases be injected at the probe or as close to the probe as possible. This specification can be satisfied in dilution systems and most source-level extractive systems, although a tee after the probe may be necessary in some cases. The point, in-stack monitors can also meet this specification. Figure 5-1 illustrates injection systems for several probe designs.

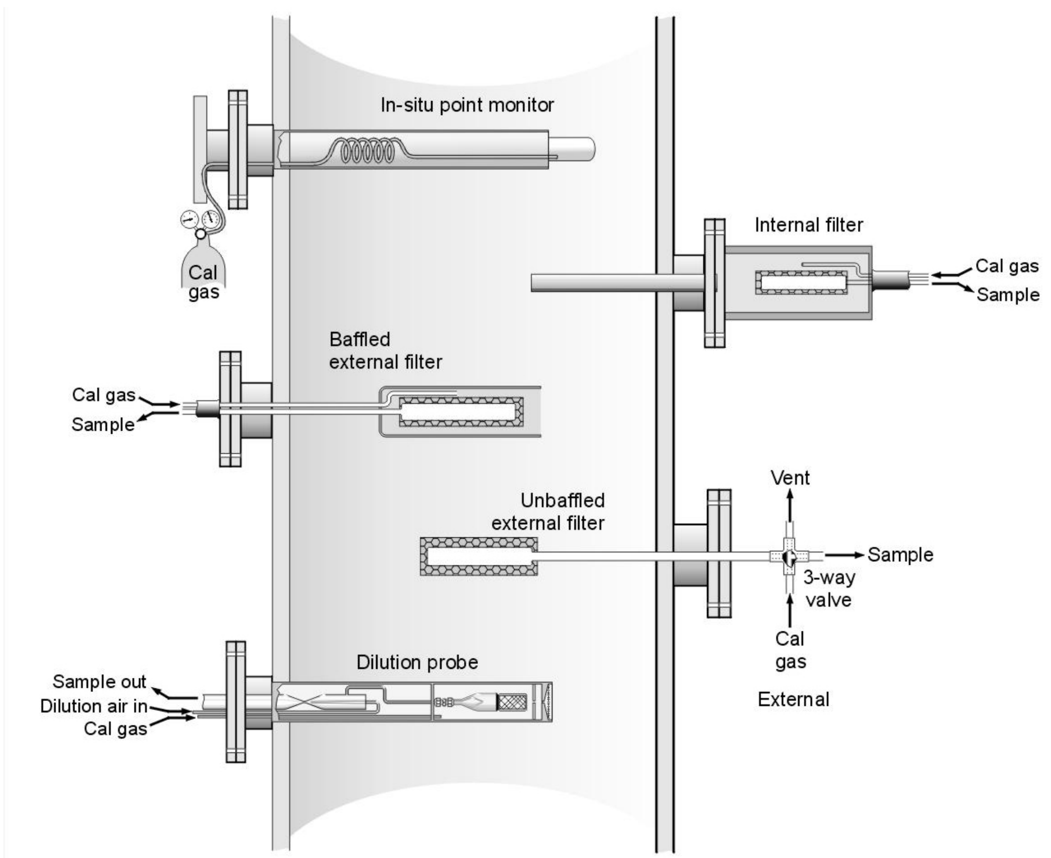

Figure 5-1
Probe Gas Cylinder Audit Techniques

Dilution probes utilize the least amount of gas to conduct these checks. In the source-level systems and *in situ* monitors, relatively greater amounts of calibration gas are needed to flush out the probe or annular spaces. Enough gas must be injected to flush out the flue gas and prevent any from diffusing into the calibration gas sample. This may require an overpressure that can affect the measurement. In fact, a frequent error is to tune the instrument or system to the cylinder tag value by varying the overpressure. This, of course, is not proper. The procedure should specify a pressure appropriate to the measurement system if one is to gain anything from the exercise.

5.2.2.1 The Part 60 Appendix F Cylinder Gas Audit (CGA)

The CGA is conducted using two calibration gases traceable to NIST standard reference materials; one having a value 20% to 30% of the instrument span, the other with a value 50% to 60% of span. When conducting the audit, the CEM system is challenged three times with each of the gases in alternation. The accuracy calculation is given by:

$$A = \frac{c_m - c_a}{c_a} \times 100 \qquad \textbf{Eq. 5-10}$$

where:

A = CGA accuracy of the CEM analyzer in terms of ppm or percentages

c_m = average analyzer response during the audit

c_a = certified value of the audit gas

An Appendix F unit is out-of-control if A exceeds ±15%. The out-of-control period begins after the audit is completed, but it would be extremely unusual to fail the audit unless a serious problem exists with the monitoring system or the audit gases used. Note, however, that it is also possible to fail the audit if expired audit gases are used in the test.

Key Technical Point

It is possible to fail the audit if expired audit gases are used in the test.

5.2.2.2 The Part 75 Appendix B Linearity Check

The Part 75 linearity check is conducted at three gas concentration levels instead of two as in Part 60 Appendix F. The additional check is made for a high level gas, so in the test, each gas monitor is challenged with protocol gases at levels of 20%–30% of span, 50%–60% of span, and 80%–100% of span. The gases are alternated in the test with no one gas being used twice in succession. Note also that the span, on which the protocol gas concentrations are based, may not necessarily be the range of the monitor. As discussed in Section 4, Part 75 span values are determined separately from the range and may or may not be equal to the range of the instrument.

The method for calculation of the linearity "error" is similar to the calculation of the CGA accuracy in Part 60 Appendix F; however, the symbols are different and the analyzer response is subtracted from the gas cylinder tag value instead of the tag value being subtracted from the analyzer response.

$$LE = \frac{R - A}{R} \times 100 \qquad \textbf{Eq. 5-11}$$

where:

LE = percentage linearity error, based upon the reference value

R = certified value of the audit gas

A = average analyzer response during the audit

The out-of-control criteria for Part 75 monitors is, that as a percentage of the cylinder gas reference value, the linearity error must be less than ±5%, rather than the ±15% allowed in Part 60; otherwise, the system is out-of-control. The linearity error must be less than ±5% for each of the audit gases; otherwise, the CEM system fails the test. This may be difficult to achieve for some systems, particularly for low values of R. In fact, if the monitor span value is ≤ 30 ppm, the monitor is exempt from the test. For dual range systems, a linearity check is required on both ranges if both were used during the quarter.

Linearity checks are conducted quarterly on SO_2 and NO_x primary monitors, backup monitors, O_2 and CO_2 monitors, and O_2 monitors used in moisture measurement systems. The EPA also requires that linearity checks be conducted after certain maintenance activities. These requirements will be discussed in the next section.

5.3 Opacity Monitor Filter Audits

The opacity monitor or filter audit provides an opportunity for checking up on the monitor and providing assurance that the instrument is operating within its design criteria. Opacity monitor availability tends to be quite high. They usually require little maintenance and, as a consequence, can be forgotten in the periodic quality control activities of the technician. Because neither Part 60 Appendix F nor Appendix B of Part 75 require that opacity monitors be included in the CEM system quality assurance manual, they often do not receive the periodic maintenance that any monitor requires.

Prior to conducting the filter audit, the blower filters should be inspected and changed if necessary, the transceiver and retroreflector assembly windows should be cleaned, the hoses should be checked for flexibility and leaks, and, if applicable, internal diagnostic indicators should be checked. The alignment of the transceiver and retroreflector should also be checked and corrected if necessary. Also, if the instrument has an automatic zero compensation function, any compensation applied must be converted to equivalent stack exit opacity and included in the audit report.

The audit is conducted by using a “zero-jig” that is designed for the instrument. The audit jigs consist of a slot that can hold audit filters and a short-range retroreflector assembled into a holder that can be attached to the transceiver (see Figure 5-2).

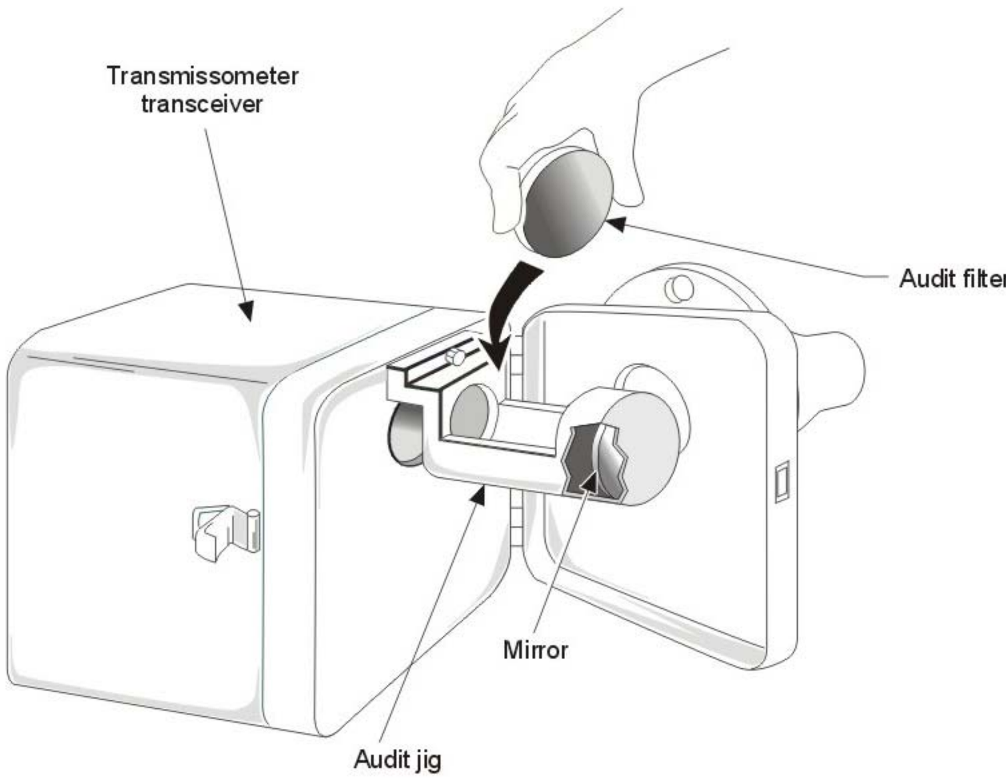

Figure 5-2
Opacity Monitor Audit Jig

Filters traceable to NIST standards are typically used in these audits and are recertified semi-annually or annually. Some monitors do not use attachable jigs but incorporate a slot to receive the filters. Three filters are used, one having a value of 20% to 60% of the emission limit (low filter), one having a value between 80% and 120% of the emission limit (mid filter), and one with a value between 150% and 200% of the emission limit (high filter).

The zero-jig is first adjusted prior to the audit so that the zero of the jig (with no filter in place) should correspond to the zero reading of the monitor when no particulate matter is in the measurement path. This adjustment should be made in a room that is free of particulate matter, such as a laboratory or office space. Even if a source is not operating, particulate matter may still circulate in the stack, so an off-stack zero adjustment is usually required. Performing this adjustment, the opacity monitor is set up so that the transceiver and retroreflector are separated by the same distance as they are on the stack. The system is aligned and the instrument adjusted to read zero. The zero jig is then attached and the iris of the zero jig adjusted until the instrument reads zero. This adjustment is particular to the monitor, so the jig can be used only on the instrument to which it has been adjusted.

When conducting the audit test with the monitor reinstalled on the stack, it is important to first notify the control room that the opacity monitor will be undergoing a test. In attaching the jig, the transceiver is unlatched and swung from its port mount. This will create a condition of 100% opacity that may alarm the control room operator if not informed. The jig is then attached across the window to reflect the light beam back into the transceiver. The filters are then placed into the filter slot to obtain three non-consecutive readings for each filter. Unless the averaging function of the DAHS or monitor control unit is otherwise bypassed, more than six minutes may be required for each reading. If possible, it is recommended that the system be set up to provide instantaneous readings during the test. The readings should be obtained from the DAHS or other data recorder providing the reportable data for the agency. The audit data should not be taken directly from the monitor control unit.

The calibration error for each filter is calculated according to the procedures of Performance Specification 1 of Part 60:

$$ER = |\bar{x}| + |cc| \qquad \textbf{Eq. 5-12}$$

where:

ER = calibration error in %

$|\bar{x}|$ = absolute value of the mean difference between the transceiver opacity and the audit filter value

$|cc|$ = absolute value of the confidence coefficient, given as $cc = \frac{t_{0.975} S_d}{\sqrt{n}}$

where:

$t_{0.975}$ = the t value from the subject t test

S_d = the standard deviation

n = the number of data pairs

A monitor passes the calibration error test if ER ≤ 3.0% opacity for each filter.

Opacity monitor audit procedures were first proposed by EPA in 1992 as proposed Method 203. The method has been redrafted and is now termed “Procedure 3” under Appendix F of Part 60. When promulgated, the procedure will apply to all opacity monitors required to be installed by a federal regulation or opacity monitors designated in a State permit or other State requirement to follow the procedure. Procedure 3 will also require that a quality control program be developed and implemented for the opacity monitor.

5.4 Flow-to-Load Tests for Flue Gas Flow Monitors

As mentioned earlier, flow monitor calibration checking techniques do little to check the primary sensors of the instruments. In most cases, the transducers or electronic systems are checked, but the measuring element itself is not always checked. Because of this, an additional flow monitor performance check is required for Part 75 affected systems. This test, called the flow-to-load test, involves the correlation of flow monitor data to plant load data. Because the flow rate increases proportionally to load, the flow rate at a given load should remain relatively constant if the same type of fuel is burned. The rationale behind this is, if one considers Equation 2-6 given in Section 2, where the flow is related to the input:

$$Q_s = F_d \frac{20.9(HI)}{(20.9 - \%O_2)} \quad \textbf{Eq. 5-13}$$

or

$$Q_s = F_c \frac{100(HI)}{\%CO_2}$$

In setting up the test, a reference value (R_{ref}) is determined each time that a successful RATA is performed for the flow monitor at normal load. The reference value is expressed as follows:

$$R_{ref} = \frac{Q_{ref}}{L_{avg}} \times 10^{-5} \quad \textbf{Eq. 5-14}$$

where:

R_{ref} = the reference flow-to-load ratio, scfh/MW or scfh/1000lb/hr of steam

Q_{ref} = the average stack gas volumetric flow rate (in scfh) measured by the reference method during the normal load RATA

L_{avg} = the average unit load during the normal load flow RATA in megawatts or 1000 lb/hr of steam

R_{ref} is always based upon the most recent normal-load RATA and is a configurable input into the DAHS. The flow-to-load ratios are calculated hourly by the DAHS and are analyzed at the end of each quarter, although a daily review of the ratios is recommended. Error in the hourly flow-to-load ratios is calculated as a percentage of R_{ref} as follows:

$$E_h = \frac{|R_{hourly} - R_{ref}|}{R_{ref}} \times 100 \quad \textbf{Eq. 5-15}$$

where:

E_h = error in the hourly flow-to-load ratio

$R_h = \frac{Q_h}{L_h} \times 10^{-5}$, which is the ratio of hourly average flow value determined by the monitor divided by the hourly average load

The results of the flow-to-load evaluation are acceptable (to EPA on a quarterly basis) if the quarterly average value, E_f, does not exceed the following limits:

1) 15%, if L_{avg} for the most recent normal load flow RATA is ≤ 60 MW and if bias-adjusted flow rates were not used in the calculations.

2) 10%, if L_{avg} for the most recent normal load flow RATA is ≤ 60 MW and if bias-adjusted flow rates were used in the calculations.

If E_f exceeds the applicable limit, either:

1) A new RATA is performed (unless a monitor malfunction is diagnosed and corrected, in which case an abbreviated flow-to-load test can be performed)

2) Re-examine the hourly data used for the flow-to-load test and recalculate E_f, after excluding all non-representative hourly flow rates (within the limits specified by the method)

Values of E_h that can be excluded include the following:

1) Any hour in which different fuel was used from when R_{ref} was determined

2) Any hour in which a bypass was used

3) Any hour in which "ramping" occurred (that is, hourly load differed by more than ±15% from the preceding or subsequent hour)

4) Any hour prior to completion of a normal-flow RATA conducted in the quarter

5) Any hour prior to completion of an abbreviated flow-to-load test conducted after maintenance

If after excluding these hours, the limits are still exceeded, the flow monitor is considered to be out-of-control beginning the first hour of the quarter after the failed quarter. If the system is out-of-control, the monitor must be inspected and repaired, or a new correction factor/calibration function applied (relinearization) to the flow monitor after suitable RATA testing. A complete or an abbreviated flow-to-load test must be conducted after maintenance or after the monitor has been relinearized.

Although a significant amount of data could be excluded, at least 168 representative hourly ratios must be available to perform the quarterly analysis to calculate a value of E_f, the quarterly flow-to-load average. If 168 hours of representative data are not available, the quarterly average need not be reported for that calendar quarter.

An alternative expression, the gross heat rate (GHR), can be used instead of the flow-to-load ratio for a flow monitor evaluation. The gross heat rate is given as follows:

$$(GHR)_h = \frac{(Heat\ Input)_h}{L_h} \times 1000 \qquad \textbf{Eq. 5-16}$$

The hourly gross heat rate values are compared to a reference value $(GHR)_{ref}$ obtained during a normal load RATA, as was the reference flow-to-load ratio, R_{ref}. The hourly and reference heat input values are obtained from the flow and diluent monitor data using either Equation 2-6 or Equation 2-7.

The quarterly error (E_h) in the flow-to-load or gross heat rate tests may not appear very useful for diagnostic purposes, but it does provide some assessment for the EPA of the performance of flow monitors. The hourly error (E_h) can however be quite useful to the technician. A greater confidence in flow monitor results can be obtained by tracking this value (assuming steady base-load operation). Table 5-2 illustrates typical flow-to-load ratios available through the CEM system DAHS.

Table 5-2
Flow-to-Load Ratios

Date	Time	Flow	MW	Flow-to-Load Ratio	% Difference
10/14/03	00:00	72733000	468	1.55	6.6
10/14/03	01:00	72691000	472	1.54	7.2
10/14/03	02:00	72616000	471	1.54	7.2
10/14/03	03:00	72859000	473	1.54	7.2
10/14/03	04:00	72602000	471	1.54	7.2
10/14/03	05:00	72579000	473	1.53	7.8
10/14/03	06:00	72964000	472	1.55	6.6
10/14/03	07:00	72282000	471	1.53	7.8
10/14/03	08:00	73010000	474	1.54	7.2
10/14/03	09:00	73118000	473	1.55	6.6
10/14/03	10:00	72093000	470	1.53	7.8
10/14/03	11:00	72209000	471	1.53	7.8
10/14/03	12:00	73325000	471	1.56	6.0
10/14/03	13:00	67496000	429	1.57	5.4
10/14/03	14:00	61490000	374	1.64	1.2
10/14/03	15:00	57630000	346	1.67	0.6
10/14/03	16:00	55648000	335	1.66	0.0
10/14/03	17:00	56663000	331	1.71	3.0
10/14/03	18:00	58118000	340	1.71	3.0

Changes in the ratios have indicated twisted pitot tubes, plugged ports, and failed transducers. The test does work and results should be examined daily along with the daily calibration error checks to get a more thorough assessment of the flow monitor performance.

5.5 Flow-to-Load Tests for Fuel Flow Monitors

Similar flow-to-load and gross heat ratio tests, given in Appendix D of Part 75, can be performed to check fuel flow meters. However, with fuel flow meters, the reference flow-to-load ratio is called instead the "baseline flow rate-to-load ratio" and is established over a minimum 168-hour period where quality assured fuel flowmeter data are being obtained. Data during periods of ramping or in which the unit load is < 25% of the unit range of operation are not included in the ratio. The baseline flow rate-to-load ratio is calculated as follows:

$$R_{base} = \frac{Q_{base}}{L_{avg}} \qquad \textbf{Eq. 5-17}$$

where:

R_{base} = Value of the fuel flow rate-to-load ratio during the baseline period; 100scfh/MWe or 100 scfh/klb per hour steam load for gas firing; (lb/hr)/MWe or (lb/hr)/klb per hour steam load for oil firing

Q_{ref} = the average fuel flow rate measured by the fuel flowmeter during the baseline period; 100 scfh for gas firing and lb/hr for oil firing

L_{avg} = the average unit load during the baseline period in megawatts or 1000 lb/hr of steam

The calculation for the baseline gross heat rate $(GHR)_{base}$ is similarly taken over a 168-hour baseline period.

Fuel flow rate-to-load or gross heat rate calculations are performed hourly, and the percentage difference from the corresponding baseline value is calculated using the symbol $\%D_h$ instead of E_h as in the case of stack gas flow monitors.

The quarterly error (E_f) is determined with a minimum of 168 hours of data during the quarter, again excluding any data obtained during ramping or in which the unit load was < 25% of the unit range of operation. The fuel flow-to-load or gross heat rate test is failed if E_f is greater than 10% when the average quarterly load was greater than 50 MWe (or 500 klb steam per hour) or 15% if the average load was less.

The hourly fuel flow rate-to-load data can again be useful to assess the quality of the fuel flow data. However, the fuel-flow meters and transmitters tend to be reliable and stable, so there may be less of a need for this check. Also, the test is optional, so there is an element of risk in performing and reporting the tests. If the quarterly value of E_f exceeds the Appendix D criteria, then a transmitter or fuel flowmeter accuracy test must be conducted and an abbreviated fuel rate-to-load test conducted. If the abbreviated test fails, then the primary element must be inspected and repaired or replaced. Missing data procedures must then be used to substitute data the first hour of the quarter after the failed test.

If the optional fuel flow rate-to-load test is not conducted, a transmitter accuracy test must be conducted once every four fuel flowmeter QA operating quarters and a primary element inspection once every twelve calendar quarters. If the fuel flow rate-to-load or gross heat rate averages are performed, transmitter and primary element inspections are required only once every 20 calendar quarters.

5.6 Mass Balance/Predictive Emission Monitoring System Correlations

Other useful CEM system validation techniques are to compare the CEM data with mass balance or engineering calculations or with the results of parameter correlations and predictive emission monitoring systems (PEMS). Such checks can be relatively easy to perform and can be proactive reality checks on the CEM systems. If one knows the amount of sulfur in the fuel and the fuel feed rate, the SO_2 emission can be readily calculated. An initial correlation between NO_x emissions and load, can serve to estimate future NO_x emissions as a function of load (see Figure 5-3).

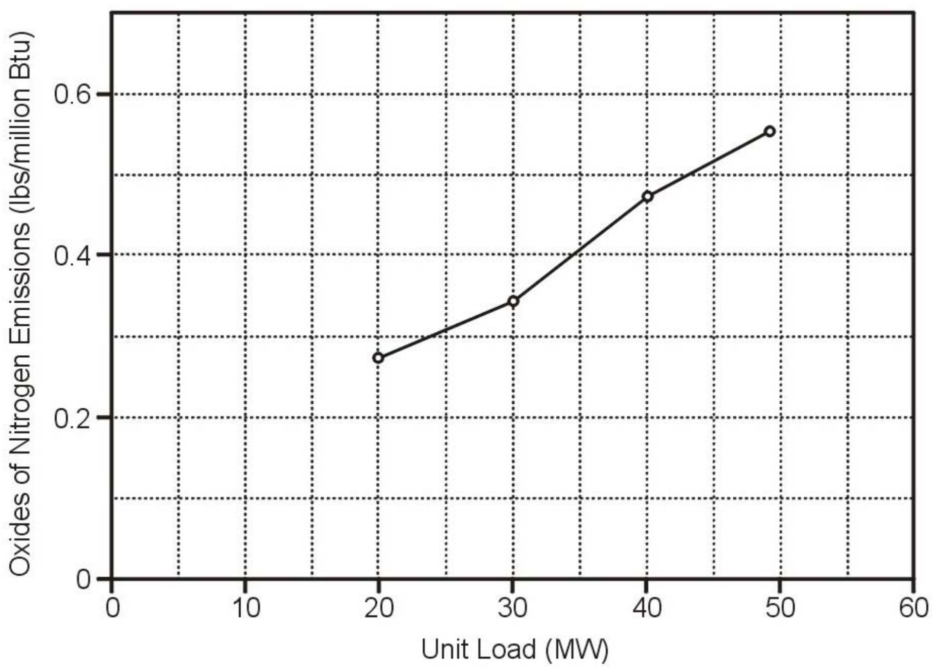

Figure 5-3
NO_x Emissions as a Function of Load

Appendix E of Part 75 gives procedures for developing such correlations for gas or oil-fired peaking units having a capacity factor of less than 10%. The intent in Appendix E is to use such correlations instead of installing a CEM system. However, if one has already installed a CEM system, a correlation can be easily developed, or multiple correlations can be developed as a function of oxygen concentration to provide greater precision. The ongoing CEM data can then be checked against the correlation either continuously, periodically, or when the CEM performance is questionable.

Plant process or operational parameters can be used to develop correlations with emissions. Pressures, temperatures, fuel flow, steam flow, water pressure, damper settings, and so on may affect the emissions and can be correlated to predict emissions. The predictive models that result weight the importance of each parameter to the emissions and there are several techniques for doing this. The best technique is to input the parameters into a mathematical relationship derived from an understanding of the operational principles of the system. The so-called phenomenological or first principle models that result can be quite robust, even at the limits of the correlation; however, they may need to be “tweaked” by the inclusion of empirical correction factors. Not all of the effects of process variables may be known and the values of the necessary input parameters may not be of sufficient accuracy to give correct results. Calculating emissions from first principles often requires too much information to be practical, hence the use of semi-empirical models. Here, the relationship between the parameters is mathematically defined, but the model is fine-tuned using experimental data.

The most common modeling techniques to be strictly used empirically are least squares regression or neural net techniques. Least squares regression is a statistical technique that is used to fit a line to emissions/parameter data. One first performs an experiment, varying load or process parameters in order to change emissions. Emissions are measured by a stack tester or an installed CEM system, and the operational parameters of the process are recorded. An equation is then developed that weights the influence of each parameter on the emissions. The equation can be quite complicated depending upon the number of parameters; however, computer software is readily available for these techniques.

Neural network models have also been applied to model source emissions. Although the neural network methods are inherently mathematical, analogies can be made to biological learning processes. In the neural net method, the model constants are not calculated (as in the least squares regression technique) but are determined by iteration. The constants in the model are varied incrementally until a set of constants is obtained that will reproduce the actual emissions of the input data set. The constants weight the importance or unimportance of different input parameters in contributing to a given result. This weighting process is conducted in a manner similar to the neural processes in the brain, hence the term “neural net.”

Neural network procedures are somewhat of a “brute force” approach in statistical model development. The procedures use the iterative capabilities of the computer to choose optimum constants that best represent how a process operates. The method is powerful since most process operations are complicated and the interrelation between input parameters is not always well understood. Neural net model software is also commercially available, so it is relatively easy to use the technique. In practice, one does not have to completely understand how a least squares or neural net modeling technique works; one has to know how to use the software.

No matter what type of model is developed, once either a simple correlation or a detailed PEMS is available for a process operation or generating unit, it can be combined with an installed CEM system to give a very powerful monitoring combination. The model should be able to predict the emissions from input parameters not associated with the CEM system. However, if the process operation changes, the original correlation or model may no longer be valid. With the CEMS-PEMS combination, the CEM system obtains data during this change, data that can then be used to retrain the model. Because the CEM can provide data under most any operating condition, the model can be continually retrained until it too can provide valid data over a range of conditions.

The interplay in a CEMS-PEMS combination is not all one way, which is the point of this discussion. If the CEM should fail, or if its operation becomes questionable or inconsistent, the PEM system can provide a quality assurance check. The PEMS should not undergo breakdowns that a CEM system might experience, so it can provide alternate data during periods of CEM system downtime. In fact, if the model passed the statistical evaluation criteria of Part 75 Subpart E, the PEMS data could be used as a backup "monitor" for the CEM system. The interplay of quality control in the CEMS-PEMS combination is illustrated in Figure 5-4.

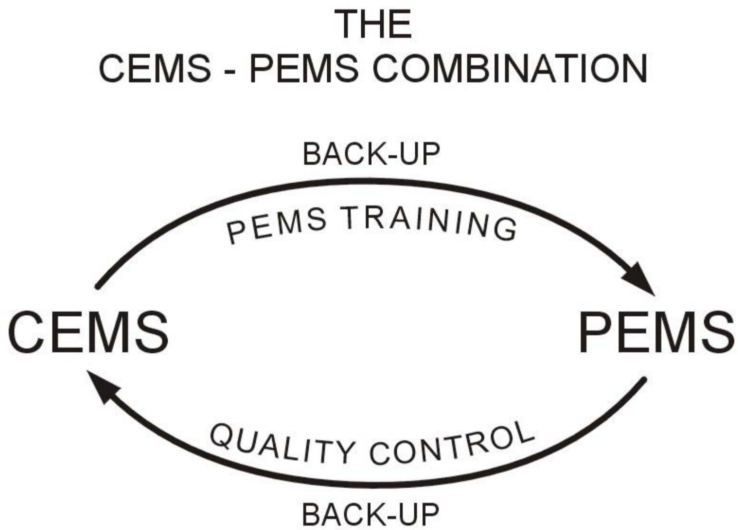

Figure 5-4
The CEMS-PEMS Combination

6 PREVENTIVE MAINTENANCE

A preventive maintenance program is an orderly program of positive actions (equipment cleaning, adjustments and/or testing, lubricating, reconditioning) for preventing failure of monitoring parts and systems during their use. Monitoring systems contain components that have limited lifetimes, where degradation in signal intensity, excessive calibration drift, or inconsistent data indicate reduction in performance of these components. The performance audit procedures discussed in the previous section provide a means of assessing the adequacy of a preventive maintenance program as well as indicate the need for corrective maintenance. This section discusses preventive maintenance and preventive maintenance procedures that can be performed to minimize the need for corrective maintenance on CEM systems.

6.1 Types of Maintenance

In addition to preventive maintenance, two other types of maintenance activities can be characterized. These are “predictive” maintenance and “proactive” maintenance. Predictive maintenance is conducted to resolve anticipated problems that could lead to corrective maintenance. Proactive maintenance is conducted to resolve the root cause of a maintenance problem to avoid conducting either preventive, predictive, or corrective maintenance in the future.

These different types of maintenance activities can be more precisely expressed as follows [17]:

- *Preventive*—Maintenance is scheduled periodically to prevent failures
- *Predictive*—Failures are anticipated and repairs are made before the equipment malfunctions
- *Proactive*—The root cause of failure is identified and fixed before failures occur
- *Corrective*—Reactive maintenance, where equipment is fixed after it fails

6.1.1 Preventive Maintenance

The CEM system technician may conduct any one of these types of maintenance in order to maintain the availability of the system; however, the preventive and corrective maintenance activities are the most commonly performed. Preventive maintenance in CEM systems is usually “fixed time maintenance” [18], where programmed overhauls and component replacements are scheduled either in the QA plan or by the plant time management planner. Major preventive maintenance activities are scheduled during outages, and the “tune up” procedures are conducted before the performance audits, the RATA and, sometimes the linearity tests.

Preventive maintenance activities should be performed on a routine schedule. There are many ways of scheduling maintenance activities, and some are more effective than others. Problems occur when either a necessary procedure is not scheduled or if a scheduled activity is not performed. In plants with insufficient personnel to maintain equipment, maintenance tends to become “reactive” rather than preventive. The amount of time necessary to troubleshoot and repair failing systems and apparatus can prevent the routine maintenance procedures from being conducted.

Relying merely on preventive maintenance to optimize the performance of a CEM system may lead to gaps in maintenance activities. The schedule may have been developed by the vendor, a contractor, or a planner prior to or just after the installation of the system. Over a period of years, parts may begin to wear out that were not anticipated in the initial planning. If the schedule of maintenance activities is not continually revised as experience is gained with the system, the system will become more prone to failures. Also, if the replacement schedule is based only on initial estimated failure rates or estimates provided by the CEM system integrator, the program may waste money and effort in replacing good parts or supplies that have not reached an appreciable percentage of their service time. One must remember that it is in the financial interest of the vendor to sell spare and replacement parts. It is also in the vendor’s interest for the system not to fail, so by specifying shorter replacement intervals, the system may have a higher availability than otherwise.

6.1.2 Predictive Maintenance

A more efficient approach to maintenance is to incorporate a predictive maintenance system within the PM program, where key parameters are tracked to predict the occurrence of failures in the future. Many analyzers today monitor internal parameters that can be accessed through the DAHS and, by extension, through a LAN, WAN, or the Internet. Depending upon programming, these component performance parameters can be trended and pending failures can be identified.

System parameters can also be programmed to predict usage rates and performance trends as well as alarming for failures. For example, cylinder gas usage can be trended by monitoring cylinder gas pressure with the installation of a pressure transducer or by merely trending estimated daily usage into the DAHS. Tracking stack/probe umbilical line temperature, vacuums and pressures, sample flow rate, chiller temperatures, and so on can monitor sample system performance.

The computer maintenance management systems (CMMS), designed ostensibly to provide for predictive maintenance, may not be predictive but reactive, unless designed properly. CMMS can track analyzer and system parameters, but, in most systems, problems do not occur on a day to day basis. Although today’s analyzers may track 20 different internal parameters, when those parameters never change, everyone loses interest. A flat line trend is not very interesting, so instead, reliance is placed on an alarm set point to essentially provide for reactive maintenance rather than predictive.

However, watching the daily trend of flow-to-load ratios, the lamp voltage near the end of a lamp’s lifetime, and the cylinder gas pressure when it reaches below 250 psi (1723.7 kPa) are all truly predictive and, when incorporated into the maintenance program, serve as valuable indicators for the technician. Quality control charts for zero and span drift can also be particularly useful for the prediction and interpretation of system performance.

Predictive maintenance does not prevent conducting maintenance activities. It provides information on problems that will lead to corrective maintenance. This information can be valuable in scheduling maintenance during windows of opportunity; periods when the plant or unit is down for maintenance; or prior to the annual RATA, when a RATA would be required after the maintenance procedure.

6.1.3 Proactive Maintenance

Proactive maintenance identifies a monitoring problem, seeks out the root cause and prevents the problem from reoccurring, or otherwise institutes procedures to manage the problem. For example, in a dilution probe, daily calibration checks exceeding quality control limits may be found to be due to swings in stack temperature or ambient pressure. DAHS correction algorithms, probe heaters, or a pressure transducer fine-tuning the dilution air pressure may stabilize the daily drift and reduce the number of call-outs for recalibration. Or, in a source-level extractive system, condensation is found in the umbilical line, which upon becoming acidic corrodes the pump and fittings. Troubleshooting may uncover cold spots in the umbilical or a misplaced thermocouple, misrepresenting the umbilical temperature. Once identified and fixed, the problem should no longer trouble the system.

Proactive maintenance may require a higher level of troubleshooting than normally conducted with monitoring systems. It may require the exchanging of parts in the hopes that something will work. However, one must first understand the problem and its root cause to effect a real solution; otherwise, “luck” may not be sufficient to prevent the problem from reoccurring. A root-cause analysis may develop into a research project, which might consume more resources than budgeted or intended. Indeed, many of the startup problems with dilution probes in Phase I and Phase II of the Acid Rain Program resulted because of an inadequate understanding of how the probes worked. These problems have been resolved after the expenditure of significant research efforts by EPRI and individual utilities.

6.1.4 Corrective Maintenance

Corrective or reactive maintenance occurs after something is broken and needs to be fixed. Normally it is unexpected and may occur at inconvenient times such as weekends and holidays. Although some may enjoy the benefits of overtime, others view overtime as inefficient and wasteful of the company’s resources. Without proper planning, an adequate supply of spare parts may not be available. The vendor’s assurance of 24-hour delivery is not always realistic during the winter or when the part must be delivered from Europe. For plants relying on vendor service contracts for system maintenance, delays in response may be even more severe if the service person is already committed. In any event, corrective maintenance leads to system downtime. This downtime can be minimized with adequate training in system repair and with adequate planning for parts and alternate approaches to problem resolution.

The goal of the plant should be to minimize occasions of reactive maintenance; however, some plant maintenance staffs work in no other way. Company cultures develop where if maintenance staff or instrument technicians are not fixing anything, nothing is being done. If nothing needs to be fixed, then the I&C staff waits until the next thing breaks, or consideration is given to reducing the staff to accommodate the breakdown rate. In this type of culture, merit is given for fixing problems but not for preventing them. Workorders are written to fix things, not to find the root cause, to develop predictive tools, or even to document the problem. This gives rise to the "maintenance hero" [18], who comes to the rescue in times of crisis. The constant "fire drill" that gives the hero a sense of purpose should be a warning that the maintenance management system has become ineffective or that it is time to buy new equipment. A maintenance hero should not be necessary to maintain a CEM system. An efficient maintenance management system should instead be organized, scheduled, and invisible.

To break out of the "reactive maintenance" mode into a predictive, preventive, proactive mode can be difficult. Many I&C supervisors inherit "fixing is performance" policies and view that time spent for systems analysis, documentation, or research is wasted time, adding to the operation and maintenance costs of the CEM system, not decreasing them. With the numerous performance indicators now available in CEM systems, from calibration quality control charts to instrument sensor trending, times for corrective maintenance can be scheduled practically. Breakdowns, however, will still occur. Lightning can strike the opacity monitor, UV lamps can fail suddenly, or a forklift can pierce an umbilical. But even then, a well managed program will have planned for such contingencies in order to minimize system downtime.

Preventive, predictive, proactive, and reactive maintenance all cost money. Few mechanical, pneumatic, or electrical systems operate without eventually requiring some repair or refurbishment. The development of a maintenance program that can swing the balance from reactive maintenance to an orderly program of scheduled activities can reduce costs and provide for more efficient management. Ideally, the CEM technician's working hours should devote 70% of the time to planned and scheduled maintenance activities, 25% for problem solving and the implementation of improvements, and 5% to corrective maintenance [18]. The costs of performance audits (RATAs and linearity tests) and the costs of calibration gases and other supplies are fixed. They are the costs of doing business, because if the plant does not comply with the requirements of the Clean Air Act, it cannot operate. Similarly, maintenance is a cost of doing business. The fallacy is that it is a nonproductive cost, because in a well managed CEM program, plant operators and engineers will have the necessary confidence in CEM system data to use it for optimizing plant performance.

6.2 Preventive Maintenance—Periodic Inspections

The cornerstone of any CEM system preventive maintenance program is the periodic inspection. Depending upon the CEM system, the inspection may be conducted daily, every few days, every week, or even less frequently. In general, the more complex the system, the more frequent the inspection will be. The periodic inspection is a routine activity, where the CEM system shelter or analyzers are visited and alarms, pressures, vacuums, flows, etc. are checked. For *in situ* systems, it may be necessary to go to the stack location, but due to the trouble involved in reaching stack mounted probes and monitors, the frequency of their inspection will often be a function of accessibility. In any inspection, a CEM system DAHS terminal will be visited to review the daily calibration drift (error) results. In some cases, this may be the only periodic check conducted on a daily basis.

A check sheet or form is traditionally used when conducting a periodic inspection. The form may require the person conducting the inspection to enter the values of the operating parameters or to merely check off a box. Inspections can also be done electronically, by configuring the DAHS to accept analyzer and system diagnostic signals. Automatic printouts for the system operational parameters can be generated, along with a summary of the calibration drift results. Such procedures can certainly save time; however, they do not take the place of actual system inspections. The system visits may be just less frequent.

Inspection check sheets may be simple or detailed but preferably are less than one page in length to minimize the volume of records retained. They are typically stored in a three ring binder located either in the CEM shelter, the instrument shop, or the environmental engineer's office. Year-old or older records should be accessible for reference when troubleshooting system problems or available upon request by an agency or corporate auditor. An example of a daily inspection form is given in Table 6-1.

The form provides three levels of validation by requiring that the value of the parameter inspected be entered into the form, an acknowledgement be made whether the value or condition is acceptable, and a check noting that the parameter was indeed validated. There are two schools of thought about preparing inspection forms. One is to provide a box for checking off the acceptability of a parameter. Another is to provide space on the form to write in the actual value of a parameter checked. The latter procedure is useful for trending the performance of the system and would be essential in an active predictive maintenance program. Checking a box takes less time than writing in pressure and temperature values, but it may be satisfactory for stable systems well-designed for the application. Advanced *in situ* systems and extractive analyzers may incorporate self-correcting routines, so parameters that may otherwise drift are maintained at their set point condition. In such cases, writing in the parameter value provides little useful information for the system operation.

Table 6-1
A Daily Inspection Form

	Activity	Tolerance Level	Enter Value	O.K.?	Done?
A.	**CEM System**				
1.	Check DAHS Screen for alarms. Are any alarms on?	None	-	Y/N	
2.	Print Daily Calibration Drift Report from DAHS.	-	-	-	
3.	Check the NO_x Zero Drift (as % of span). Enter value on form.	< 2.5%			
4.	Check the NO_x FS Drift (as % of span). Enter value on form.	< 2.5%			
5.	Check the SO_2 Zero Drift (as % of span). Enter value on form.	< 2.5%			

6.	Check the SO_2 FS Drift (as % of span). Enter value on form.	< 2.5%			
7.	Check CO_2 Analyzer Zero Drift (as % CO_2). Enter value on form.	< 1% CO_2			
8.	Check CO_2 Analyzer FS Drift (as % CO_2). Enter value on form.	< 1% CO_2			
9.	Check the Flow Zero Cal. Drift (as %). Enter value on form.	< 2.5%			
10.	Check the Flow FS Drift (as %). Enter value on form.	< 2.5%			
B.	**Opacity Monitor**				
1.	Check Opacity Monitor Control Panel for alarms. Alarms on?	None	-	Y/N	
2.	Read Zero value (% Opacity) from strip chart. Enter on form.	< 2% Op			
3.	Read upscale Cal. value (% Op) from strip chart. Enter on form.	< 2% Op			
C.	**Dilution Extractive System**				
1.	Check inlet air to air-cleanup system	> 55 psi		Y/N	
2.	Check auto drain filters on air cleanup system	-			
3.	Check outlet air from air-cleanup system	> 40 psi			
4.	Check Purafil on air-cleanup system (purple = good/ brown = bad)	purple			
5.	Check Silica gel on air-cleanup system (blue = good/ pink = bad)	blue			
6.	Check probe vacuum on dilution system control panel	16"–18" Hg			
7.	Check dilution air pressure on dilution system control panel	25 psi			
8.	Check probe heater temperature set point	330°F			
9.	Check flow on analyzers	1 lpm			
10.	Check the NO_x converter temperature	325°C			
11.	Check NO_x vacuum	-20–24 in.			
12.	Check Drierite for NO_x analyzer (blue = good/pink = bad)	blue			
13.	Check gas cylinders. Tank pressure >150 psi/Del. Press. 20 psi	> 150/20			

14.	Record shelter temperature	68°F–72°F			
15.	Record barometric pressure (altimeter) from airport	-	in. Hg	-	
D.	If alarms are noted or if zero or span drift exceed tolerance levels, call the I&C Supervisor & Environmental Engineer.				
E.	If it was necessary to call the Supervisor, provide the reasons why this was done in the space below.				
F.	Attach Calibration Reports from the DAHS and file this form in the 3-ring binder in the CEM shelter.				
Comments:					

At a minimum, the inspection form should check the following information:

- Pass/fail status of daily zero and span calibration checks for each analyzer
- Values of (or acceptability of) system vacuums, pressures, and sample flow
- Values of (or acceptability of) system temperatures (probe, umbilical, conditioner)
- Values of (or acceptability of) air clean up inlet/outlet pressures
- Status (color) of dryer/scrubbing materials
- Status of system and analyzer alarm indicators
- Status of recording systems (data logger, strip charts, DAHS-inking, paper, and ribbons)

Cylinder gas pressures can be checked daily, but for dilution systems, the usage rate is usually well enough known to allow this check to be conducted weekly. Source-level extractive systems and *in situ* probe type systems will have higher calibration gas usage rates than dilution systems and it may be necessary to check the gas cylinders more frequently to avoid inadvertently dropping below the 150 psi (1034.2 kPa) recommended.

Other parameters may be included on the list if they are suspected of having some influence on the operation of the system. These may be:

- CEM shelter temperature
- Barometric pressure
- Megawatts
- Fuel flow
- Flue gas opacity/flow
- Flowmeters clean/dry?
- Sample pump sound O.K.?
- Heatless dryer cycling?
- Peristaltic pump leakage?

These parameters may be tracked for a period of time, a solution found to their influence on the system, and then may be removed from the inspection form.

The inspection form illustrated in Table 6-1 is merely a typical example. Forms tend to be personal and should reflect the way that the CEM technician thinks about the system. Ideally, the technician should develop the form because he or she has first-hand knowledge of the system operation and knows the key points that must be inspected. However, the inspection form is frequently prepared by the engineer who writes the CEM system quality assurance manual. In an effort to be thorough, the resulting form may require that too many parameters be checked or require too much information to be provided on the form. As a result, the inspection takes excessive time to conduct, adds little value to the maintenance of the system, and leads to grumbling by those assigned to inspect the system.

A "daily" inspection may not be necessarily conducted daily. For well-running systems, the site inspection may be less frequent: perhaps once every two days or only weekly—on Friday, to check the system before the weekend. However, in programs with less frequent inspections, the daily calibration drift/error still usually is checked to see that the system is within mandated control limits. The technician, environmental engineer, control room operator, or shift supervisor may do this check.

There are several purposes for conducting periodic inspections. In the case of alarm conditions, or system failures, the inspections serve to warn of the need for *corrective action*. Also, when the inspection activities are properly documented, they provide operational data that can be used for *predictive maintenance*. One of the most obvious activities, by noting the cylinder gas bottle pressures, one can easily predict when new cylinders should be ordered and cylinders replaced. The daily inspection also provides a basis for *proactive maintenance*. If the daily calibration drift (error) is tracked, it may be found that instrument drift can be correlated to ambient pressure or room temperature. If the pressure drift fluctuations are unacceptable, plans might be initiated to incorporate pressure correction algorithms in the DAHS or to purchase pressure compensated analyzers or pressure compensation systems for dilution air control in dilution systems. Drift due to room temperature fluctuations may indicate a need to improve or modify the heating and air conditioning system of the CEM shelter.

The inspection activities could be part of a "job maintenance request" prepared by the plant job planner, who received input to prepare a computerized list of scheduled activities that the technician must follow. These job maintenance requests may be for daily, weekly, monthly, annually, and so on or for corrective maintenance. They are usually given to the I&C supervisor who then assigns the work to the technician. Job maintenance requests are used to keep track of work performed, ostensibly to maximize manpower efficiency. To be blunt, such management schemes tend not to work too well. Everyone tolerates them because they are mandated by management but then does what is necessary, either ignoring the paperwork or filling in the computerized form by rote at the end of the day. The form is given back to the supervisor or sent back to the planner's office, whereupon it disappears into the plant computer system. Where such programs are in effect, it may be useful for the technician to photocopy the form before returning it and to maintain it in shop files for easier retrieval. Paradoxically, time management through the use of job maintenance requests can add layers of paperwork to the maintenance process that can lead to inefficiencies in the operation of a CEM system.

Because daily or otherwise periodic inspections are routine, they may not necessarily be conducted by the CEM technician. Other maintenance personnel or unit operators may conduct this function, depending upon the plant organization. Whoever conducts the inspection, they must receive sufficient training to recognize system problems and the occurrence of drift excursions. In fact, drift beyond out-of-tolerance limits or the out-of-control limit tends to be the greatest concern in the inspection. The shift supervisor and CEM technician will most likely be notified if an out-of-control limit is noted during the weekend or holidays. During the week, the environmental engineer and CEM technician may check the calibration drift results themselves, daily, even though someone else may be conducting the walk-through inspection.

6.3 Preventive Maintenance—Scheduled Activities

Preventive maintenance activities are scheduled to prevent the occurrence of problems that lead to corrective maintenance. The frequency of these activities is again dependent upon the type of CEM system installed. Preventive maintenance can be scheduled over any time period (or periods) but are typically conducted quarterly and annually. If preventive maintenance needs to be conducted more frequently than monthly, the system needs to be upgraded, redesigned, or replaced. Figure 6-1 shows a quarterly check of an out-of-stack dilution probe filter.

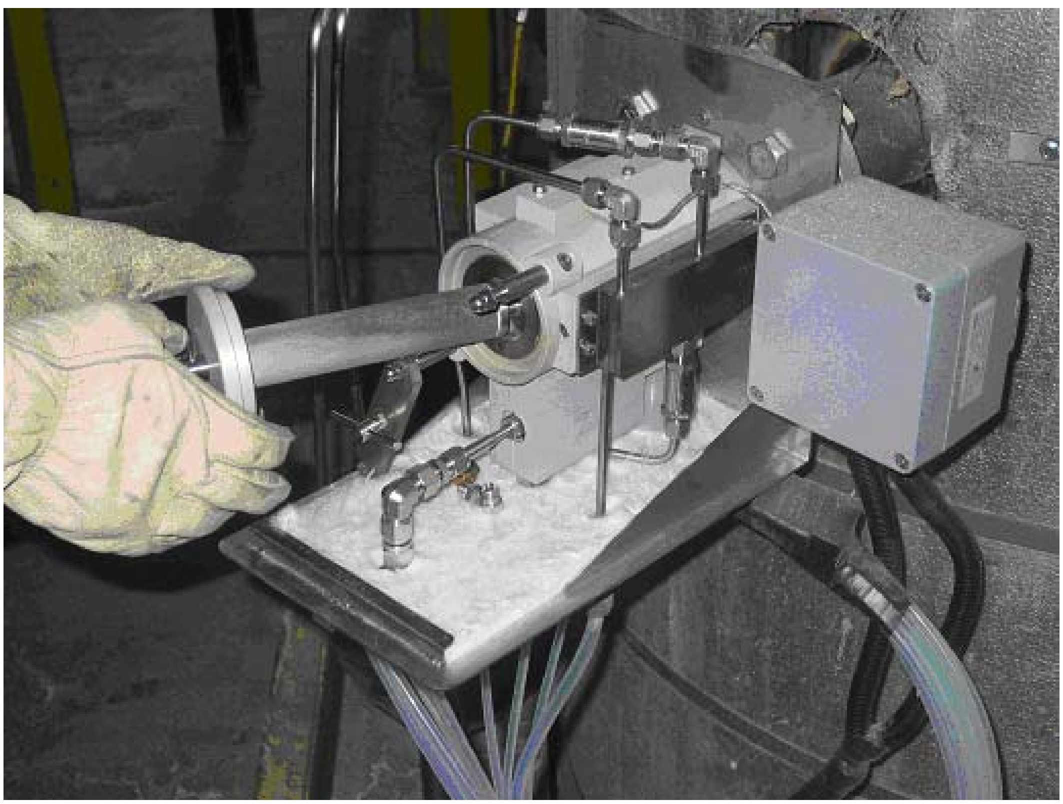

Figure 6-1
Checking the Filter of an Out-of-Stack Dilution Probe

Upon purchasing a new CEM system, the vendor should provide a list or table of preventive maintenance activities necessary to keep the system in good operating order. This list may be somewhat abbreviated if the vendor attempts to give the impression from a marketing standpoint that the system is relatively “maintenance free.” This may at first seem desirable, but systems advertised as being "low maintenance" may engender a false sense of confidence. Inevitably, maintenance requirements must then be learned either as the system ages or by contacting users of similar systems who have gained experience with their operational characteristics. Vendor preventive maintenance recommendations may also be self-serving in another way, by over-specifying maintenance requirements and frequencies in order to sell more spare parts and system components than necessary. These recommendations often come with the stipulation that only vendor-specified or vendor-manufactured parts are to be used in order to assure proper operation and adherence to warranty requirements.

Preventive maintenance intervals should not be assumed to be fixed. A conservative estimate on the life of a UV lamp may be six months, but because UV lamps are expensive, a technician will either take a "run to failure" approach or incrementally extend the replacement period until a practical replacement period can be determined. There is nothing wrong in doing this, if the possible inconvenience of replacing a failed lamp does not result in a period of extended downtime. However, if the replacement period is changed, the preventive maintenance procedures detailed in the CEM system quality assurance manual should be changed accordingly. If the manual is not revised, the QA program can come under question when audited, with the possible assumption arising that preventive maintenance is not being conducted. The quality assurance manual can be revised at any time but must reflect the actual quality control practices currently in place.

The preventive maintenance section of the quality control manual should include a table of scheduled preventive maintenance activities conducted over the year. Whether quarterly, annually, every two years, or every five years, the activity should be listed, primarily to remind the technician that it must be done. Table 6-2 gives an example of a preventive maintenance schedule.

Table 6-2
Matrix of Preventive Maintenance Activities

Activity	Weekly	Quarterly	Semi-Annual	Annual/ Other
Dilution probe filters replaced		x		
Umbilical line leak checked				x
Air-cleanup system checked		x		
Remove/check/replace solenoid valves, and orifice glands in air-cleanup system				x
Replace air drying & CO2 towers in air-cleanup system				3 yr
Replace CEM cabinet fan and vent filters		x		
Lubricated exhaust blower motor		x		
Replace vacuum pump diaphragms				x
SO2 Analyzer checked	x	x		
SO2 Analyzer fan filter cleaned			x	
SO2 Analyzer capillary cleaned/replaced				3 yr

Activity	Weekly	Quarterly	Semi-Annual	Annual/ Other
NOx (Stack) Analyzer checked	x	x		
NOx (Stack) Analyzer desiccant replaced (as required)		x		
NOx (Stack) Analyzer Teflon particulate filter replaced		x		
NOx (Stack) Analyzer capillary cleaned/replaced				3 yr
NOx (Stack) Analyzer fan filters cleaned			x	
NOx (Stack) Analyzer clean PMT Chamber cooling fins			x	
CO2 (Stack) Analyzer checked	x	x		
CO2 (Stack) Analyzer sample cell cleaned				3 yr
CO2 (Stack) Analyzer—Replace IR source				x
CO2 (Stack) Analyzer—Check for leaks				x
Opacity Monitor checked	x	x		
Opacity monitor on-stack checks conducted		x		
Opacity Monitor purge air filters replaced		x		
Conduct Filter Audit (SOP:11) with Cal Kit		x		
Adjust 0% and 100% Opacity values and perform Stack Set and Cal Set.		x		
Flow Monitor checked	x	x		
Flow Monitor purge air filters replaced		x		
Check flow monitor lockup times		x		
Check sound transducers		x		

The major problem in preventive maintenance programs is when this schedule is forgotten, the activities are not checked off, and the system operates for extended periods of time without being serviced properly. Again, the use of computer-generated maintenance request forms or work order(s) is one method of scheduling these activities. A work order is generated prior to the scheduled maintenance job, usually a few weeks prior to the time it is to be performed. The technician performs the work within a given period, fills out the form, and submits it to the I&C supervisor when the job is completed. This procedure is a good management technique but can have drawbacks, if the work order is not sufficiently detailed. The work order should list all the procedures to be conducted, not just give a generic statement that "quarterly preventive maintenance activities are to be performed." The generic list does not allow the I&C supervisor to determine whether all of the required activities have been performed. Another problem occurs when the work order(s) are not taken seriously. Here, the forms get lost in the piles of papers or reports, and management does not follow up their return or the completion of the work. In many ways, the effective performance of preventive maintenance for a CEM system depends more on the initiative and conscientiousness of the technician rather than on the design of the management program.

An alternative or backup to using the work order is to prepare a separate form or listing of the procedures that need to be conducted. Completing this form can be part of the preventive maintenance procedures and would be incorporated into the quality control procedures of the CEM quality assurance manual. Because the PM activities are scheduled at different frequencies (it is not necessary to do everything quarterly), the intent of the form would be to keep a running record of these activities over the year. Much like the 20,000 mile checklist for the maintenance of a new car, this checklist provides assurance that everything has been done to keep the car or CEM system running for another year. Table 6-3 gives an example of a checklist for a source-level extractive system.

Table 6-3
Preventive Maintenance Form for a Source-Level Extractive System and Opacity Monitor

QUARTERLY PREVENTIVE MAINTENANCE

	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
Date				
Start Time/End Time				
Initials				
OUTLET PROBE LOCATION				
Clean or change internal probe filters				
Check heated sample line for condition/damage				
Inspect all tubing. Blow out sample Lines. Annotate				
Check opacity blower motors for noise/condition				
Check transceiver/retro ports for particulate build-up				
Check and change (if necessary) opacity blower filters				
Clean opacity monitor optics				
Check opacity monitor transceiver alignment				
Check condition of all stack mounted equipment				
CEM SHELTER—SAMPLING SYSTEMS				
Rebuild Neuberger pumps				
Clean heated flow meters				
Leak test sampling systems				
Leak test calibration gas lines. Check flow rates				

Clean out O_2 Monitor Manifolds				
Check Flow Monitor lines for condensate				
Check and bleed Flow Monitor drip leg if necessary				
Observe Flow Monitor blowback system				
Inspect and replace instrument air tubing & fitting as necessary				
CEM SHELTER—ANALYZERS				
Calibrate O_2 Monitor Cell				
Check zero and span settings for flow monitor				
FINAL CHECKS AND ADJUSTMENTS				
Return system to normal operation				
Manually recalibrate gas analyzers				
Schedule or conduct quarterly CGA				
Check operation of opacity monitor control unit				
Check opacity monitor calibration				
Schedule or conduct quarterly opacity audit				
MISCELLANEOUS				
Count, check, set aside, or return CGA bottles				
Clean CEM shelter and equipment				

SEMIANNUAL PREVENTIVE MAINTENANCE

	1st Half	2nd Half
Date		
Start Time/End Time		
Initials		
Replace condensate pump		
Remove Air Monitor Probes—Inspect/repair/replace		
Simulate all CEM alarm conditions & verify		

ANNUAL PREVENTIVE MAINTENANCE

Date	
Start Time/End Time	
Initials	
CLEAN ROOM LOCATION	
Configure the opacity monitor for clear-path zero check.	
Conduct clear-path zero check according to manufacturer's instructions	
Initiate an automatic calibration.	
Re-install the opacity monitor	
Reprogram control unit/DAS with new reference values.	
Initiate an automatic calibration. Enter cal. value here.	
Comments	

The form given in Table 6-3 is somewhat schematic, giving merely an outline of the primary maintenance activities to be performed. Again, there are many ways to prepare forms, and they should be formatted so that they are useful but do not take an excessive amount of time in filling out. The important point is to perform the maintenance, document that it has been done, and note any observations that may be important for the present or future operation of the system. A second example is given in Table 6-4. This form is prepared in more of discussion format and provides the operator with a step-by-step procedure for conducting the activity.

Table 6-4
Semiannual Preventive Maintenance Form for a NO_x Dilution Extractive System on a Gas-Fired Boiler

Semiannual CEM System Preventive Maintenance Check Sheet	
Name___________________________________	Date__________________
Stack Probe Semiannual Maintenance	
Perform the following procedures semiannually for the (Unit 2) probe. Fill out this Stack Probe Semiannual Maintenance form for each system as the procedure is conducted.	
Action	**Comments**
1. Record the dilution air pressure and vacuum readings from the control panels.	

2. Put the CO_2 and NO_x monitors in maintenance mode. Be sure to have two good quarters of the hour if on line. Call the control room and inform them of the impending alarms. Inform the control room that probe maintenance will be performed.	
3. Turn off the CO_2 and NO_x monitors and unplug the CO_2 pump.	
4. Turn the dilution air off by adjusting the dilution air regulator to zero.	
5. Turn on the purge air.	
6. Turn off the probe heater breaker.	
7. Take the following tools and materials and go to the probe location. adjustable wrenches regular screwdriver 3/8" allen wrench set pipe wrench (14") wire brush gloves (if unit is on line) silver goop quartz wool graphite ferrules	
8. Visually inspect the probe.	
9. Remove the probe from the stack (this should take three men, two to pull the probe and one to hold the tubing bundle to keep from damaging the tubing).	
10. Unscrew the mantle at the second joint from the tip of the probe (about 8" back) and remove it carefully.	
11. Inspect the calibration port for blockage. Purge air should be coming through.	
12. Clean screen on mantel with the wire brush.	

13. Inspect the orifice for tightness by gently trying to wiggle it. If you can wiggle it, replace the graphite ferrule and re-tighten. Insure that the old ferrule is completely removed.	
14. Replace the quartz wool.	
15. Clean old silver goop from the threads.	
16. Reapply silver goop, replace mantle, and insert the probe with the purge air on.	
17. Ensure that all tubing fittings are tight. Do not over-tighten.	
18. Turn the dilution air back on. Leak check the fittings at the probe with the purge air on.	
19. Plug the CO_2 pump back in and turn on the CO_2 and NO_x monitors.	
20. Turn the purge air off and check the vacuum to make sure that it has returned to the pre-maintenance value.	
21. Turn on the probe heater breaker.	
22. Take the CO_2 and NO_x monitors out of maintenance mode. Enter reason codes for alarms. Inform the control room that probe maintenance is finished.	
23. Note in the system logbook the date and times of the maintenance.	
Air System and CO_2 and NO_x Monitor Semiannual Maintenance	
Perform the following procedures semi-annually for both air system and CO_2 and NO_x monitors. Fill out this Air System/Monitor Semi-Annual Maintenance sheet as the procedure is conducted.	
Action	**Comments**
1. Put the CO_2 and NO_x monitors in maintenance mode. Call the control room and inform them of the pending alarms.	

Action	Comments
2. On the air system, take down readings for: dilution air pressure probe vacuum air system supply pressure air system outlet pressure chiller refrigeration suction pressure.	 ________________ ________________ ________________ ________________ ________________
3. Press down the STAT button on the NO_x monitor and take down the diagnostic readings as follows: Full Scale ________ CL ________ nr ________ AR ________ Ct ________ O ________ A ________ rc ________ dip ________ b ________ b3 ________ 1-8 all LEDs off time ________ SF ________ ºC ________ trb ________ CE ________	
4. Write down the NO_x monitor vacuum.	
5. Watch the needle on the front panel of the CO_2 monitor for one cycle of the dryers. Does the needle move?	
6. Close the supply valve to the chiller and watch the pressure go to zero.	
7. After the air system output goes to zero and the air dyers cycle twice, unplug the air dryers and turn off the switch.	
8. Turn off the monitors and unplug the CO_2 pump in the back of the rack.	
9. Perform maintenance on the chiller and chiller filters.	
10. Inspect and/or replace all filters and desiccants on the air-cleanup system.	
11. Change the Teflon filter on the inlet sample side of the NO_x monitor.	

Action	Comments
12. Inspect and/or replace the capillaries in the reaction chamber of the NO_x monitor.	
13. Inspect and clean thermoelectric cooler fins in the NO_x monitor.	
14. Change the glass filter on the inlet sample of the CO_2 monitor.	
15. Check the potentiometers on the front panel of the CO_2 monitor to see if they are at the end of their adjustment.	
16. Plug the CO_2 pump back in, turn on the monitors, and slowly open the air supply valve to the chiller.	
17. Plug the air dryers back in, wait 15 seconds, and turn the switch back on.	
18. See that all pressures are adjusted to pre-maintenance levels.	
19. Take the monitors out of maintenance mode. Enter reason codes in the CEM DAHS for alarms. Call the control room and inform them that the maintenance is completed.	
20. Note in the system logbook the date and times of the maintenance.	

Although it is more detailed, all of the necessary procedures are not all included on the form, and an inexperienced technician may have to consult the system or analyzer operation and maintenance manuals to conduct the maintenance properly. But this type of form still may be more useful than a simple checklist (such as that given in Table 6-3), if a technician conducts the activity only once or twice a year. The more information put on the form to jog the memory, the more helpful it may be for conducting maintenance properly and efficiently.

6.3.1 Maintenance Frequency

When preventive and corrective maintenance activities are far too frequent than anticipated, what may have become accepted as a maintenance problem may actually be a design problem. If the probe was not designed for a high temperature, high particulate loaded flue gas, it may have to be serviced and/or replaced frequently. If the probe filter keeps getting plugged or acid gases condense in the sample line, redesigning or replumbing the system might be considered rather than repeatedly preempting or fixing known failure points.

High levels of maintenance in CEM systems often lead back to poor choices in the original system design. Design problems become evident within the first year of operation, where a decision must be made either to live with the problem and devote the resources necessary to maintain accuracy and availability, to modify the system, or to give up and purchase a new system.

Much of the literature on CEM systems is devoted to proper CEM system design [2,19]. Materials of construction, choice of conditioning system, probe and umbilical lines, and analytical techniques are all important when selecting a system for a given application. This and other available information should be consulted before the CEM technical specifications are prepared for a purchase order request or request for proposal (RFP).

6.3.1.1 A Typical Preventive Maintenance Schedule

Maintenance activities for a well running CEM system can be conducted on a routine schedule. These activities can be scheduled by the planner, but, for preventive maintenance, the technician should keep independent records to double-check that all necessary maintenance is performed throughout the year.

Monday to Thursday: Check the daily calibration error results for each analyzer. Perform the daily inspection and complete the inspection form (may be done less frequently if system parameters are relatively stable):

- Friday: Check calibration error results. Perform inspection. Check the system for the weekend. Recalibrate analyzers if near out-of-control limits.
- Weekends: Unit operators respond to CEM system alarms and call in technicians if not onsite.
- Preventive Maintenance: PMs conducted typically quarterly or semi-annually with major maintenance conducted during outages.
- Performance Audits: Conducted quarterly (linearity checks or cylinder gas audits, opacity monitor audits and annually (relative accuracy tests).

6.3.1.2 Component Check/Replacement Frequencies Summary

CEM system components have various maintenance or replacement frequencies. These frequencies are dependent upon the types of systems, the quality of the system, and its monitoring environment. Clearly, a system installed at a facility having high levels of particulate matter or condensing acid gases or one subject to frequent upsets with slurries or acid materials impacting the probe will require more maintenance than one installed on a relatively clean source, such as a gas-fired boiler or gas turbine. Tables 6-2, 6-3, and 6-4 provide examples of various maintenance schedules.

General maintenance or replacement frequencies for CEM system components are estimated in Table 6-5.

Table 6-5
CEM System Component Maintenance or Replacement Frequency

Dilution Systems	
Dilution probe	
Screen	Clean annually
Orifice	Check/Clean annually
Unheated sample line	System Lifetime
Freeze-Protect Sample line	9-10 years
Ex-situ filter	Clean quarterly
Dry-Extractive Systems	
Probe filters	1 month–quarterly
Probes	Check annually
Heated Sample line	5–10 years
Conditioning System (Peltier cooler)	Check daily
Conditioning System (Refrigerated Chiller)	Check daily
Peristaltic Pump	Check daily
Vacuum Pumps (semiannually)	Check quarterly—Overhaul
Solenoids	1–2 years
Valves	5+ years, depending on corrosion
***In Situ* Systems**	
Blower filter	Change Quarterly
Blower Motors (5-10 yrs)	Check quarterly/replace-recondition
Blower Hoses	Check quarterly/replace 5-10 years
Cables/Connectors	Check quarterly/replace 5-10 years
Zero-Pipes	Check monthly
In-stack probe	Check semi-annually
Monitor desiccant cartridges	Check quarterly/replace annually
Windows	Clean monthly/quarterly
Flow monitor transducer	Clean quarterly/replace 1 – 2 years
UV lamps	Replace 1-2 years

Analyzers	
Fine Filters	Check/replace annually
Fan Filters	Check/replace annually
Capillaries	Check quarterly/replace as needed
O-ring capillaries	Check quarterly/replace as needed
Charcoal Adsorber (ozone scrubber)	Replace annually
Drierite	Replace when pink
Sample pumps	Rebuild or replace annually
Chopper Belt	Check annually
Chopper Motor	Check/recondition annually
PMT cooling fins	Clean annually
Lamp	Replace 1–2 years (UV)
Air-Cleanup System	
Coalescer	Check/replace annually
Charcoal filter	Replace quarterly
Drierite	Replace quarterly or when pink
Purafil	Replace quarterly
Solenoids	Check weekly/replace 1–2 years
CO_2/Moisture Removal Towers	Replace every 3 years
CEM Shelter	
Air Conditioner	Check monthly/Replace after 5 years
Instrument rack filters	Clean or replace annually
Gas cylinder regulators	Replace after 3–5 years if exposed

Many system components and analyzer components should last the lifetime of the system. Basic electronics, circuit boards, detectors, etc. are not usually prone to failure unless the manufacturer did not quality assure the instrument before delivery. Unfortunately, manufacturer quality assurance programs are sometimes lacking and instrument failures will occur shortly after installation. In such cases, the instruments are usually still under warranty and the manufacturer will usually honor such warranty. However, scheduling delays and the time necessary to resolve these initial problems create unnecessary trouble for the technician.

In well, manufactured systems that use quality components, valves, fittings, and tubing should last the lifetime of the system. However, in sources where acid gases are prone to condensing (such as in some dry extractive systems), corrosion will shorten the lifetime of system components rapidly. There have been cases where plant upsets or condensing gases made it necessary to replace probe filters, probes, or sample pumps weekly. Clearly, such a situation is unsustainable and these systems are rapidly redesigned or replaced with a system that is less susceptible to damage.

Component lifetimes can be increased through proper housekeeping. *In situ* blower filters can be rapidly plugged if the blowers are located in a dusty plant environment. Placed in a cleaner location, the intake air will be cleaner and reduce the frequency of filter replacement. Extractive system analyzers should be in a clean environment maintained at a stable temperature. High ambient temperatures, high humidity, or high dust levels do not promote longevity for these instruments.

However, despite all efforts to minimize component failures, failures occur that could have been prevented but only in hindsight. Lightning strikes, power surges, power outages, a bad run of vendor replacement parts, and other things that should not happen but do are the bane of the technician. These situations can only be addressed as they occur, and, if reoccurring, steps can be taken in the future to minimize their impact.

6.3.2 Recertification Activities after Maintenance

Maintenance for a CEM system differs from that for process analyzers since the CEM system maintenance is subject to a number of regulatory conditions. Because the CEM system data are used for regulatory reporting, any maintenance that "significantly affects the ability of the system to accurately measure or record...." may trigger a recertification of the system. Maintenance activities that require a recertification are well defined for Part 75 systems in 40 CFR 75.20 and associated guidance in the EPA's Recertification and Diagnostic Testing Policy Document of October 24, 2001. Part 60 system recertification criteria are not well defined and are usually left to the discretion of the State or local agency administrator.

Part 75.20 and the associated Diagnostic Testing Policy provide a programmatic approach that reduces the ambiguity associated with recertification after conducting maintenance or completing repairs on a CEM system. Although the policy applies only to Part 75 CEM systems, it could also be used with Part 60 systems if one wished to follow the Part 75 precedent. The Policy distinguishes between two types of tests, namely:

- *The Diagnostic Test*—the tests required to verify that a CEM system is operating accurately following certain preventive or corrective maintenance procedures.
- *The Recertification Test*—the tests required to recertify a CEMS or system component following a major repair, replacement, or modifications.

A recertification test is simply the test conducted to initially certify the system. A repeat of these tests can be expensive, particularly if they need to be conducted separately from the annual RATA. Accordingly, most major modifications to a CEM system are usually planned just prior to the annual RATA and also, if timely, in association with a unit shutdown so that emissions data will not be lost while the modifications are being made.

Diagnostic tests are merely those tests that a technician would conduct to assure that an analyzer or the system works after the maintenance is performed. The diagnostic testing *policy*, however, applies certain conditions and penalties in case the system does **not** work after the maintenance is performed. Diagnostic tests are conducted when the maintenance performed does not significantly affect the ability of the system to measure accurately. The maintenance may be merely the replacement of a filter, repair of a moisture removal system, reconditioning a pump, or modifying an air-cleanup system. The diagnostic tests themselves are simply the calibration error checks, linearity tests, response time tests, etc. that one would conduct during the original certification or as part of the quarterly quality assurance cycle.

Before detailing the diagnostic test procedures, two other terms need to be explained. These are the *probationary calibration error test* and *conditionally valid data:*

- *The Probationary Calibration Error Test*—an on-line calibration error test that is used to initiate a conditionally valid data period.
- *Conditionally Valid Data*—data from a CEM system that are not quality assured but that may become quality assured if certain conditions are met.

A monitoring system must pass a probationary calibration error test to initiate the conditionally valid data status:

- In order for conditionally valid emission data to become quality assured, one or more quality assurance tests or diagnostic tests must be passed within a specified time period.
- The probationary calibration error test is merely the daily calibration drift (error) check defined in §2.1.1 of Part 75 Appendix B and performed according to the procedures of §6.3.1 of Part 75 Appendix A.

6.3.2.1 Maintenance Requiring Diagnostic Tests

Data are conditionally valid after the probationary calibration error test is completed until the time the diagnostic test is completed. The time periods allowed to conduct the diagnostic test are specified (in §75.20 (b)) and are given below in Table 6-6.

Table 6-6
Time Periods Data are Conditionally Valid until Diagnostic Test is Performed

Diagnostic Test	Maximum Time Period to Complete Test
Linearity	168 hrs
Cycle Time	168 hrs
Leak Check	168 hrs
7-Day Calibration Error Test	7 days
RATA	720 hrs

If a required test is not completed within the applicable timeline, the data are then considered invalid beginning with the first operating hour after the expiration of the test period, regardless of the eventual test results. Because of this stipulation, it is best to conduct the diagnostic tests as soon as possible after the maintenance is completed. Examples of maintenance that allows diagnostic testing are:

- Temporary like-kind analyzer replacement
- Replace analyzer lam —(7-day calibration error test, linearity test)
- Replace flow monitor transducer—abbreviated flow-to-load test
- Change analyzer span—linearity test

Maintenance activities that might trigger a diagnostic test should be scheduled, if possible, to coincide with the routine quality assurance tests. A diagnostic linearity tests counts as a quarterly linearity test, so to avoid having to do more linearity tests than necessary, the maintenance should be scheduled toward the end of the quarter.

For minor maintenance, the whole routine of the diagnostic test [§75.20(b)] does not need to be followed. A simple calibration error test can be conducted, and it is not necessary to call it a "probationary calibration error test." It is just done to see if the system response from the injection of a calibration gas is satisfactory after fixing or modifying the system. Actions that can be performed and checked by conducting a calibration error test only (not initiating a probationary test period) are as follows:

- Minor component replacement (for example, filter/valve replacement)
- When a daily calibration error check fails
- After making routine or non-routine calibration adjustments
- When a monitor is returned to service following a minor repair or corrective maintenance

6.3.2.2 Maintenance Requiring Recertification

Recertification of the system is required whenever a replacement, modification, or change in a certified system may significantly affect the ability of the system to accurately measure the gas concentration, flow, or opacity or to meet Part 75 QA/QC requirements. Examples of conditions that require recertification are as follows:

- Replacing an analyzer permanently
- Replacing an umbilical line
- Changing the probe location
- Replacing the critical orifice of a dilution system with an orifice of a different size
- Changing the type of system (for example, dilution to extractive or *in situ*)

Again, before initiating maintenance that can trigger a recertification, attempts should be made to conduct the maintenance in conjunction with the annual RATA. In either case, a recertification test application must be made to the EPA 21 days prior to the test (although, if it is an emergency, 7 days may be allowed).

6.3.2.3 Failure of Diagnostic or Recertification Tests

If a diagnostic or recertification test is failed, the data collected from the hour of completing the maintenance that triggered the test to the hour of the failed test is considered invalid (note that is from the hour of completing the maintenance, not the hour from when the probationary error test was completed). When the data are invalidated, missing data substitution routines are triggered, of course, negatively impacts data availability. This can result in punitive data substitution and can possibly create the potential for targeting for an EPA CEM systems audit.

6.3.2.4 Documentation

Maintenance activities should always be documented in the CEM logbook. To track the diagnostic tests, the results of the probationary calibration error test should also be documented in the logbook, as well as the performance and results of the diagnostic tests. Management (the designated representative, I&C supervisor, and/or environmental engineer) should be informed when a probationary test period has been initiated and whether the diagnostic tests have been completed successfully. For Part 75 systems, both diagnostic and recertification tests are required to be reported in the Electronic Data Report (Record Type #556).

6.3.2.5 Summary

Summaries of validation procedures that are to be performed upon modifying a dilution-extractive or source-level extractive system are given in Tables 6-6 and 6-7. The tests necessary are dependent upon the degree of change and extend from by simply conducting a calibration error test to essentially repeating a certification test. The guidance given in this policy, when followed, should provide sufficient assurance that data quality is not compromised by system changes. Table 6-7 summarizes the diagnostic test policy for dilution-extractive systems.

Table 6-7
Diagnostic Test Policy for Dilution Systems

Description of Action	Status	Rata	7-Day Drift	Cycle Time	Linearity Check	Cal Error Test	RT 556
Permanently replace NO_x, SO_2, O_2, or CO_2 analyzer with like-kind analyzers	R	X	X			X	X
Permanently replace NO_x, SO_2, O_2, or CO_2 analyzer with new analyzer that does not qualify as a like-kind analyzer	R	X	X	X	X	X	X
Replace critical orifice in dilution system with orifice of different size	R	X	X	X	X	X	X
Change from in-stack dilution to out-of-stack dilution methodology (or vice-versa)	R	X	X	X	X	X	X
Replace umbilical line	R	X	X	X	X	X	X

Description of Action	Status	Rata	7-Day Drift	Cycle Time	Linearity Check	Cal Error Test	RT 556
Change probe dimensions or location	R	X	X	X		X	X
Change from dilution CEMS to *in situ* CEMS	R	X	X	X	X	X	X
Change from dilution CEMS to extractive CEMS	R	X	X	X	X	X	X
Replace or repair a major analyzer component that may be subject to drift	D		X		X	X	X
Replace or repair a major analyzer part that is not likely to be subject to drift	D				X	X	X
Replace or repair vacuum pump or pressure pump	D			X		X	X
Replace probe (same probe material, dimension, and location)	D					X	X
Change probe material	D					X	X
Replace critical orifice in dilution system with orifice of the same size	D			X	X	X	X
Dissasemble or reassemble dilution probe for maintenance or service	D				X	X	X
Replace CEMS probe (same material, dimension, and location)	D				X	X	X
Major changes to dilution air supply	D				X	X	X
Replace probe heater or sample line heaters	CE					X	
Replace or repair minor analyzer component or perform routine analyzer maintenance (as specified in the QA/QC plan)	C					X	
Replace or repair wiring in CEM shelter	C					X	
Routine probe filter maintenance (for example, clean coarse filter)	C					X	
Replace probe heater/sample line heaters	C					X	

Notes: D = Diagnostic test
R = Recertification event
CE = Calibration Error test only

Table 6-8 summarizes the diagnostic test policy for dry-extractive systems.

Table 6-8
Diagnostic Test Policy for Dry-Extractive Systems

Description of Action	Status	Rata	7-Day Drift	Cycle Time	Linearity Check	Cal Error Test	RT 556
Permanently replace NO_x, SO_2, O_2, or CO_2 analyzer with like-kind analyzers	R	X	X		X	X	X
Permanently replace NO_x, SO_2, O_2, or CO_2 analyzer with new analyzer that does not qualify as a like-kind analyzer	R	X	X	X	X	X	X
Change probe dimensions or location	R	X	X	X		X	X
Replace heated umbilical line	R	X	X	X	X	X	X
Change from extractive CEMS to *in situ* CEMS	R	X	X	X	X	X	X
Change from extractive CEMS to dilution CEMS	R	X	X	X	X	X	X
Replace or repair a major analyzer component that may be subject to drift	D		X		X	X	X
Replace or repair a major analyzer component that is not likely to be subject to drift	D				X	X	X
Replace or repair vacuum pump or pressure pump	D			X		X	X
Replace probe (same probe material, dimension, and location)	D				X	X	X
Change probe material	D				X	X	X
Replace or repair minor analyzer component or perform routine analyzer maintenance (as specified in the QA/QC plan)	CE					X	
Replace or repair signal wiring in CEMS shelter	CE					X	
Replace or repair sample tubing in CEMS shelter	CE					X	
Replace or repair moisture removal system (chiller)	CE					X	

Description of Action	Status	Rata	7-Day Drift	Cycle Time	Linearity Check	Cal Error Test	RT 556
Routine probe filter maintenance (for example, clean coarse filter)	CE					X	
Replace probe heater or sample line heaters	CE					X	

Notes: D = Diagnostic test
R = Recertification event
CE = Calibration error test only

7
CORRECTIVE MAINTENANCE—TROUBLESHOOTING

Corrective action is performed when the CEM system or part of the system fails. This may also be termed corrective maintenance or non-routine maintenance or work. A failure of the system may just occur; it may be uncovered during an operation check or while conducing routine maintenance; or it may be discovered during a performance audit. When there is a breakdown in the operation of the system, the data becomes questionable, and the monitoring system is considered “unavailable” for providing quality assured data.

A CEM system should be reliable after it has been installed and certified. The CEM system supplier will probably offer guarantees and warranties, but if system failures are frequent after certification, the system may have some fundamental design problems or factors unique to the installation that may be affecting its performance. The application dependence of CEM systems is not always appreciated by either vendors or users. Aggressive CEM system salesmen or their regional reps may sell monitors and systems indiscriminately in order to increase sales and commissions. Or, through corporate policies or agreements with an architectural/engineering (A&E) firm, a plant may be forced to buy monitoring systems from a stipulated vendor without a proper technical evaluation. It is also common to purchase CEM systems by “word-of-mouth”: by networking with friends and colleagues and then settling on the same type of system that everyone else has bought. As a result, the system may not be fit for use after its installation. It may have barely passed certification, but its subsequent performance will not be what was expected.

Key Technical Point

If system failures are frequent after certification, the system may have some fundamental design problems or factors unique to the installation that may be affecting its performance.

Examples of such problem CEM systems are probe-type dilution systems installed on cycling units, *in situ* systems installed on stacks or ducts having high flue gas temperatures or corrosive liquids, or source-level extractive systems that are not designed to handle high concentrations of sticky particulate matter in a condensing flue gas stream. Through over 30 years of CEM system development, most of the mistakes have already been made, and experienced CEM system integrators can design systems for even the most difficult applications. It is when a CEM program becomes too rushed, when proper engineering evaluations are not made or are prevented, that the best possible system and vendor for the application is not chosen. An improperly specified system can then become a maintenance nightmare and a project suitable for the “maintenance hero.”

It is best to start off with a good system that operates well and requires only preventive maintenance until it begins to age. Here, “age” can be a relative term. High temperature, corrosive flue gases, or dirty corrosive ambient conditions can rapidly age a system. The replacement of filters, probes, valves, and other system components may be more frequent than in easier applications, but such replacements can be handled readily in a routine, orderly preventive maintenance program. If the preventive maintenance is not performed, then corrective maintenance must be done when the system fails.

Of course, a part or component can break down as a matter of chance or because of some unexpected external event such as a power surge from a lightning strike. A circuit board failure, a software glitch, or a lamp failure may just happen and is often dependent upon the quality of the system components, over which the CEM system integrator may have little control. Such problems often occur within the first year of operation and may still be within a warranty period, whereupon they can be resolved with the vendor's assistance. Random events from external sources can occur at any time and are often the least expected. Although a stack mounted *in situ* may be prone to lightning strikes, insulators and lightning arrestors may help to resolve the problem in the future. However, the slip of a welder's torch on an umbilical line, a break in the stack liner, or bricks falling from the stack onto the probe (all of these have happened) can seldom be anticipated. Such external events must be dealt with as they occur.

To summarize, the causes that lead to corrective maintenance are in Table 7-1.

Table 7-1
Causes of Corrective Maintenance

Typical Failure Causes
Inadequate initial system design
System/component aging
Preventive maintenance not conducted
Random events: • Component failures • External events

When a system or component failure is not immediately obvious, it can be difficult to correct. The instrument manuals provided by instrument manufacturers often include a troubleshooting guide that may be useful in resolving an instrument problem. However, the operation and maintenance manuals provided by the CEM systems integrators are usually little help in resolving systems problems. Either they are written generically and do not address the installed system except for the engineering drawings in the back or they merely state the obvious, without enough detailed guidance to find the root of the problem. It is in such cases that the experience and skill of the CEM technician becomes most important.

There are two approaches to resolving a CEM system problem. One is to do a quick fix and hope that it goes away. The other is to find the root cause of the problem and resolve it.

7.1 The Quick Fix

A quick fix can be made to many system malfunctions without resolving their cause. In order to save time, the more expedient action is taken. For example, when a quality control limit for drift is exceeded, it is often quite simple to recalibrate an analyzer and hope that the problem goes away. If the drift was caused by a change in temperature or barometric pressure, there may not be a drift excursion the next day, but there may be one the next week. Here, the effect of the problem is fixed but not the problem itself. If the drift of an analyzer was caused by a failing lamp or detector, the analyzer might drift more the next day. The analyzer could again be recalibrated but will eventually fail. When the same failure repeats, its cause has not been removed.

As another example, a filter might tend to plug frequently. Sample flow decreases and a maintenance alarm registers in the control room. The filter is replaced and the system works well until it plugs again. A filter replacement once every six months may be considered reasonable (depending upon the cost of the filter), but a filter replacement every week may not be reasonable when one considers both the cost of the filter and the time that it takes to replace it.

Approaching system and analyzer problems by performing quick fixes can lead to the toleration of the fix as the normal way to maintain the system. The maintenance problem is not so much prevented as accommodated as the normal mode of operation of the system, without ever determining the cause of the problem. The maintenance hero repeatedly comes to the rescue, but the I&C supervisor will complain about how much maintenance CEM systems require.

7.2 Finding the Root Cause

A more efficient approach to system or analyzer problems is to find the “root cause” of the problem and to fix the problem. Finding the underlying weakness in the system may require some detective work or research, but once identified and eliminated, the problem should not reoccur. Identifying a root cause requires familiarity with a system and how it operates. It requires knowledge of instrumentation systems and some common sense in relating an effect with a cause. After becoming frustrated with the lack of guidance in the system or instrument troubleshooting guides, the real work of identifying the cause often begins.

When analysis leads to desperation, the most common strategy is to begin replacing parts. The circuit board shuffle is a technique that can be successful in narrowing down the failing component, but replacing parts can be expensive if it is not done systematically. Many companies purchase spare analyzers, so for major instrument problems, the spare can verify if the analyzer is indeed the problem and, if so, can temporarily replace the failed monitor while it is either serviced or sent back to the manufacturer for repair.

But one of the major causes of system or instrument failure is that of inadequate initial design, as listed in Table 7-1. The root cause may be a bad system to begin with or a monitor that should never have been installed for the application. More often than not, the technician knows this but can do little about it if management is unwilling to expend the effort and funds to redo the system. Frequently, technicians have to service poorly designed or antiquated equipment for ten years or more until financial justifications are strong enough to upgrade the system. The issue becomes a balance between technician time and materials expenses and new capital equipment costs. The matter of pride also enters into such a problem—those who made the original engineering assessment and purchase decision may be unwilling to admit that they made a mistake and would rather that efforts be made to work with the equipment than to replace it.

Key Human Performance Point

The matter of pride also enters into such a problem—those who made the original engineering assessment and purchase decision may be unwilling to admit that they made a mistake and would rather that efforts be made to work with the equipment than to replace it.

The search for the root cause of instrument failures is somewhat easier today with the internal diagnostic techniques in microprocessor-based analyzers. Internal parameters can be readily accessed and trending routines can sometimes be used to look backward on a developing component failure. The use of trend plots and correlation techniques can also be helpful. If a performance trend is correlated with ambient conditions, plant operations, the instrument air supply, or other variables entering into the system operation, progress can be made in identifying the root cause or, at least, eliminating possibilities.

For problems that are not resolved on their first occurrence, documenting the event thoroughly can assist in finding the problem later. Trends or correlations may develop data and information is accumulated. Particularly for multifaceted or hidden causes, it may take time to acquire the information necessary to link a cause to an effect. Table 7-2 provides a form that can be used to track such observations and/or remind one of the conditions of previous malfunction events.

Table 7-2
Corrective Maintenance Input Form

Corrective Action Form (Optional)

Unit__________________**Analyzer**_______________________**Date**_______________

Time Action Initiated________________**Time Action Completed**__________________

Report Prepared By:____

Describe the problem
Diagram

Describe the corrective action performed.	
What do you think is the cause of the problem? (The Root Cause)	
How can QA/QC procedures be changed so this does not happen again?	
Estimated Costs:	
Parts/Supplies	

7.4 Troubleshooting

Troubleshooting tables or diagrams are provided for most monitoring instruments and vary in their level of detail. Some merely indicate the potential source of a problem but provide little guidance for repairs, recommending replacement instead. Microprocessors used in many of today's analyzers allow one to sequence through numbers of diagnostic steps to help identify more precisely the potential cause of a problem. Troubleshooting guides provided by systems integrators for monitoring systems are often more schematic. System integrators build systems but do not operate them on a long-term basis. Many problems are application dependent, which are resolved on a case-by-case basis. Certain problems may occur infrequently, and it does not give a good impression for a client to open a new operations and maintenance manual and see 50 pages of things that can go wrong with the system. Systems integrators are therefore reluctant to assemble a detailed troubleshooting section and provide it in their guidance.

Some problems are generic to the type of system. The following tables provide an overview of possible causes for monitoring problems that require corrective maintenance. Because of the wide variety of systems, specific details of actual repair procedures are not given, but these can be found in the instrument manuals for systems; however, these details may have to be worked out while consulting with the system manufacturer.

Table 7-3
Troubleshooting—Source-Level Extractive Systems

Problem	Cause	Short Term Action	Long Term Action
No or low sample flow	Plugged probe/umbilical	Find and remove plug. Increase blow-back frequency. Check/replace gaskets/O-rings	Change filter size, flow rate, modify sampling system
	Failed or failing pump	Replace/Recondition pump	Change pump
Unusual decrease in emission readings	Leaks	Leak test, find and remove leak.	Change from negative to positive pressure system
	Water entrainment	Acidify gas stream or condensate	Change water removal method
	Gas adsorption on walls	Clean sample lines. Increase sample flow rate	Change sample line size, and/or materials
	Precipitates on probe, scrub or react with gas to be measured		Change to dilution or *in situ* system
Condensation in Sample line	Sample line temperature too low	Increase sample line temperature, check/ replace controller. Add knock-out jar.	Replace, upgrade sample line

Table 7-4
Troubleshooting—Dilution Extractive Systems

Problem	Cause	Short Term Action	Long Term Action
Readings change with atmospheric pressure changes	Critical orifice dependence on pressure	Recalibrate at current pressure	Install pressure transducer—incorporate correction algorithm into DAHS. Or install pressure compensation device
Readings change when unit cycles or flue temperature changes	Critical orifice dependence on temperature	Recalibrate at current temperature	Monitor flue gas temperature. Incorporate correction algorithm in DAHS. Change from in-stack dilution to out-of-stack dilution probe

Problem	Cause	Short Term Action	Long Term Action
Cannot pass linearity checks	Critical orifice dependence on sample gas molecular weight	Calculate molecular weight corrections	Buy new cal. and audit gases—preferably triple-blends with about the same CO_2 conc.
Abnormally high readings	Dilution air contaminated	Check system using zero quality air cylinder gas—change filters, scrubbers, towers of air-cleanup system	Modify dilution air-cleanup system. Install pre-chiller to remove plant air H20. Do not use plant air; use instrument air, or install separate compressor.
Erratic readings	Variable dilution air pressure	Recalibrate	Change to better quality pressure regulator or install mass flow controller. Add surge tank to dilution air supply
No sample flow	Plugged orifice from water scrubber droplets or particulate	Clean/change orifice	Change from in-stack dilution probe to out-of-stack probe
Cannot calibrate analyzers–no more pot. on scale	Over-compensated for dilution air pressure changes in instrument calibration	Calibrate CO_2 analyzer at the instrument using 3000 ppm (or other) gas. Adjust dilution air pressure to correspond	Change dilution air pressure regulator.

Table 7-5
Troubleshooting—Extractive Systems Analyzers

Problem	Cause	Short Term Action	Long Term Action
Fails calibration drift/error repeatedly	Sensitive to ambient pressure changes	Recalibrate	Replace with pressure compensated analyzer
	Sensitive to ambient temperature changes	Recalibrate	Improve shelter heating/air conditioning system
Fails calibration when too many people in shelter	Sensitive to ambient air concentrations (CO_2)	Keep people out of room. Blow clean air into instrument	Purchase new analyzer with enclosed cell.
Fails RATA but passes calibration and linearities/GGA	Subject to interferences by other gases		Monitor other gases and correct. Scrub out interfering gases. Buy an analyzer not subject to interferences

Problem	Cause	Short Term Action	Long Term Action
Noisy signals/inconsistent readings	Failing lamp or detector	Replace in kind.	Replace with components having longer lifetimes
Erratic calibration error (drift) results	Fluctuating gas flow rates	Recalibrate	Maintain consistency in calibration gas flow rates.
	Dirt collected on optics		
	P and T fluctuations		
	Failing ozonator (NO_x analyzers)		
	Lamp/detector failure		
	Plugged capillary		
	Failing sample pump		

Table 7-6
Troubleshooting—*In Situ* Point Systems

Problem	Cause	Short Term Action	Long Term Action
Slow response to changes in flue gas concentrations	Blinding of probe filter	Clean or replace filter	Change probe design, incorporate blowback system.
Difficulty in calibrating with cal. gases or passing cylinder gas audits	Variable overpressure of gas in probe; improper, variable gas injection flow rate	Maintain pressure at setpoint when checking with cylinder gas	
Readings change with weather	Barometric pressure effects	Recalibrate at new pressure	Install/replace pressure transducer. Apply pressure correction.
Readings change with flue gas temperature	Faulty temperature correction device or board	Disconnect, monitor with separate thermocouple, and correct readings	Replace thermocouple or board. Send back to manufacturer for repair or upgrade
Will not calibrate	Internal gas calibration cell leaks	Replace cell.	Install probe that can use calibration gases.
Failed RATA/Audit/ Calibration	Optics misaligned—loosened by stack vibration	Repair—send back to manufacturer.	Stand-off transceiver from duct/stack

Problem	Cause	Short Term Action	Long Term Action
Suddenly Inoperative	Lightning strike	Replace boards/return to manufacturer	Ground stack, insulate transceiver from stack, install lightning arrestors

Table 7-7
Troubleshooting—*In Situ* Path Systems (Gas Analyzers)

Problem	Cause	Short Term Action	Long Term Action
Will not calibrate	Internal gas calibration cell leaks	Replace cell.	Install probe that can use calibration gases.
Readings change with weather	Barometric pressure effects	Recalibrate at new pressure	Install/replace pressure transducer Apply pressure correction
Readings change with flue gas temperature	Faulty temperature correction device or board	Disconnect, monitor with separate thermocouple and correct readings	Replace thermocouple or board. Send back to manufacturer for repair or upgrade
Failed RATA	Optics misaligned—loosened by stack vibration	Repair—send back to manufacturer.	Stand-off transceiver/retroreflector from duct/stack
Noisy signal	Not enough light returning from retro—dirty windows	Clean windows, change blower filters	Increase blower air supply. Change blower system
	Circuit boards, components loose due to vibration	Repair—send back to manufacturer	Stand-off transceiver/retroreflector from duct/stack
Fried	Lightning strike	Replace boards/return to manufacturer	Ground stack, insulate transceiver from stack, install lightning arrestors

Table 7-8
Troubleshooting—Calibration Gases and Gas Handling System

Problem	Cause	Short Term Action	Long Term Action
Fail linearity test and/or Calibration error test	Inaccurate calibration/linearity gases	Replace gas with another cylinder	Choose different gas supplier
	Calibrating with single-blend/auditing with triple-blend or vice versa	Correct for MW	Use triple-blend gases both for calibration and auditing
	Moisture in cal. gas lines	Clean lines with 80% isopropanol	Clean lines periodically with 80% isopropanol
	Condensing of CO_2 at temperatures < 0°F (< -17.8°C)	Warm cylinder and repeat	Move cylinder to heated shelter.
	Gas cylinder pressure low < 150 psi (< 1034 kPa)	Change cylinder	Track gas cylinder pressures at least weekly. Write SOP to replace cylinders at < 150 psi (< 1034 kPa).

Table 7-9
Troubleshooting—Opacity Monitors

Problem	Cause	Short Term Action	Long Term Action
High Opacity readings	Closed shutter	Re-set the shutter/ensure that it opens and closes freely/Check shutter alarm	
	Purge air blower failure	Repair blower/check blower hoses & clamps/ Clean windows/Replace blower filters	Replace blower bearings/replace blower
	Retro-reflector misalignment	Check alignment/realign	For severe misalignment problems, support transceiver and retro separately from stack.
	Water droplets in path		Eliminate source of droplets/Relocate monitor
Erratic behavior	Electronic problems	Correct as required. For defective circuit boards—replace	Upgrade to an ASTM D6216 compliant system.

Table 7-10
Troubleshooting—Flow Monitors

Problem	Cause	Short Term Action	Long Term Action
High velocity compared with heat input calculations	Bias from Method 2 calibration of flow monitor	Redo same calibration	Recalibrate using Test Methods 2F or 2G and 2H. Research and remove other positive biases. Add flow straighteners
Diminished/erratic response	Dirt on sensor, probe plugging	Clean probe or sensor	Modify purge air system to accommodate particulate load

Table 7-11
Troubleshooting—Data Acquisition Systems

Problem	Cause	Short Term Action	Long Term Action
DAHS data inconsistent when evaluated independently	Input signals to DAHS from controller, analyzers, etc. are distorted	Repair/replace faulty components	Replace DAHS vendor or upgrade to software more suitable for the purpose.
	Controller and DAHS clocks not synchronized	Fix mismatch	
	Rounding errors	Change programming	
	User-configurable parameters incorrect	Correct and re-enter	
	Incorrect equations	Change programming	
	User-configurable parameters incorrect	Reconfigure	
	Programming routines incorrect	Reprogram	
	Improper correction algorithms, for example: 1. Automated zero/span corrections 2. Flow-monitor calibration incorrect 3. Faulty P/T corrections 4. Incorrect BAF	Reprogram/reconfigure or delete correction routine	

7.5 Corrective Maintenance and the Good System

A "good" CEM system can be defined as one that was purchased at reasonable cost, has low operating costs, and when a systematic program of preventive maintenance is followed, will generate quality data that meets the expectations of both the plant and regulatory agency. With "good" systems, troubleshooting techniques for that particular system may be applied only infrequently, and the system should run for years before requiring corrective maintenance as the parts begin to age.

However, with a system that needs little attention, the vigilance necessary to sense impending malfunctions or inconsistencies in the data may begin to decline. The process of evaluation, looking for potential problems or factors that might impact the system performance, may give way to other plant responsibilities until a problem is detected in a performance audit. Training in the operation and maintenance of the system may also be forgotten if years elapse before a specific repair or adjustment becomes necessary. Another problem with "good" systems is that they can raise expectations to the level where it is felt that the capability for performing "corrective" maintenance is not necessary in-house. The technician staff may be reduced and reliance placed on outside servicemen to repair the system.

In situ monitors provide an example. A pollutant gas *in situ* monitor usually consists of a brightly colored box installed on a stack or duct, with a cable running down to a control unit and the data acquisition system. The workings of the instrument are often not well understood because of the complex nature of the electro-optic techniques applied, and daily calibration is commonly performed using an internal optical or gas filter rather than independent calibration gases. Such instruments usually exhibit very little zero or span drift and because there are few other performance indicators (such as pressure, vacuum, or flow gauges, as are common in extractive systems), it is assumed that the instrument is working well as long as there are no diagnostic alarms. This is the dream of the engineering staff—a CEM system that sits on the stack, runs, and provides the necessary data. Such instruments may receive little attention because there is no need to provide any.

However, problems can occur that cannot be detected by the internal calibration technique or the sophisticated diagnostics programs in the microprocessor. The retroreflector may become misaligned because of stack temperature fluctuations, the probe may become blinded by scrubber slurry, the pressure and temperature compensation may become compromised, or the internal optics may become misaligned. Also, because little attention is necessary, preventive maintenance procedures may be postponed or forgotten altogether. For example, failure to replace *in situ* monitor blower filters is one of the most common lapses in many preventive maintenance programs.

Regardless of the day-to-day performance of a monitoring system, it still remains the responsibility of the technician to interpret the performance of the instrument and ensure that the information it provides is reliable. Discipline in assessing data quality is necessary in both good times and bad times. The maintenance "hero" may not have time to assess data, but a "caretaker" for a "good" system may become complacent in such assessments. No matter how well the system works, the technician is still accountable for the data quality.

8
DOCUMENTING WORK

Documentation of work performed on an analyzer or monitoring system is important in the development and continuance of a preventive maintenance program. When malfunctions occur and problems are resolved, writing down what happened and what was done may avoid having to repeat the troubleshooting process if the problem reoccurs. Documenting preventive maintenance activities may, in some cases, seem trivial, but a notation that a filter was cleaned but not replaced, or that a nut was tightened because of a suspected leak, may be an important clue to future problems. Beyond the practical aspects of documenting work, CEM system data reported to a regulatory agency must be defensible. If an EPA inspector should conduct an audit of the CEM system quality assurance program, a focus of the audit may be how malfunctions that resulted in missing data were resolved. The system documentation should be sufficient to reconstruct any such events.

8.1 The CEM System Logbook

The CEM system logbook serves as a historical record for actions performed on the system. Malfunctions, maintenance problems, and system changes or replacements should all be noted. If something out of the ordinary occurs, such as a recalibration of a monitor or switching out a calibration gas cylinder, the activity should be noted and the reason why the activity was conducted should be recorded. Preventive maintenance and performance audit activities should all be documented, providing confirmation that procedures specified in the quality assurance manual have indeed been performed. The logbook is a diary about the life of a CEM system. Logbook entries should be made in a fashion such that any event that affected the system could be reconstructed from information. The logbook is a key factor in supporting the defensibility of the CEM system data, because it provides justification for activities during missing data periods and the verification that quality control procedures have been performed. A typical logbook entry should include the following:

- Date
- A statement of the problem or action
- A discussion of activities performed
- A discussion of possible causes of the problem (if possible or appropriate)
- Actions suggested to prevent a reoccurrence of the problem
- Signature or initials

It is not necessary to rewrite into the logbook information that is documented elsewhere, such as daily inspection forms, daily calibration drift printouts, or other activities that are understood to be routine. However, major scheduled activities, such as linearity tests and RATAs, that are documented in separate reports should be addressed in the logbook by entering at least the time and date of the activity and any special observations on the performance of the test that may not be included in the report.

Logbooks should be in the form of a bound ledger with numbered pages. Three ring notebooks or spiral binders allow pages to be lost or torn out without accountability and are not appropriate. Although some may differ, computers are also not appropriate for this activity. It may be easier to enter information into a PC, but computer files are easily changed, misfiled, or destroyed. Frequently, the only person with access to the files, without difficulty, is the one who entered them, thus shutting out information from other technicians, auditors, or management.

Entries into the logbook should be made as soon as possible or while the activity is being performed. When there are many maintenance requests during the day, the tendency is to procrastinate and get back to it when more time is available. That time may be the next day or next week and as memory fades, the entries tend to perfunctory, less complete, and less accurate. Logbook documentation does not have to be written in perfect English, nor does neatness count. It is a waste of time to write down comments somewhere else and then write them neatly in the logbook. However, entries should be made in ink and pages should never be torn out; otherwise, there may be concern on the part of an auditor that there is something to hide. If a chart or graph is available from the DAHS that may support the description of the work, it is acceptable to paste it into the logbook.

Although most people do not like to write, when given proper direction and encouragement by management, technicians will accept the importance of the activity and provide descriptions of their actions, sometimes even to excess detail. A technician who has taken “ownership” of the CEM system will be the most likely to do this; however, when he or she is on vacation or if other technicians rotate through the CEM responsibilities, documentation becomes erratic. Invariably, a malfunction will occur, the problem will be resolved, and the logbook will have a brief entry that “the monitor was repaired.” To provide a consistent record, alternate technicians should be trained also in proper documentation techniques and should be further advised when entries do not contain sufficient information.

The key points in maintaining the logbook are:

- Maintenance events should be able to be reconstructed from logbook entries.
- Documentation for any unscheduled activity should be entered into the logbook.
- Any preventive maintenance activities conducted should be documented in the logbook (even if already listed on maintenance request forms).
- Parts replacements, system modifications, and controller or DAHS hardware or software revisions should be documented.
- Times and dates for conducting major scheduled activities (linearity tests, RATAs) documented elsewhere should be entered into the logbook.

8.2 The Quality Assurance Manual

The quality assurance manual gives the company's policy toward the operation and maintenance of the CEM system. It includes a description of the CEM system and sets forth both the quality control and quality assurance procedures necessary to ensure that quality data are generated from the system. The quality control procedures, usually presented as standard operating procedures (SOPs), give the operating steps that are conducted daily, and throughout the year to ensure that quality data are generated by the system. Appendix F of 40 CFR 60 and Appendix B of 40 CFR 75 require that a minimum set of quality control procedures be developed and implement by the plan. Quality control procedures specified include the following:

1. Procedures for the determination of calibration drift/error and linearity
2. Methods used for the adjustment of calibration drift/error and linearity
3. Preventive maintenance procedures
4. Data recording, calculation, and reporting procedures
5. Corrective action procedure for malfunctioning systems
6. Procedures for conducting performance audits

The quality assurance manual will typically include the quality assurance plan, which discusses the quality assurance policies and objectives; the QA requirements of the agency; and the policies that are instituted to implement them. The manual will also include the quality control procedures (standard operating procedures) that will be performed so that the data will meet the quality assurance objectives stated in the plan. Table 8-1 provides an example of a typical quality assurance manual table of contents.

Table 8-1
Typical Quality Assurance Manual Table of Contents

TABLE OF CONTENTS
System Description
Quality Assurance Plan
Quality Policy and Objectives

Document Control System
    Organization and Responsibilities
    Quality Control—Calibration
    Quality Control—Preventive Maintenance
    Quality Assurance—Performance Evaluations
    Quality Control—Records and Reports

Standard Operating Procedures

TABLE OF CONTENTS

8.2.1 Records

Records on analyzer and system operation and maintenance are typically kept either in three-ring binders or file cabinets so that they may be available for review. Records that are usually retained include the following:

- Daily calibration report
- Daily checklist
- Preventive maintenance documentation
- CEM system logbooks

8.2.2 Manuals

Manuals provided originally with the system should be kept either in the CEM shelter or instrument shop. Manuals can include:

- System/analyzer/DAHS operation
- Maintenance manuals

8.2.3 Reports

Reports submitted to the agency will typically include the following:

- Linearity Test (Cylinder Gas Audit)
- Opacity Monitor Quarterly Audit
- Relative Accuracy Test Audit

- Electronic Data Report
- Excess Emission Report

The Electronic Data Report is generated by the DAHS. The report includes information required by 40 CFR 75.50. These data can include:

- Hourly average SO_2 concentration
- Hourly average SO_2 emission rate
- Hourly average NO_x concentration
- Hourly average NO_x emission rate
- Hourly average CO_2 concentration
- Percent monitoring system data availability
- Hourly average CO_2 mass emissions

These data are incorporated automatically into an EDR report by the DAHS. Unit operating data and quality control data are also included in the report.

Quality assurance performance data obtained during the quarter are also submitted into the EDR (see 40 CFR 75.52). This information includes:

- Daily calibration error test results
- Quarterly linearity test results
- RATA and bias test data and results

The results of these QA performance tests are entered either automatically (for example, calibration error test data) or manually (for example, RATA results) into the DAHS database.

8.2.4 Excess Emission Reports

Excess emission reports (EERs) are required to be submitted quarterly or semi-annually through the requirements of 40 CFR 60.7. Excess emission reports may be required for both opacity and pollutant gas emissions. The excess emission reports include the following:

- Unit information
- Magnitude of excess emissions and date and time of periods of excess emissions; process operating time
- Specific identification of each period of excess emissions—nature and cause of malfunctions
- CEM system downtime—nature of system repairs and adjustments

9
CEM SYSTEM OBSOLESCENCE

In many companies, there exists a tendency not to admit that monitoring systems can become obsolete. The maintenance department or instrument shop has a job to do, which is to maintain equipment and keep the plant running. This is typically done admirably; otherwise, the plant or company would have difficulty in meeting its production goals or financial objectives. But, as systems age, more and more resources must be devoted to maintaining equipment. Parts age and need to be replaced, and maintenance demands imperceptibly increase. Or the original vendor of the equipment is bought out by a competitor, who, in turn, wants to either upgrade the product or eliminate the competition totally and discontinues the production and distribution of parts necessary to maintain previous systems. In any of these scenarios, a point is eventually reached where frustrations levels rise so high that it is better to call the equipment obsolete and replace it.

9.1 Aging Systems

Aging systems can be a source of frustration, but they can still operate well and meet data quality requirements. Maintenance levels may increase and every component in the system may have been replaced, but instrument technicians are familiar with the equipment, know all of the problem areas, and are able to repair malfunctions without undue loss of system availability. The root causes for practically all malfunctions are known, so repairs are executed efficiently without having to plod through the detective work that is often necessary to determine what went wrong.

A case in point is the Dupont UV photometric SO_2 analyzer marketed in the late 1960s. This hot-wet system used an air aspirator eductor to draw sample through a heated cell, through which a UV light beam passed to effect the measurement. Good for measurements in the range of 1000 ppm, it was popular in the electric utilities and copper smelters and was once regarded as the “Cadillac” of CEM systems. An example of spare, efficient plumbing, every part could be easily replaced, and most parts were available on the commercial market, until the demise of vacuum tubes. Some systems were operating into the 1990s until it became necessary to measure at lower concentrations and caches of vacuum tubes were used up. Although solid-state upgrade packages became available, the original vendor had since moved on and no longer supported the product.

Key O&M Cost Point

When it becomes necessary to dedicate full-time technicians to the maintenance of a CEM system, it is time to consider changing the system.

Although a classic product in CEM systems, the Dupont analyzer reached a point where its operation could no longer be sustained. Other systems have reached that point more quickly. When it becomes necessary to dedicate full-time technicians to the maintenance of a CEM system, it is time to consider changing the system. The analogy of the CEM system and the car is again appropriate. Old cars may be kept and maintained for sentimental, financial, or other reasons. But at some point, the time necessary to keep the car running, the difficulty in finding replacement parts, and the absence of modern features either relegates the car to the antique car show circuit or the junkyard.

Key O&M Cost Point

Ten years is considered a reasonable service lifetime for most CEM systems.

Ten years is considered a reasonable service lifetime for most CEM systems. Even if the system maintenance demands become excessive after five years, most companies are unwilling to admit their initial failure in purchasing an adequate system, but they also need to depreciate the cost of the equipment over a suitable number of years. Dedicated technicians can operate and maintain practically any system to meet regulated performance specifications and availability requirements, the problem is that the level of effort necessary to do so may not be appreciated or sustained by the plant or company. When there are too many alarms from too many systems, technicians do not have the time to perform necessary preventive maintenance or the root cause analysis necessary to minimize the continuing demands for corrective maintenance.

The lack of vendor support over a sustained period is one of the key reasons why older systems begin to be replaced. The system may be working well, maintained consistently, and have few malfunctions, but without a supply of spare parts and occasional service support, the continued operation of the system may become untenable. Various strategies can be used to extend lifetimes, if desired. Spare parts can be stockpiled, or like-for-like parts might be available from other vendors. Parts can also be cannibalized from analyzers either purchased or acquired from plants where they have since been replaced. Good technicians are quite resourceful and are often able to get several more years of operation from systems that are no longer supported by their manufacturer.

The passage of time may age a monitoring system, but with time, the original parameters under which the system was installed may change. For example, the promulgation of the Part 75 Acid Rain CEM requirements led to the wholesale replacement of CEM systems in the electric utilities. The more stringent monitoring specifications and extensive reporting requirements provided enough justification to replace most existing systems. But the net result of the Acid Rain Program was to reduce SO_2 emissions, primarily through the use of low sulfur coal. Correspondingly, flue gas SO_2 concentrations decreased significantly from their levels in the 1970s and 1980s when most of the existing equipment was purchased. Although many of the existing systems could have been upgraded to meet the new regulatory and technical challenges, the prevailing sentiment within the utility monitoring community was to purchase new systems.

As a note, changes in technology and regulation can sometimes take extreme turns. NO_x emissions levels and emission limits in the 1-5 ppm range for gas turbines have strained the capability of many CEM systems vendors. In such cases, both the system design and analyzer technology have to be considered anew to make honest measurements at these levels.

9.2 System Upgrades

Most vendors seek to upgrade their products after they have had a reasonable commercial run. If they do not upgrade, competition will nevertheless force them into improving their products. Vendors in the U.S. frequently become complacent with systems designs and analyzer specifications required either explicitly or implicitly by U.S. regulations. Competition from Europe and Japan periodically brings awareness that there are other ways of monitoring flue gas concentrations than those generally accepted in the U.S. and U.S. companies will sometimes upgrade their analyzers or systems accordingly.

The U.S. CEM rules emphasize the daily check of instrument and system performance using calibration gases that are traceable to NIST standard reference materials. Theoretically, U.S. CEM system data are comparable from plant to plant or State-to-State, because they are all calibrated to the same standard reference materials. In Europe, however, more emphasis is placed upon the CEM system's correlation to the reference methods. Data are viewed as being comparable from plant to plant if the systems have all been certified with respect to the appropriate reference method. Calibration checks with calibration gases are not required daily, and the use of internal calibration filters or cells are allowed (as they still are in Part 60). Also, in Germany, calibration adjustments were not required until the "maintenance interval," which might be a week, a month, or several months, as determined by testing conducted under the direction of the environmental ministry. As a result of these European requirements, CEM system analyzers have been built to be stable, incorporating self-correcting diagnostic routines using the outputs from the internal calibration techniques to minimize drift and noise. The switch from analog to microprocessor based digital instruments occurred in the 1990s and was paralleled by similar developments in the U.S.

The advent of microprocessor-based instruments was one of the biggest advances in CEM systems in the 1990s (the maturation of dilution systems and development of diode laser systems were others). Because of the internal diagnostics capabilities and the ability to connect with a PC, LAN, or WAN, these analyzers have become popular for CEM system upgrades when monies become available in the annual plant budget. Such upgrades have been incremental, occurring to eliminate original "lemons" from the system or to reduce the frequency of maintenance in the system.

Advances in dilution system technology, particularly new designs for out-of-stack dilution systems, allowed the application of the technology for units where the use of the in-stack probe was marginal, such as after wet scrubbers, high temperature sources, and cycling units. These upgrades were not a result of the original equipment necessarily being "obsolete," but because designs came on the market that were better suited for specific applications.

The problem comes, however, when the plant is satisfied with the original system, but the original vendor has passed him by. The upgrades, the new analyzers or systems, become more commercially viable and the older products are discontinued. The expected 10-year life cycle now becomes difficult to meet as parts become unavailable and service support dwindles. A heavier burden is now placed on the technician, who must be able to troubleshoot and repair the system without expectation of assistance from the manufacturer. In addition, the search for spare parts becomes a treasure hunt.

9.3 Abandoned/Discontinued Systems

CEM systems and their components can be discontinued purposely by their manufacturer or made obsolete by changes in rules and reporting requirements.

9.3.1 Vendor-Caused Obsolescence

Systems or analyzers can be discontinued through developments within the company, as previously discussed, or through abandonment. Abandonment occurs when the manufacturer abruptly discontinues a product line. This most typically occurs when the company is sold and the new owner assesses which products are viable and which are not. If there are no orders pending and the marketing personnel and reps from the former company have been released, there is little possibility that there will be future sales of the product.

The company may have been purchased for the express purpose of eliminating a competitor, in which case efforts will be made to cut losses as much as possible from the purchase. Inventory will be sold, the manufacturing facilities and office will be moved to discourage employee retention, and only key personnel will be retained (for a year) to reconcile issues between former customers and the new owners. As a result, support for the system will diminish rapidly after the first year and after that, the system can be considered obsolete.

There are, however, two remedies to extend the lifetime of obsolete systems. One, as mentioned, when upgraded systems supplant existing systems, is to develop skills within the plant to maintain the system. The other is to contract a consultant to assist in the maintenance of the system. Because the system was discontinued, many of the personnel involved in the manufacture and servicing of the system or instrument will not be invited to join the new company. The best of such personnel will often survey former customers and find that they can form an independent company to provide maintenance and repair services for the existing systems. Knowing former clients, they can acquire parts inventories, analyzers, and system components when they become available through new system purchases. By cannibalizing discarded equipment, parts can be made available for continuing users. To be profitable, these consults tend to be local, centered typically in either the Northeast or California, establishing service contracts with several companies to provide a core for their business.

9.3.2 Regulatory-Caused Obsolescence

Product obsolescence can also be caused by a change in regulatory policies or requirements. The promulgation of Appendix F (40 CFR 60) and Part 75 had the greatest impact on CEM systems since the original performance specifications were published in 1975.

Promulgated in 1987, Appendix F required the use of certified gas to conduct quarterly cylinder gas audits (CGA). Although path *in situ* monitors could still be audited using an abbreviated RATA, the so-called “Relative Accuracy Audit (RAA),” this was used as a selling point against the technology because conducting an RAA is still more expensive than a CGA. In addition, problems in maintaining misapplied path monitoring systems led to the discounting of this technology by the electric utility industry as a viable monitoring option. Although the U.S. was once the leader in the development of *in situ* systems, it declined by acquisition and abandonment, aggressive competition, and the demands of Appendix F. The Part 75 requirements placed even more emphasis on the use of cylinder gases in the daily calibration error and quarterly linearity tests. As a result, path *in situ* monitoring systems in the U.S. rapidly became obsolete.

However, in the 1990s, European firms came back with new versions of path and point *in situ* monitors, which were commercially successful in Europe, Asia, and Canada, where options to conducting cylinder gas audit or linearity tests are provided. In fact, today over 50% of the CEM systems installed in Canada for monitoring gases are *in situ* systems. Path *in situ* tunable diode laser systems are widely regarded as one of the best methods for monitoring NH_3, whereas there is little question with regard to their ability to measure hydrogen fluoride in aluminum refineries.

Changes in the EPA reporting requirements have affected the developments of CEM system software. This software was remarkably primitive prior to 1993 because the CEM business in the late 1980s was static, and resources were not available to upgrade software. The Clean Air Act of 1990 changed that, and with influx of orders for Part 75 CEM systems, new software was developed for both Part 60 and Part 75 systems. The Part 75 mandated electronic data report formats were, however, complicated, and much of the software developed was discarded rather rapidly as it failed to meet either user’s needs or Part 75 requirements. Surviving software had to be updated approximately every two years as EDR formats changed resulting in the obsolescence of the previous versions.

From the demise of *in situ* path monitoring systems to the advances of CEM software, regulations have diminished or enhanced the marketing of monitoring products. Part 75 popularized dilution systems and flow monitors, while discouraging *in situ* monitors and PEMS. The form of a rule, either in a permit or in CFR regulation, always has some impact on CEM system design. For this reason, plant engineers must keep up-to-date on new requirements and specifications to assess their effect on current instrumentation and their implications for future monitoring.

9.4 Summary

From the discussion in the section, it is apparent that there are various avenues by which a CEM system or its components and subsystems can become obsolete. Some of these can be anticipated—system aging or the availability of upgrades will typically lead to replacements with new equipment. But obsolescence can also be unexpected. The product line may be discontinued or the rules can change where the measurement or reporting methods no longer meet the requirements of the agency. Table 9-1 summarizes conditions where monitoring systems or analyzers may be replaced.

Table 9-1
Warning Signs for System/Equipment Obsolescence

System/Equipment Obsolescence	Warning Signs of Failure
Aging Systems	Increasing maintenance demands Lack of vendor support Difficulty in finding parts No longer applicable for original purpose
System Upgrades	Upgrade replaces earlier systems Notice given when parts no longer manufactured Servicemen not trained in previous products
Abandoned/Discontinued Systems	Competitor purchases original company: – Upgrades system without support of old system – Eliminates product line to reduce competition with own products Regulations/reporting requirements change

A
REFERENCES AND BIBLIOGRAPHY

A.1 References

1. U.S. EPA. 2003a. *Subpart A General Provisions.* Code of Federal Regulations—Protection of the Environment—Standards of Performance for New Stationary Sources—General Provisions: Subpart A. 40 CFR 60 Subpart A.

2. *Continuous Emission Monitoring Guidelines–2002 Update.* EPRI, Palo Alto, CA: 2002. 1004179.

3. Jahnke, J.A. 1994. *An Operator's Guide to Eliminating Bias in CEM Systems*. U.S. EPA. EPA 430-R-94-016, November 1994.

4. McNulty, K.J., McCoy, J.F., Becker, J.H., Ehrenfeld, J.R. and Goldsmith R.L. (1974). Investigation of Extractive Sampling Interface Parameters, EPA-650/2-74-089. Washington, D. C.

5. U.S. EPA. 2003g. NO_x Mass Emissions Provisions. Acid Rain Program: Part 75—Continuous Emission Monitoring. 40 CFR 75 Subpart H.

6. U.S. EPA. 2003i. Quality Assurance and Quality Control Procedures. Acid Rain Program: Part 75—Continuous Emission Monitoring. 40 CFR 75 Appendix B.

7. U.S. EPA. 2003k. Optional NO_x Emissions Estimation Protocol for Gas-fired Peaking Units and Oil-fired Peaking Units. Acid Rain Program: Part 75—Continuous Emission Monitoring. 40 CFR 75 Appendix E.

8. ASTM. 2003. Annual Book of ASTM Standards 2003. Atmospheric Analysis. Volume 11.03. American Society for Testing and Materials. West Conshohocken, PA.

9. U.S. EPA. 2003d. *Appendix B Performance Specifications-Performance Specification 1—Specifications and Test Procedures for Opacity Continuous Emission Monitoring Systems in Stationary Sources*. . Code of Federal Regulations-Protection of the Environment. Standards of Performance for New Stationary Sources 40 CFR 60 Appendix B.

10. U.S. EPA. 2003h. Specifications and Test Procedures. Acid Rain Program: Part 75—Continuous Emission Monitoring. 40 CFR 75 Appendix A.

11. U.S. EPA. 2003b. *Appendix A Test Methods.* Code of Federal Regulations—Protection of the Environment. Standards of Performance for New Stationary Sources. 40 CFR 60 Appendix A.

12. U.S. EPA. 2003j. Optional SO_2 Emissions Data Protocol for Gas-fired and Oil-fired Units. Acid Rain Program: Part 75—Continuous Emission Monitoring. 40 CFR 75 Appendix D.

13. U.S. EPA. 2003f. Monitoring Provisions. Acid Rain Program: Part 75—Continuous Emission Monitoring. 40 CFR 75 Subpart B.

14. U.S. EPA. 2003e. *Appendix F Quality Assurance Procedures.* Code of Federal Regulations—Protection of the Environment. Standards of Performance for New Stationary Sources 40 CFR 60 Appendix F.

15. U.S. EPA. 2003c. *Appendix B Performance Specifications*. Code of Federal Regulations—Protection of the Environment. Standards of Performance for New Stationary Sources. 40 CFR 60 Appendix B.

16. U.S. EPA. 1997.*EPA Traceability Protocol for Assay and Certification of Gaseous Calibration Standards*., EPA-600/R-97/121

17. Petersen, D.G., Jendzurski, T, and Bernard, A. 1994. Capacitance: Redefineing Maintenance. Chemical Engineering . August 1994. pp76-82

18. Idhammer,C. 1997. Strive for Maintenance without Waste. Chemical Engineering. November 1997 pp 163-171,

19. Jahnke, J.A. 2000. *Continuous Emission Monitoring Systems—Second Editon*. John Wiley & Sons. New York.

A.2 Bibliography

Acklin, M.W., McCullough, and Tolk, J.D. 1995. Utility Engineering's experience in the design, equipment selection, and operation of CEMS for utilities. In *Proceedings—Acid Rain & Electric Utilities—Permits, Allowances, Monitoring, & Meteorology.* Air & Waste Management Association, Pittsburgh. pp. 190-198.

Allen, J.D., Billingsley, J., and Shaw, J.T. 1974. Evaluation of the Measurement of Oxides of Nitrogen in Combustion Products by the Chemiluminescence Method. *J. Institute of Fuel.* 12:275-280.

Appel, D. 1994. *Calibration of Dilution Extractive Systems.* Thermo Environmental Instruments, Inc. Guideline.

Baugham, L. 1996. Active control of Dilution Probes. In *Proceedings—Continuous Compliance Monitoring Under the Clean Air Act Amendments.* Air and Waste Management Association, Pittsburgh. pp. 154-161.

Bensink, Beachler, D., and Joseph, J. 1995. Certification of Flow Monitors for Utility Boilers. In *Proceedings—Acid Rain & Electric Utilities-Permits, Allowances, Monitoring, & Meteorology.* Air & Waste Management Association, Pittsburgh. pp. 222-230.

Bergshoeff, G. and van Ijssel, F.W. 1978. Monitoring Gases—A New Stack Sampler: Parts 1 & 2. *International Environment & Safety.* March 1978:32-34, June 1978:134-16.

Bloomer, B. J. and Winkler, J. P. 1995. The Quality Assurance Manual and EPA's Acid Rain Data Quality. In *Proceedings—Acid Rain & Electric Utilities—Permits, Allowances, Monitoring, & Meteorology.* Air & Waste Management Association, Pittsburgh. pp. 610-621.

Brooks, E.F., Beder, E.C., Flegal, C.A., Luciani, D.J., and Williams, R. 1975. *Continuous Measurement of Total Gas Flow rate from Stationary Sources.* EPA 650/2-75-020.

Brooks, E.F. and Williams, R.L. 1976. *Flow and Gas Sampling Manual.* EPA-600/2-76-203.

Brouwers, H.J. and Verdoorn, A.J. 1990. A Simple and Low Cost Dilution System for *In Situ* Sample Conditioning of Stack Gases. *Proceedings—Specialty Conference on: Continuous Emission Monitoring—Present and Future Applications.* Air and Waste Mgmt. Assoc. pp. 380-389.

Carlyle, T. E. 1995. Quality Assurance Plans for Continuous Emission Monitoring Systems: Compliance with 40 CFR 75. In *Proceedings—Acid Rain & Electric Utilities-Permits, Allowances, Monitoring, & Meteorology.* Air & Waste Management Association, Pittsburgh. pp. 589-593.

Cashin, M.G., Love, J.E., and Miller, J.D. 1996. Resolving the Difference—Mass balance vs CEM air emission estimates. Paper presented at the EPRI CEM Users Group Meeting, Kansas City, May 8-10, 1996. Electric Power Research Institute, Palo Alto.

Clough, P.N., and Thrush,, B.A. 1967. Mechanism of Chemiluminescent Reaction Between Nitric Oxide and Ozone. Faraday Soc. 63:915-925.

Cohen, J.B. and Ross, R.C. 1989. Use of Precalibrated Optical Density Filters in the *In situ* Calibration of Opacity Monitors. *Air Poll. Control Assoc. Meeting Paper.* Montreal: 80-42.4.

Dvorak, K.J. 1996. How to Develop a Quality Assurance/Quality Control Manual. Paper presented at the Air & Waste Management Association Meeting, Nashville TN. Paper 96-WP67.01.

Continuous Emission Monitoring Guidelines: Update. EPRI, Palo Alto, CA: 1988. *CS-5988.*

Continuous Emission Monitoring Guidelines: Update EPRI, Palo Alto, CA: 1993. TR-102386-V1.

Continuous Emission Monitoring Guidelines: Update. EPRI, Palo Alto, CA: 1993. TR-102386-V2.

Ellis, H. M., Plante, V., and Arruda, C. 1996. Successful Service Support Strategies for 40CFR75 CEM Systems. In *Proceedings—Continuous Compliance Monitoring Under the Clean Air Act Amendments.* Air and Waste Management Association, Pittsburgh. pp. 132-142.

Environmental Protection Agency. 1976 (1/9/84 update). *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume I—Principles.* EPA 600/9-76-005.

Environmental Protection Agency. 1977. (11/5/85 update). Calculations and Interpretation of Accuracy for Continuous Emission Monitoring Systems (CEMS). *Section 3.0.7. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II—Ambient Air specific Methods.* EPA 600/4-77-027a.

Environmental Protection Agency. 1977. (6/1/86 update). Continuous Emission Monitoring (CEM) Systems Good Operating Practices. *Section 3.0.9. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III—Stationary Source Specific Methods.* EPA 600/4-77-027b.

Environmental Protection Agency. 1977. (6/9/87 update). Procedure for NBS-Traceable Certification of Compressed Gas Working Standards Used for Calibration and Audit of Continuous Source Emission Monitors (Revised Traceability Protocol No. 1). *Section 3.0.4. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III—Stationary Source Specific Methods.* EPA 600/4-77-027b.

Environmental Protection Agency. 1977. (11/26/85 update). Guideline for Developing Quality Control Procedures for Gaseous Continuous Emission Monitoring Systems. *Section 3.0.10. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III—Stationary Source Specific Methods.* EPA 600/4-77-027b

Environmental Protection Agency. 1982. *Performance Audit Procedures for SO_2, NO_x, CO_2, and O_2 Continuous Emission Monitors.* CEM Report Series No. 5-371-7/82. EPA Division of Stationary Source Enforcement.

Environmental Protection Agency. 1983. Standard of Performance for New Stationary Sources; Performance Specification 1. 40 FR 46259 October 6, 1975.

Environmental Protection Agency. 2003. Part 75 CEMS Field Audit Manual. Clean Air Markets Division. Washington, D.C.

Farber, P.S. 1995. Options for gas flow measurement. Environmental Protection. January 1995. pp 15-18.

Potential Pitfalls in Using Multi-Component EPA Protocol Mixtures. CEM Users Group Meeting. Flaherty, E. Bartel, D., Zaicow, T., Grant, D. Electric Power Research Institute. Palo Alto, CA: May 1998.

Frank, H. and Mullowney, R. 1990. Recycling Ambient Monitors as Stack Gas Monitors at Dairyland Power. *Proceedings-Specialty Conference on: Continuous Emission Monitoring—Present and Future Applications.* Air and Waste Mgmt. Assoc. pp. 390-392.

Gschwandtner, G. and Winkler, J.P. 1997. Effective Auditing of CEM Systems. In proceedings of *Acid Rain & Electric Utilities II*-Scottsdale, AZ. Air & Waste Management Association. Pittsburgh. pp. 781-796.

Hamil, H.F. 1980. *The Development of Performance Audit Devices for Optical Transmissometers.* Unpublished. EPA contract 68-02-2489. EPA Quality Assurance Division, RTP, NC 27711. Draft Final Report.

Heyman, G.A., and Turner, G.S. 1976. Some Considerations in Determining Oxides of Nitrogen in Stack Gases by Chemiluminescence Analyzers. *Air Poll. Control Assoc. Meeting Paper.* San Francisco: 76-13.8.

Hughes, E.E. 1981. Certified Reference Materials for Continuous Emission Monitoring. *Proceedings-Continuous Emission Monitoring: Design, Operation and Experience.* Air Poll. Control Assoc. pp. 187-196.

Hughes, E. and Mandel, J. 1981. *A Procedure for Establishing Traceability of Gas Mixtures to Certain National Bureau of Standards Standard Reference Materials.* EPA-600/7-81-010.

Jahnke, J.A., Cheney, J.L., and Homolya, J.B., 1976. "Quenching Effects in SO_2 Fluorescence Monitoring Instruments," *Environmental Sci. and Technology,* 10:1246-1250.

Jahnke, J. A. 1984. *Transmissometer Systems—Operation and Maintenance, An Advanced Course. APTI Course 476A.* EPA-450-84-004.

Jahnke, J.A. 2000. *Continuous Emission Monitoring Systems-Second Editon.* John Wiley & Sons. New York.

Jahnke, J.A. 1994. *An Operator's Guide to Eliminating Bias in CEM Systems.* U.S. EPA. EPA 430-R-94-016, November 1994.

Jahnke, J.A. and Marshall, R.P. 1994. *Pressure and Temperature Effects in Dilution Extractive Continuous Emission Monitoring Systems.* Electric Power Research Institute. Palo Alto, CA. Report TR-104700.

Jahnke, J. A. 1995. Eliminating Bias in CEM Systems. In *Proceedings—Acid Rain & Electric Utilities—Permits, Allowances, Monitoring, & Meteorology.* Air & Waste Management Association, Pittsburgh. pp. 391-400.

Jahnke, J.A. and Peeler, J.W. 1997. *A Handbook for Continuous Emissions Monitoring Systems for Non-Criteria Pollutants.* Environmental Protection Agency. Center for Environmental Research Information. Cincinnati, OH. EPA/625/R-97/001.

James, R.E. 1979. Quality Assurance of Data from SO_2 and NO_x Monitors Required by EPA New Source Performance Standards. *Proceedings—Specialty Conference on: Quality Assurance in Air Pollution Measurement.* Air Poll. Control Assoc. pp. 419-429.

Jernigan, J. R. 1993. Three-dimensional Flow Profile Measurements for Ascertaining Acceptable Flow Rate Monitor Installation Locations. In *Proceedings—Continuous Emission Monitoring-A Technology for the 90s.* Air and Waste Management Association, Pittsburgh. pp. 397-413.

Kearney, B. 1995. Penelec Experience with flue gas flow vs heat rate. Paper presented at Electric Power Research Institute CEM Workshop, Atlanta, GA. Electric Power Research Institute, Palo Alto.

Laird, J.C., Patton, J.C., Zolner, W.J., and Tomlin, R.L. 1978. Unique Extractive Stack Sampling System for Continuous Emission Monitoring. *Instrument Society of America. Meeting Paper.* Houston.

Lieberman, E. and Schakenbach, J. 1997. The flow measurement puzzle—Putting the pieces together. In *Proceedings—Acid Rain & Electric Utilities II.* Air & Waste Management Association, Pittsburgh. pp. 313-322.

Lieberman, E. 1998. Improving Today's CEMS—Flow monitoring example—U.S. EPA's field and lab studies of volumetric flow reference method. *Proceedings-CEM 98 International Workshop on Continuous Emissions Monitoring.* IEA Coal Research. London. pp. 193-207.

Logan, T.J. and Midgett, M.R. 1979. Quality Assurance Programs to Support the Use of Continuous Emission Monitors for Direct Compliance. *Proceedings-Specialty Conference on: Quality Assurance in Air Pollution Measurement.* Air Poll. Control Assoc. pp. 413-418.

Luft, K.F., Kesseler, G., and Zorner. 1967. *Non-dispersive Infrared Gas Analysis with the Unor Analyzer.* Chemie-Ingenieur-Technik. 29(16):937-952.

Lynnworth, L.C., Matson, J.E., Bradshaw, K.A., Hal, S.A., Jacobson, P.G., Kucmas, R.J., Murphy, T.H., Nguyen, T.H., and Talcherkar, N.S. 1992. *Point, Line and Area-Averaging Ultrasonic Flow Measurements in Ducts and Stacks.* Paper presented at the EPRI/ASME Heat Rate Improvement Conference, Birmingham, November 17-19,1992.

Maurice, R.L., Robertson, J.A., and Howder, J.M. 1986. Design, Specification, and Installation of a Replacement CEM at Apache Station. *Transactions-Continuous Emission Monitoring-Advances and Issues.* Air Poll. Control Assoc. pp. 44-51.

McGowan, G.F. 1994. *A Review of CEM Measurement Techniques.* Paper presented at Northern Rocky Mountain ISA Conference. ISA May 1994.

The Electric Power Research Institute Continuous Emissions Monitoring Heat Rate Discrepancy Project. What Has Been Learned and Future Activities. McRanie, R.D., Norfleet, S.K., and Dene, D.E.. EPRI CEM Users Group Meeting. Electric Power Research Institute. Palo Alto,CA: 1997.

McRanie, R.D., Norfleet, S.K., and Dene, C.E. 1997. The Electric Power Research Institute Continuous Emissions Monitoring heat rate discrepancy project—An update report. In

Proceedings—Acid Rain & Electric Utilities II. Air & Waste Management Association, Pittsburgh. pp. 351-363.

Certification and Utilization of Multicomponent EPA Protocol Gases. Miller, S.B. Paper presented at EPRI CEM Users Group Meeting, Minneapolis, MN. Electric Power Research Institute, Palo Alto, CA: April 1994.

Munukutla, S.S. 1992. *Theory-Based Evaluation of Pressure, Temperature and Density Effects on the Operation of the Dilution Probe.* Unpublished Preliminary Report. EPRI.

Myers, R.L. 1986. Field Experiences Using Dilution Probe Techniques for Continuous Source Emission Monitoring. *Transactions-Continuous Emission Monitoring-Advances and Issues.* Air Poll. Control Assoc. pp. 431-439.

Myers, R.L., Gaffron, G., and Traina, J.E. 1997. Verification procedure following repairs or upgrades of flow monitors without the need for RATA testing. In *Proceedings—Acid Rain & Electric Utilities II.* Air & Waste Management Association, Pittsburgh. pp. 769-780.

Myers, R.L. and Traina, J.E. 1997. Completely automated methods for 40CFR 75 audits including capability for yaw compensation -- Early field test results. Paper presented at the Air& Waste Management Association Meeting. Toronto. Paper No. 97-MP7.02

Myers, R.L. and Traina, J.E. 1997. Completely automated methods for 40 CFR 75 audits including capability for yaw compensation -- early field test results. In *Proceedings—Acid Rain & Electric Utilities II.* Air & Waste Management Association, Pittsburgh. pp. 340-350.

Norfleet, S.K., Muzio, l.J., and Martz, T.D. 1997 An examination of bias in Method 2 measurements under controlled non-axial flow conditions. In *Proceedings—Acid Rain & Electric Utilities II.* Air & Waste Management Association, Pittsburgh. pp. 328-339.

An Evaluation of Wall Effects on Stack Flow Velocities and Related Overestimation Bias in EPA's Stack Flow Reference Methods. Norfleet, S.K. EPRI CEM Users Group Meeting—New Orleans. Electric Power Research Institute. Palo Alto, CA: 1998.

Nguyen, K.T., Alexander, T.H., and Dupree, J.C. 1997. *Acid Rain Program CEM Auditing Program*. In proceedings of Acid Rain & Electric Utilities II—Scottsdale, AZ. Air & Waste Management Association. Pittsburgh. pp 753-756.

Okabe, H., Splitstone, P.L., and Ball, J.J., 1973. *Ambient and Source SO_2 Detection Based on a Fluorescence Method.* J. of the Air Poll. Control Assoc. 23:514-516.

Oldaker, G.B., Rosenquest, J.M., and Purcell, R.Y. 1981. Quality Assurance Evaluation of Transmissometers. *Proceedings—Specialty Conference on: Continuous Emission Monitoring-Design, Operation, and Experience.* Air Poll. Control Assoc. pp 285-292.

Passmore, J.G. and Brodmerkle, S.L. 1991. *A Systematic Approach to the Selection and Installation of Continuous Emissions Monitoring Systems.* Paper presented at the Power-Gen 1991 Conference, Tampa FL, December, 1991.

Peeler, J.W. 1986. *Recommended Quality Assurance Procedures for Opacity Continuous Emission Monitoring Systems.* EPA-340/1-86-010.

Peeler, J.W. 1986. *CEMS Pilot Project: Evaluation of Opacity CEMS Reliability and QA Procedures Volume I.* EPA-340/1-86-009a.

Peeler, J.W. 1986. *CEMS Pilot Project: Evaluation of Opacity CEMS Reliability and QA Procedures—Volume II (Appendices).* EPA-340/1-86-009b.

Peeler, J.W., Fox, V.L., and Plaisance, S.J. 1988. *Inspection Guide for Opacity Continuous Emission Monitoring Systems.* EPA-340/1-88-002.

Plaisance, S.J., 1988. *Advances in Opacity CEMS Performance Auditing.* Air Poll. Control Assoc. Meeting Paper. Dallas: 88-137.7.

Purcell, R.Y. and Rosenquest, J.M. 1982. *Field Performance Audit Procedures for Opacity Monitors.* Environmental Protection Agency CEM Report Series No. 5-271-7.

Reynolds, W.E. 1984. *Development and Evaluation of* SO_2 *CEM QA Procedures. Quality Assurance in Air Pollution Measurements.* Air Poll. Control Assoc./American Soc. for Quality Control. Pittsburgh. pp. 752-760.

Reynolds, W.E. 1989. *Field Inspector's Audit Techniques: Gas CEMS's Which Accept Calibration Gases.* U.S. Environmental Protection Agency. EPA/340/1-89-003.

Sanders, D.C. 1996. *Part 75 Continuous Emission Monitoring System Quality Assurance Audit Results-Issues Observed within the Utility Industry.* Paper presented at the Air & Waste Management Association Meeting, Nashville, TN. Paper 96-WP67.04.

Schakenbach, J. T. Lieberman, E.R., Etchison, T., and Warren-Hicks, W. J. 1995. Observations and Hypotheses Regarding Combined SO_2-Flow Relative Accuracies Calculated from Part 75 Phase I Certification and Simulated Data. In *Proceedings—Acid Rain & Electric Utilities—Permits, Allowances, Monitoring, & Meteorology.* Air & Waste Management Association, Pittsburgh. pp. 210-221.

Scott, N. E. 1995. The Care and Feeding of Your CEMS. In *Proceedings—Acid Rain & Electric Utilities—Permits, Allowances, Monitoring, & Meteorology.* Air & Waste Management Association, Pittsburgh. pp. 594-601.

Shattuck, D.M. 1998. *Auditing Part 75 CEMS*. Paper presented at the Air & Waste Management Association Meeting, San Diego, CA. Paper 98-WP81.02.

Shea, T.D. 1993. Continuous Compliance/Monitoring of Opacity: Method 203 Example Test Method for Sate Implementation Plans. In *Proceeding—Continuous Emission Monitoring—A Technology for the 90s.* Publication SP-85. Air & Waste Management Association. Pittsburgh. pp 89-95.

Sherman, R.E. 2002. *Process Analyzer Sample-Conditioning System Technology.* John Wiley & Sons, New York.

Sneek, E. 1997. Optimization of Continuous Emission Monitoring of NO_x and SO_2. In: *Proceedings—International Workshop on Continuous Emissions Monitoring (CEM97).* IEA Coal Research, London. pp. 87-99.

Tidona, R.J. 1988. *Reducing Interference Effects in the Chemiluminescent Measurement of Nitric Oxides from Combustion Systems.* J. Air & Waste Mgmt. Assoc. 38: 806-811.

Ueda, S. and Watanabe, A. 1978. *The Nondispersive Infrared (NDIR) Analyzer with Improved Selectivity and Sensitivity for Pollutants Measurement*. Air Poll. Control Assoc. Meeting Paper. Houston: 78-25.6.

Vogelsang, R.F. 1987. *Second Generation-Analyzer Cross Flow Modulation Techniques-Precision, Sensitive, Continuous Measurements*. Instrument Society of America. Meeting Paper. 87-1091.

Whitaker, C. 1996. Human Factors of Continuous Compliance: CEM Data and Beyond. *In Proceedings—Continuous Compliance Monitoring Under the Clean Air Act Amendments.* Air and Waste Management Association, Pittsburgh. pp 49-56.

Walker, K. 1996. Select a Continuous Emissions Monitoring System. Chemical Engineering Progress. February 1996. pp 28-34.

Whitaker, CH. 1996. Assuring Quality Data from CEM Systems. Paper presented at the Air & Waste Management Association Meeting. Nashville, TN. Paper 96-WP67.02.

Whitaker, C. 1999. Time Requirements for Quality Assuring CEMS Data. In Proceedings of *Electric Utilities Environmental Conference.* Tucson, AZ.

White, J.R. 1995. *Survey Your Options: Continuous Emissions Monitoring*. Environmental Engineering World. July-August 1995. pp 6-10.

White, J.R. 1995. *Technologies for Enhanced Monitoring.*

Pollution Engineering. June 1995. pp 47-50.

Winkler, J., DuPree. J. and Gschwandtner, G. 1999. *Elements of an Effective QA Program*. In proceedings of Electric Utilities Environmental Conference. Tucson, AZ.

Wohlschlegel, P. 1976. *Guidelines for Development of a Quality Assurance Program-Volume XV-Determination of Sulfur Dioxide Emissions from Stationary Sources by Continuous Monitors.* EPA 650/4-74-005o.

B
GLOSSARY

Acid rain—a byproduct of air *pollution* produced when acid chemicals are incorporated into rain, snow, fog or mist. The "acid" in acid rain comes from sulfur oxides and *nitrogen* oxides, products of burning coal and other fuels and from certain industrial.

Administrator—the Administrator of the EPA or the Administrator's duly authorized representative.

Allowance—an authorization by the Administrator under the Acid Rain Program to emit up to one ton of SO_2 during or after a specified calendar year.

Authorized representative–the person responsible for the emissions at a particular facility.

Calibration gas—a gas used as a referenced material (traceable to NIST) for checking performance of continuous emission monitors.

Carbon monoxide (CO)—a colorless, odorless, poisonous gas produced by incomplete burning of carbon-based fuels, including gasoline, oil, and wood. Carbon monoxide is also produced from incomplete *combustion* of many natural and synthetic products.

Clean Air Act—the original Clean Air Act was passed in 1963, but U.S. national air pollution control program is actually based on the 1970 version of the law. The 1990 Clean Air Act Amendments are the most far-reaching revisions of the 1970 law.

***Continuous emission monitoring systems* (CEMS)**—machines which measure, on a continuous basis, *pollutants* released by a *source*. The 1990 *Clean Air Act* requires continuous emission monitoring systems for certain large sources.

Control technology; control measures—equipment, processes, or actions used to reduce air pollution. The extent of pollution reduction varies among technologies and measures. In general, control technologies and measures that do the best job of reducing pollution will be required in the areas with the worst pollution.

Criteria air pollutants—a group of very common air *pollutants* regulated by EPA on the basis of criteria (information on health and/or environmental effects of pollution). Criteria air pollutants are widely distributed all over the country.

Dessicant dryer—a device that removes moisture from the air by exposing humid air to an adsorbent material. This process can be a passive or active process.

Emission—release of *pollutants* into the air from a *source*.

Enforcement—the legal methods used to make polluters obey the *Clean Air Act*. Enforcement methods include citations of polluters for violations of the law, fines, and even jail terms. The EPA and the state and local governments are responsible for enforcement of the *Clean Air Act*, but if they do not enforce the law, members of the public can sue EPA or the states to get action.

Fossil fuel—any fuel derived from products such as petroleum, coal, or natural gas that is burned to produce power.

***Material safety data sheets* (MSDS)**—product safety information sheets prepared by manufacturers and marketers of products containing toxic chemicals. These sheets can be obtained by requesting them from the manufacturer or marketer. Some stores, such as hardware stores, may have material safety data sheets on hand for products they sell.

***Monitoring* (monitor)** measurement of air *pollution* is referred to as monitoring. The EPA, state, and local agencies measure the types and amounts of pollutants in community air. The 1990 *Clean Air Act* requires certain large polluters to perform enhanced monitoring to provide an accurate picture of their pollutant releases. Continuous emission monitoring systems will measure, on a continuous basis, how much pollution is being released into the air.

NESHAP—National Emission Standard for Hazardous Air Pollutants (NESHAP) is a technology-based standard of performance prescribed for hazardous air pollutants from certain stationary source categories under Section 112 of the Clean Air Act.

***New source review* (NSR)**—new major stationary sources of air pollution and major modifications to major stationary sources are required by the Clean Air Act to obtain an air pollution permit before commencing construction. This process is called new source review (NSR) and is required whether the major source or modification is planned for an area where the national ambient air quality standards (NAAQS) are exceeded (nonattainment areas) or an area where air quality is acceptable (attainment and unclassifiable areas). Permits for sources in attainment areas are referred to as prevention of significant air quality deterioration (PSD) permits, while permits for sources located in nonattainment areas (NAA) are referred to as nonattainment permits. The entire program, including both PSD and NAA permit reviews, is referred to as the NSR program.

***Nitrogen oxides* (NO_x)**—nitrogen oxides are produced from burning fuels, including gasoline and coal. Nitrogen oxides react with volatile organic compounds to form smog. Nitrogen oxides are also major components of acid rain.

Opacity—the degree to which emissions reduce the transmission of lights and obscure the view of an object in the background.

Ozone—a gas that is a variant of oxygen. The oxygen gas found in the air consists of two oxygen atoms stuck together; this is molecular oxygen. Ozone consists of three oxygen atoms stuck together into an ozone molecule. Ozone occurs in nature; it produces the sharp smell you notice near a lightning strike. High concentrations of ozone gas are found in a layer of the atmosphere (the *stratosphere)* high above the Earth. Stratospheric ozone shields the Earth against harmful rays from the sun, particularly *ultraviolet B*. *Smog's* main component is ozone. Ground-level ozone is a product of reactions among chemicals produced by burning coal, gasoline and other fuels, and chemicals found in products including solvents, paints, hairsprays, and similar products.

Particulates particulate matter **(PM-10)**—a *criteria air pollutant*. Particulate matter includes dust, soot, and other tiny bits of solid materials that are released into and move around in the air. Particulates are produced by many sources, including burning of diesel fuels by trucks and buses; incineration of garbage; mixing and application of fertilizers and pesticides; road construction; industrial processes such as steel making, mining operations, agricultural burning (field and slash burning); and operation of fireplaces and woodstoves. Particulate pollution can cause eye, nose, and throat irritation and other health problems.

Peltier cooler**—**thermoelectric coolers are solid-state heat pumps used in applications where temperature stabilization, temperature cycling, or cooling below ambient are required. These devices are based on the Peltier Effect, discovered in 1834, by which dc current applied across two dissimilar materials causes a temperature differential.

Peristaltic pump**—**pump in which fluid is forced along by waves of contraction produced mechanically on flexible tubing. The peristaltic pumping principle is based on the capacity of a soft elastomer tube to accept a deformation and subsequently recover its initial shape. The flow obtained is a function of the tube bore and the pump rotational speed.

Permeation dryer**—**a membrane type dryer that uses selective permeation, which allows water vapor to permeate the membrane wall while not allowing nitrogen and oxygen to pass through the wall. The permeated water and a sufficient amount of air (to retain the water as vapor) are vented to the atmosphere outside of the cylinder.

Permit**—**a document that resembles a license, required by the *Clean Air Act* for big (major) sources of air pollution, such as power plants, chemical factories, and, in some cases, smaller polluters. Usually permits will be given out by states, but if the EPA has disapproved part or all of a state permit program, the EPA will give out the permits in that state. Permits will have, in one place, information on all the regulated pollutants at a source. Permits include information on which pollutants are being released, how much the source is allowed to release, and the program that will be used to meet pollutant release requirements. Permits are required both for the operation of plants (operating permits) and for the construction of new plants.

Pollutants **(pollution)—**unwanted chemicals or other materials found in the air. Pollutants can harm health, the environment, and property. Many air pollutants occur as gases or vapors, but some are very tiny solid particles: dust, smoke, or soot.

Smog**—**a mixture of *pollutants*, principally ground-level *ozone*, produced by chemical reactions in the air involving smog-forming chemicals.

***State implementation plan* (SIP)—**a detailed description of the programs a state will use to carry out its responsibilities under the *Clean Air Act*. State implementation plans are collections of the regulations used by a state to reduce air *pollution*. The Clean Air Act requires that EPA approve each state implementation plan. Members of the public are given opportunities to participate in review and approval of state implementation plans.

***Stationary source*—**a place or object from which *pollutants* are released and that does not move around. Stationary sources include power plants, gas stations, incinerators, houses, and so on.

***Sulfur dioxide*—**sulfur dioxide is a gas produced by burning coal, most notably in power plants. Some industrial processes, such as production of paper and smelting of metals, produce sulfur dioxide. Sulfur dioxide is closely related to sulfuric acid, a strong acid. Sulfur dioxide plays an important role in the production of *acid rain*.

***Thermoelectric coolers*—**see Peltier coolers

***Volatile organic compounds* (VOCs)—**organic chemicals all contain the element carbon (C); organic chemicals are the basic chemicals found in living things and in products derived from living things, such as coal, petroleum, and refined petroleum products. *Volatile* chemicals produce *vapors* readily; at room temperature and normal atmospheric pressure, vapors escape easily from volatile liquid chemicals. Many volatile organic chemicals are also *hazardous air pollutants*; for example, benzene causes cancer.

C ACRONYMS

AAR	Authorized Account Representative
ASTM	American Society for Testing and Materials
BAF	Bias Adjustment Factor
CD	Calibration Drift
CE	Calibration Error
CEM	Continuous Emission Monitor
CEMS	Continuous Emission Monitoring System
CFR	Code of Federal Regulations
CGA	Cylinder Gas Audit
CMMS	Computer Maintenance Management System
COMS	Continuous Opacity Monitoring System
CRM	Certified Reference Material
DAHS	Data Acquisition and Handling System
DAS	Data Acquisition System
DR	Designated Representative
EDR	Electronic Data Report
EER	Excess Emission Report
EPA	Environmental Protection Agency
EPM	(Logo for the instrument company, EPM, Inc.)

EPRI	Electric Power Research Institute
FID	Flame Ionization Detector
FR	Federal Register
GCV	Gross Calorific Value
GHR	Gross Heat Rate
GMIS	Gas Manufacturer's Intermediate Standard
HI	Heat Input
I&C	Instrument and Controls
LAN	Local Area Network
MACT	Maximum Achievable Control Technology
MDC	Monitor Data Checking
MEC	Maximum Expected Concentration
MPC	Maximum Potential Concentration
MR	Maintenance Request
MSDS	Material Safety Data Sheet
NAA	Nonattainment Area
NAAQS	National Ambient Air Quality Standards
NDIR	Non Dispersive Infrared
NDUV	Non Dispersive Ultraviolet
NESHAP	National Emission Standard for Hazardous Air Pollutants
NIST	National Institute of Standards and Technology
NMI	Netherlands Measurement Institute
NSR	New Source Review
NTRM	NIST Traceable Reference Material

O&M	Operation and Maintenance
PC	Personal Computer
PEMS	Predictive Emission Monitoring System
PM	Preventive Maintenance
PMT	Photomultiplier Tube
PRM	Primary Reference Material
PSD	Prevention of Significant Deterioration
QA	Quality Assurance
QC	Quality Control
RAA	Relative Accuracy Audit
RATA	Relative Accuracy Test Audit
RFP	Request for Proposal
RTU	Remote Terminal Unit
SIP	State Implementation Plan
SRM	Standard Reference Material
TDL	Tunable Diode Laser
TE	Thermo-Electric
UV	Ultraviolet
VOC	Volatile Organic Compound
WAN	Wide Area Network

C.1 Chemicals

CO	carbon monoxide
CO_2	carbon dioxide

HF	hydrogen fluoride
H_2S	hydrogen sulfide
NH_3	ammonia
NO	nitric oxide (nitrogen monoxide)
NO_2	nitrogen dioxide
NO_2*	nitrogen dioxide in an electronically excited state
NO_x	oxides of nitrogen (NO + NO_2)
O_2	oxygen
O_3	ozone
SO_2	sulfur dioxide
SO_2*	sulfur dioxide in an electronically excited state
ZrO_2	zirconium oxide

D

VENDORS OF CEM SYSTEMS AND EQUIPMENT

EXTRACTIVE SYSTEMS VENDORS
VENDORS OF SOURCE-LEVEL EXTRACTIVE SYSTEMS

ABB Inc. 843 N. Jefferson Stret Lewisburg, WV 24901 (304) 647-4358 www.abb.com	CEM Specialties,Inc. 1100 Deerness Drive London, Ontario, Canada N6L 1N9 (514) 681-9595 www.cemsi.on.ca
AIM (Absolytics LLC) 3579 E. Foothills Blvd Pasadena, CA 91107-3119 (626) 791-1912 www.aimanalysis.com	CEMTEK Systems Inc. 2121 South Yale St. Santa Ana, CA 92704 (888) 400-0200 www.cemteks.com
Air-World Environmental, Inc. (A-WE) 15101 NE 21st Ave. North Miami Beach, FL 33162 www.airworldenviro.com	Continuous Emissions Monitoring, Inc. 1318 Bammel Road Houston, TX 77073 (832) 295-1200
Altech (Environnement, S.A.) 2623 Kaneville Court Geneva, IL 60134 (630) 262-4400 www.altechusa.com www.environnement-sa.com	Control Analytics, Inc. 125 Theobold Avenue Greensburg, PA 15601 (800) 240-8619 www.controlanalytics.com
Ametek (Bovar/Western Research) 8 Manning Close,N.E. Calgary, AB Canada T2E 7N5 (403) 235-8300 1-800-661-9198	Custom Instrumentation Services Corporation (CISCO) 7325 South Revere Parkway Englewood, CO 80112 (303) 790-1000 www.ciscocems.com
Ametek/Thermox Process & Analytical Instruments Division 150 Freeport Road Pittsburgh, PA 15238 (412) 828-9040 www.thermox.com	Datatest 6850 Hibbs Lane Levittown, PA 19057 (215) 943-0668 www.datatest-inc.com
Brimstone Instrumentation #8, 1820-30 Avenue N.E. Calgary, AB Canada T2E 7M5 (403) 735-0520 www.brimstone-online.net	Eagle Mountain Scientific, Inc. 820 Commonwealth Drive Warrendale, PA 15086 (724) 742-2060 www.eagle-msi.com

Vendors of CEM Systems and Equipment

Ecochem Analytics (Aldora) 202 Reynolds Ave. League City, TX 77573 (281) 338-9888 www.ecochem.biz	Hull Corporation 3535 Davisville Road Hatboro, PA 19040 (215) 672-7800
Eco Monitoring (ESC) 200 Tech Center Drive Knoxville, TN 37912 (865) 688-7900 www.esc-ecomonitoring.com	Innovative Solutions, Inc. 1254-3 Craven Lane Carpenteria, CA 93013 (805) 644-1099
Fluid Data Inc. 1844 Lansdowne Ave. Merrick, NY 11566 (516) 223-2190	K2BW Environmental Equipment Services Co. 35 North York Road, Suite B Willow Grove PA 19090 (215) 830-8882 www.k2bw.com
Forney Corporation (Columbia Scientific/Anarad) 3405 Wiley Post Road Carrollton, TX 75006 (972) 458-6100 www.forneycorp.com	Land Combustion 10 Friends Lane Newton, PA 18940 (215) 504-8000 www.landinst.com
GE Power Systems KVB-Enertech 2849 Sterling Drive Hatfield, PA 19440 (215) 996-4088 www.gepower.com	Measurement Technologies 3485 Sacramento Drive, Suite F San Luis Obispo, CA (805) 549-0595 http://home.earthlink.net/~measurementtech
Monitoring Solutions 4440 S. High School Road, Suite D Indianapolis, IN 46241 (317) 856-9410 www.monsol.com	Servomex Company, Inc. 90 Kerry Place Norwood, MA 02062 (781) 769-7710 www.servomex.com
Opsis 1165 Linda Vista Drive-Suite112 San Marcos, CA 92069 (760) 752-3005 www.opsis.se	Sick Maihak 6900 West 110th Street Bloomington, MN 55438 (952) 941-6780 www.sickmaihak.com
Pace Envir. Products, Inc. 5240 West Coplay Road Whitehall, PA 18052 (610) 262-3818 www.pacecems.com	Siemens Applied Automation, Inc. P.O. Box 9999 Bartlesville, OK 74005 (918) 662-7000 www.sea.siemens.com
Horiba Instruments Inc. 17671 Armstrong Ave. Irvine, CA 92614 (949) 250-4811 www.environ.hii.horiba.com	Rosemount Analytical (Emerson) 1201 North Main Street Orrville, Ohio 44667 1-800-628-120 www.emersonprocess.com

Teledyne Monitor Labs 76 Inverness Drive East Englewood, CO 80112 (303) 792-3300 www.monitorlabs.com	URS Corporation CEM System Services 1093 Commerce Park Dr. Ste. 100 Oak Ridge, TN 37830-8029 (877) 40-6161 www.urscems.com

DILUTION EXTRACTIVE SYSTEM VENDORS

Altech (Environnement, S.A.) 2623 Kaneville Court Geneva, IL 60134 (630) 262-4400 www.altechusa.com www.environnement-sa.com	Control Solutions 1447-G South Enterprise Springfield, MO 65804 (417) 886-5748
Automated Control Systems (CEM.SYS) 122 Woodburn Drive Dothan, AL 36301 (334) 792-0113 www.automatedcontrolsys.com	Eagle Mountain Scientific, Inc. 820 Commonwealth Drive Warrendale, PA 15086 (724) 742-2060 www.eagle-msi.com
Calibrated Instruments, Inc. 200 Saw Mill River Rd. Hawthorne, NY 10532 (914) 741-5700	Eco Monitoring (ESC) 200 Tech Center Drive Knoxville, TN 37912 (865) 688-7900 www.escdas.com
EMC 171 Sola Drive Gilberts, IL 60136 (708) 426-3331	Phoenix Instruments, Inc. 65 North Plains Industrial Road Wallingford, CT 06492 (203) 269-4331 www.phoenix-instruments.com
Forney Corporation (Columbia Scientific/Anarad/Williams/Kidde) 3405 Wiley Post Road Carrolton, TX 75006-5185 (972) 458-6100 www.forneycorp.com	Spectrum Systems (M&C Box) 3410 West Nine Mile Road Pensacola, FL 32526-7808 (877) 837-6644 www.specsys.com
GE Power Systems KVB-Enertech 2849 Sterling Drive Hatfield, PA 19440 (215) 996-4088 www.gepower.com	Teledyne Monitor Labs 76 Inverness Drive East Englewood, CO 80112 (303) 792-3300 www.monitorlabs.com
Measurement Technologies 3485 Sacramento Drive, Suite F San Luis Obispo, CA 93401 (805) 549-0595 http://home.earthlink.net/~measurementtech	Thermo Environmental Instruments Inc. 27 West Forge Parkway Franklin, MA 02038 (508) 520-0430 www.thermo.com/source
Maxxam Analytics, Inc. (Using Paragon Box) 2021 - 41 Avenue NE Calgary, AB Canada T2E 6P2 (403) 291-3077 www.maxxam.ca	(Note: some stack sampling companies, consultants, and start-ups are now integrating CEM systems - these companies usually provide local or regional services.)
Mechanical Systems, Inc. 480 Progress Way Sun Prarie, WI 53590 (608) 825-2055 www.msicems.com	Opsis 1165 Linda Vista Drive-Suite112 San Marcos, CA 92069 (760) 752-3005 www.opsis.se

Monitoring Solutions 4440 S. High School Road, Suite D Indianapolis, IN 46241 (317) 856-9410 www.monsol.com	

VENDORS OF DILUTION PROBES AND BOXES

M&C Products 1879 Portola Road-Suite G Ventura, CA 93003 (805) 654-6970 www.mac-products.de	Thermo Environmental Instruments Inc. 27 West Forge Parkway Franklin, MA 02038 (508) 520-0430 www.thermo.com/source
Paragon Research, Inc. (Probes) Rt. 1 Box 195 2 Rockyroad Drive Cameron, OK 74932 (918) 654-3002	Universal Analyzers, Inc. 1771 South Sutro Terrace Carson City, NV 89706 (775) 883-2500 www.universalanalyzers.com

VENDORS OF OPACITY MONITORS

Ducon Technologies, Inc. (Mip Oy) 19 Engineer's Lane Farmingdale, NY 11735 (631) 694-1700 www.ducon.com	Rosemount Analytical, Inc. (Emerson) 1201 North Main St. Orrville, OH 44667-9010 (330) 682-9010 www.emersonprocess.com
Durag, Inc. 1970 Christensen Ave. West St. Paul, MN 55118 (651) 451-1710 www. durag.com or www.durag.de	Sick Maihak 6900 West 110th Street Bloomington, MN 55438 (952) 941-6780 www.sickmaihak.com
Environmental Monitor Service, Inc. 380 Main St. Box 4340 Yalesville, CT 06492 (203) 265-0598 www.emsct.com	Spectrum Systems, Inc. 3410 West Nine Mile Road Pensacola, FL 32526 (850) 944-3392 www.specsys.com
Land Combustion 10 Friends Lane Newton, PA 18940 (215) 504-8000 www.landinst.com	Teledyne Monitor Labs (United Sciences) 5310 North Pioneer Road Gibsonia, PA 15044 (412) 443-8610 www.monitorlabs.com
OptoMonitor 270 Polaris Avenue Mountain View, CA 94043 (650) 967-8992 www.optomonitor.com	Thermo Environmental Instruments Inc. 27 West Forge Parkway Franklin, MA 02038 (508) 520-0430 www.thermo.com/source
Phoenix Instruments, Inc. 65 North Plains Industrial Road Wallingford, CT 06492 (203) 269-4331 www.phoenix-instruments.com	

OPACITY JIGS/NEUTRAL DENSITY FILTERS
FILTER CERTIFICATION

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DIGITAL VE OBSERVER CAMERA

Jay Stretch Scientech Ogden, Utah (801) 392-6980	

PARTICULATE MONITOR VENDORS

Altech (Beta Gauge) (Environnement, S.A.) 2623 Kaneville Court Geneva, IL 60134 (630) 262-6220 www.altechusa.com www.environnement-sa.com	Goyen Valve Corporation (Tyco) 1195 Airport Road Lakewood, NJ 08701 (732) 364-7800 www.cleanairsystems.com
Auburn International, Inc. (DC Charge transfer) Eight Electronics Ave. Danvers, MA 01923 (508) 777-2460 www.world.std.com/-auburn	Jonas, Inc. (Impact shock wave) 1113 Faun Road Wilmington, DE 19803 (302) 478-1375 www.mindspring.com/~jonasinc
BHA (Opacity fluctuation) 8800 East 63rd St Kansas City, MO 64133 (816) 356-2400 www.bhagroup.com	Mechanical Systems, Inc. (Beta Gauge) 480 Progress Way Sun Prarie, WI 53590 (608) 825-2055 www.msicems.com
Durag, Inc. (Scattering, Beta Gauge) 1970 Christensen Ave. West St. Paul, MN 55118 (651) 451-1710 www. durag.com or www.durag.de	Norsk Elecktro Optik A/S (Laser) P.O. Box 384 N-1471 Skarer, Norway +47-67-97 4700 +47-67-97 4700 (281) 488-4971 www.neo.no/usa or www.analyzer.com
Environmental Systems Corp. (Back-Scattering) 200 Tech Center Drive Knoxville, TN 37912 (615) 688-7900 www.envirosys.com	PCME Ltd. (AC charge transfer) Andersen Instruments, Inc. 500 Technology Court Smyrna, GA (770) 319-9999 www.pcme.co.uk
Process Metrix, LLC (laser par ticle sizing) 2110 Omega Rd., Ste. D San Ramon, CA 94583 (925) 837-1330 www.processmetrix.com	Sigrist (Extractive Forward-Scattering) Peak Process Controls 17817 Leslie St - Unit 45 New Market, Ontario Canada L3Y 8C6 (905) 830 6835 www.photometer.com
Rupprecht & Patashnick Co., (Oscillator-for source-testing) 25 Corporate Circle Albany, NY 12203 (518) 452-0065	Sintrol OY (Tribolelectric) Karvaamokuja 4 00380 Helsinki Finland +358 9 5617 3664

www.rpco.com	www.sintrol.com
Sick Maihak. (Side-scattering) 6900 West 110th Street Bloomington, MN 55438 (952) 941-6780 www.sickmaihak.com	Teledyne Monitor Labs (Scattering) (United Sciences) 5310 North Pioneer Road Gibsonia, PA 15044 (412) 443-8610 www.monitorlabs.com

IN SITU MONITOR VENDORS
POINT (IN-STACK) POLLUTANT GAS MONITORS

Delta Instrument LLC (Procal) 148 Veterans Drive Northvale, NJ 07647 (201) 768-7200 www.deltainstrument.com	Land Combustion 10 Friends Lane Newton, PA 18940 (215) 504-8000 www.landinst.com
Environmental Monitor Service, Inc. (O_2 only) 380 Main St. Box 4340 Yalesville, CT 06492 (203) 265-0598 www.emsct.com	Opsis 1165 Linda Vista Drive-Suite 112 San Marcos, CA 90206 (619) 752-3005 www.opsis.se
Norsk Elektro Optikk A/S (Laser Monitors) P.O. Box 384 N-1471 Skarer, Norway +47-67-97 4700	Analytical Specialties, Inc. 1030 Hercules Houston, TX 77058 (281) 488-4971 www.analyzer.com
Opsis 1165 Linda Vista Drive-Suite 112 San Marcos, CA 92069 (760) 752-3005 www.opsis.se	Unisearch Associates Inc. (Diode Laser) 96 Bradwick Drive Concord, Ontario L4K 1K8 Canada (905) 669-3547
Sick Maihak. 6900 West 110th Street Bloomington, MN 55438 (952) 941-6780 www.sickmaihak.com	Zirtek Corporation (O_2 only) P.O. Box 539 Dewey, OK 74029 (918) 534-0143
Rosemount Analytical 1201 North Main Street Orrville, Ohio 44667 (216) 682-9010 www.process-analytic,com	Sick Optic-Electronic, Inc. 6900 West 110th Street Bloomington, MN 55438 (612) 941-9287 www.sickoptic.com

PATH POLLUTANT GAS
GAS MONITORS

Air Instruments & Measurements, Inc. (AIM) 13300 Brooks Drive-Suite A Baldwin Park, CA 91706-2272 (626) 813-1460 www.aimanalysis.com	Norsk Elektro Optikk A/S P.O. Box 384 N-1471 Skarer, Norway +47-67-97 4700 www.neo.no/usa www.analyzer.com

Analytical Specialties (Norsk Elektro Optik) 1030 Hercules Houston, TX 77058 (281) 488-049 www.analyzer.com	Opsis 1165 Linda Vista Drive-Suite 112 San Marcos, CA 92069 (760) 752-3005 www.opsis.se
Boreal Laser #13 51127 Range Road Spruce Grove, Alberta Canada T7Y 1A8 (403) 271-2007 www.boreal-laser.com	Siemens Laser Analytics AB (formerly Alt Optronic AG) Box 5065 SE-402 22 Göteborg, Sweden +46 (0)31 776 86 00 www.siemens.se/sla
Codel International Limited Station Building Station Road, Bakewell Derbyshire, England DE45 1GE 021629 814351	Unisearch Associates Inc. 96 Bradwick Drive Concord, Ontario L4K 1K8 (905) 669-3547 Canada www.unissearch-associates.com
Land Combustion 10 Friends Lane Newton, PA 18940 (215) 504-8000 www.landinst.com	

FLOW MONITORS

Air Monitor Corporation 1050 Hopper Avenue Santa Rosa, CA 95403 (707) 544-2706 www.airmonitor.com	J-Tec Associates, Inc. (Ultrasonic Vortex) 5255 Rockwell Drive NE Cedar Rapids, Iowa 52402-2020 (319) 393-5200 www.j-tecassociates.com
Codel International Limited 408 S State St. Newton, PA 18940 (215) 504-4600	Kurz Instruments, Inc. 2411 Garden Road Monterey, CA 93940 (408) 646-8901 www.kurzinstruments.com
Dieterich Standard (Fisher-Rosemount/Emerson) Box 9000 Boulder, CO 80301 (303) 530-9600 www.frco.com/dieterich	Optical Scientific, Inc. (optical scintillation) 205 Perry Parkway, Suite 14 Gaithersburg, MD 20877 (301) 670-2100 www.opticalscientific.com
Durag, Inc. (Diff. Pressure, Ultrasonic) 1970 Christensen Ave. West St. Paul, MN 55118 (651) 451-1710 www. durag.com or www.durag.de	Panametrics, Inc. 221 Crescent St. Waltham, MA 02154 (800) 833-9438 www.panametrics.com
EEMC/EMRC 3730 N. Pelligrino Drive Tucson, AZ 85749 (520) 749-2167	Scientific Engineering Instruments, Inc. (SEI) (Sonic) 1275 Kleppe Lane-Suite 14 Sparks, Nevada 89431 (702) 358-0937
Eco Monitoring (ESC) (Differential Pressure) 200 Tech Center Drive Knoxville, TN 37912 (865) 688-7900 www.escdas.com	Sick Maihak 6900 West 110th Street Bloomington, MN 55438 (952) 941-6780 www.sickmaihak.com

Fluid Components, Int. (FCI) 1755 LaCosta Meadows Drive San Marcos, CA 92069 (760) 744-6950 (800) 854-1993 www.fluidcomponents.com	Sierra Instruments 5 Harris Court, Bldg. L Monterey, CA 93940 (831) 373-0200 www.sierrainstruments.com
Southern Scientific Industries P.O. Box 767250 Roswell, GA 30076 (404) 392-0459	Teledyne Hastings Instruments Box 1436 Hampton, VA 23661 (757) 723-6531 www.hastings-inst.com
Teledyne Monitor Labs (United Sciences) (Bowthorpe) 5310 North Pioneer Road Gibsonia, PA 15044 (412) 443-8610 www.monitorlabs.com	Thermo Environmental Instruments Inc. 27 West Forge Parkway Franklin, MA 02038 (508) 520-0430 www.thermo.com/source

FLOW MODELING

Airflow Sciences Corporation 37453 Schoolcraft Road Livonia, MI (313) 464-8900 www.airflowsciences.com	Alden Research Laboratory, Inc. 30 Shrewsbury St. Holden, MA 01520 (508) 829-6000 www.aldenlab.com

CONSTRUCTED MODELS

NELS Consulting Services, Inc. 7334 Garner Road Niagara Falls,Ontario Canada L2E 6S5 (905) 374-1566	

AUTOPROBE

AEP United Sciences Testing, Inc. 5475 William Flynn Highway Gibsonia, PA 15044 (614) 716-6875 www.ustirata.com	

DIODE LASER SYSTEMS

Analytical Specialties (Norsk Elecktro Optikk) 1030 Hercules Houston, TX 77058 (281) 488-0409 www.analyzer.com	Boreal Laser #13 51127 Range Road Spruce Grove, Alberta Canada T7Y 1A8 (403) 271-2007 www.boreal-laser.com
Norsk Elektro Optikk A/S P.O. Box 384 N-1471 Skarer, Norway +47-67-97 4700 www.neo.no	Opsis (LD 500) 1165 Linda Vista Drive-Suite 112 San Marcos, CA 92069 (619) 752-3005 www.opsis.se
Siemens Applied Automation (formerly Alt Optronic AG) 500 West Highway 660 Bartlesville, OK 74003 (918) 662-7000 www.siemens.se/sla	Unisearch Associates Inc. 96 Bradwick Drive Concord, Ontario L4K 1K8 (905) 669-3547 Canada www.unissearch-associates.com

EXTRACTIVE ANALYZER MANUFACTURERS

ABB Inc. Applied Automation (Hartmann & Braun/Elsag Bailey/Compur) 843 N. Jefferson Stret Lewisburg, WV 24901 (304) 647-4358 www.abb.com	Anacon Corp. (SO_2 NDUV, O_2 ZrO_2) 117 South Street Hopkinton, MA 01748 (508) 435-6973
AIM 13111 Brooks Drive-Suite D Baldwin Park, CA 91706 (818) 813-1460 www.aimanalysis.com	Applied Analyutics, Inc. PO Box 670129 Chestnut Hill, MA 02467 (617) 277-6502 www.a-a-inc.com
Air Quality Analytical, Inc. (FTIR) PO 204084 Austin, TX 78720 (512) 331-0073 www.airqa.com www.gasmet.fi	Baldwin Environmental,Inc. (O_2) 895 E. Patriot Blvd. #107 Reno, NV 89511 (702) 828-1300 www.bei-reno.com
American Gauge Corporation P.O. Box 219 Suwanee, GA 30714 (404) 932-0500	Brand-Gaus 15603 Delahunty Lane Pflugerville, TX 78660 (888) 698-7304 www.brandgaus.com/cems
Ametek Process Instruments (SO_2 NDUV/NOX)) 455Corporate Blvd. Newark, DE 19702 (302) 456-4400 www.ametekpi.com	Bodenseework (Perkin Elmer GmbH) (IR GFC) POB 101164 D-7770 Uberlingen Federal Republic of Germany 07532-801-1008
Ametek Thermox Instruments Division 150 Freeport Road Pittsburgh, PA 15238 (412) 828-9040 www.thermox.com	California Analytical Instruments, Inc. (Fuji, IR) 1238 West Grove Avenue Orange, CA 92865 (714) 974-5560 (800) 959-0959 www.gasanalyzers.com
Datatest, Inc. 6850 Hibbs Ln. Levittown, PA 19057 (215) 943-0668 www.datatest-inc.com	Innova Air Tech Instruments (Bruel & Kjaer) Linde Alle 36 (Photoacoustic Analyzer) 2850 Naerum Denmark 45-45-80-05-00 800-332-2040 (US)
EcoChem Analytics (Aldora) 202 Reynolds Ave. League City, TX 77573 (281) 338-9888 www.ecochem.biz	Land Combustion 10 Friends Lane Newton, PA 18940 (215) 504-8000 www.landinst.com/comb/
Eco Physics, Inc. (NO_x) 3915 Research Park Drive Ste A-3 Ann Arbor, MI 48108-2200 (734) 998-1180 www.ic.net/~ecophys	Liston Scientific (NDIR) 18900 Teller Avenue Irvine, CA 92612-1617 (949) 756-1632
Energy Efficiency Systems, Inc. ("Enerac") 1300 Shames Drive (Electrochem.) Westbury, NY 11590 (800) 695-3637 www.enerac.com	Lynn Products Company (O_2, combustion analyzers) 400 Boston Street Lynn, MA 01905 (617) 593-2500

Environmental Monitor Service, Inc. (O_2) 380 Main St. Box 4340 Yalesville, CT 06492 (203) 265-0598 www.emsct.com	Molecular Analytics (Formerly ETG) 25 Loveton Circle (Ion-Mobility Spec.) PO Box 1123 Sparks, MD 21152-1123 (410) 472-2146
Environnement S.A. 111 Boulevard Robespieere BP 4513 Poissy Cedex, France 33 1 39 22 38 00 www.environnement-sa.com	Monitor Labs (Bowthorpe) 74 Inverness Drive East Englewood, CO 80112-5189 (303) 792-3300 www.monitorlabs.com
Hewlett Packard - MTI Analytical Instruments (Micro-GC) 41762 Christy Street Fremont, CA 94538 (510) 490-0900	Monitor European Limited (Part of ETI Group) (Makes Monitor Labs gas analyzers)
Horiba Instruments Inc. 17671 Armstrong Ave. Irvine, CA 92614 (949) 250-4811 www.environ.hii.horiba.com	MSA Instrument Division (NDIR,GC) PO Box 426 Pittsburgh, PA 15230 (800) 672-2222 www.msanet.com
Nova Analytical Systems Inc. 1925 Pine Ave. Niagara Falls, NY 14301 (800) 295-3771 (716) 285-0418	Severn Science Limited (HCl, SO_3, NH_3) 4 Short Way, thornbury (Ion-Sel. Electrode) Bristol, England BS12 2UT (0454) 414723 Marketed by EESI PO Box 871 Ridgefield, CT 06877 (203) 438-5442
Novachem (Diode Array Process Monitors) One Gateway Center (NCl_3, Cl_2, NH_3, NO_x, COS, CO_2, SO_2) Suite 415 Newton, MA 02158 (617) 527-8885	Shimadzu Scientific Instruments, Inc. 7102 Riverwood Drive Columbia, MD 21046 (410) 381-1227 www.shimadzu.com
Onix Process Analysis, Inc. (Thermo) (H_2S) (Houston Atlas) 1201 N. Velasco Angleton, TX (979) 849-2344 www.fluid-data.com	Sick Maihak. 6900 West 110th Street Bloomington, MN 55438 (952) 941-6780 www.sickmaihak.com
Panametrics, Inc. (O_2) 221 Crescent St. Waltham, MA 02254 (617) 894-8582	Siemens Applied Automation, Inc. P.O. Box 9999 Bartlesville, OK 74005 (918) 662-7000 www.sea.siemens.com
Paragon Research, Inc. (Cl_2, ClO_2) Rt. 1 Box 195 2 Rockyroad Drive Cameron, OK 74932 (918) 654-3002	Teledyne Analytical Instruments (O_2 Fuel Cell) 16830 Chestnut St. (SO_2 NDUV) City of Industry, CA 91749 (626) 961-2538 www.teledyne-ai.com
PPM Systems Oy Ruukinkuja 1 FIN-02320 Espoo, Finland 358-9-02 5200	Teledyne-Advanced Pollution Instrumentation 6565 Nancy Ridge Drive San Diego, CA 92121 (858) 657-9800

Rosemount Analytical P.O. Box 901 1201 Main Street Orrville, OH 44667 (330) 682-9010 www.emersonprocess.com	Testo, Inc. 230 Rte. 206 Flanders, NJ 07836 (973) 252-1720 www.testo.com
Rosemount Analytical, Inc. 600 South Harbor Blvd. La Habra, CA 90631 (213) 690-7123	Thermo Environmental Instruments Inc. (SO_2 , NO_x, CO, NH_3, HCL, CO_2) 27 West Forge Parkway Franklin, MA 02038 (508) 520-0430 www.thermo.com/source
Servomex Company, Inc. 90 Kerry Place Norwood, MA 02062 (781) 769-7710 www.servomex.com	

CEM DATA ACQUISITION SYSTEMS VENDORS

Contec Systems 262 King Street Pottstown, PA 19464 (610) 326-3235 www.contecsystems.com	H2NS Environmental 12108A Roxie Drive Austin, TX 78729 (512) 918-8035 www.h2ns.com
Dr DAS 4105 Circletree Loop Austin, TX 78731 (512) 231-8487 www.montz.com	Nexus Solutions, Inc. 1100 Dearness Drive London, Ontario Canada N6E 1N9 (519) 649-6100 www.nexussi.com
Ecochem Analytics (Aldora)-CEMTRAC 202 Reynolds Ave. League City, TX 77573 (281) 338-9888 www.ecochem.biz	Process Analysts, Inc. (PAI-Honeywell) 555 Zang St., Suite 200 Lakewood, CO 80228 (303) 987-6100 www.honeywell.pai.com
Environmental Systems Corporation 200 Tech Center Drive Knoxville, TN 37912 (865) 688-7900 www.escdas.com	RiiSearch Environmental (Canada) AMKO Systems, Inc. 250 West Beaver Creek Rd., Unit 6 Richmond Hill, Ontario L4B 1C7 Canada (905) 771-1444
Environmental Telesis & Controls (ETC) 2301 Denton Drive-Suite A Austin, TX 78758 (512) 835-0330	Spectrum Systems 3410 West Nine Mile Road Pensacola, FL 32526-7808 (850) 944-3392
GE Power Systems (KVB Enertech) 2849 Sterling Drive Hatfield, PA 19440 (215) 996-4088 www.gepower.com	Teledyne Monitor Labs (RegPerfect, MLDASx & MLea2) 76 Inverness Drive East Englewood, CO 80112 (303) 792-3300 www.monitorlabs.com
Trace Environmental Systems 45 Route 46-P.O. Box 2010 Pine Brook, NJ 07058 (973) 227-8383 www.traceenv.com	WTC Engineering, Inc. (ASOMA) 2000 Fairway Drive Bozeman, MT 59715 (406) 586-1511

VIM Technologies Inc. 7464 new Ridge Road Hanover, MD 21076 (410) 859-5455 www.vimtechnologies.com	

PREDICTIVE EMISSION MONITORING SYSTEMS (PEMS)

AspenTech Ten Canal Park Cambridge, MA 02141-2201 (617) 949-1000 www.aspentech.com	Pegasus Technologies, Inc. (Neural Net Models) (Applies Pavilion's Software CEMs™) 5970 Heisley Road Suite 300 Mentor, Ohio 44060-1872 (440) 357-7794 www.pegasustec.com
General Electric-Reuter-Stokes (First Principles Models) Edison Park Twinsburg, Ohio 44087 (216) 425-3755 www.gepower.com	Petrocon 8901 Market Street Houston, TX 77029 (713) 880-6200 Petrocon.com
Horiba Instruments Inc. (In conjunction with PAI-Honeywell) 17671 Armstrong Ave. Irvine, CA 92614 (949) 250-4811 www.environ.hii.horiba.com	Solar Turbines, Inc. (First Principles Model for Solar Turbines) 2200 Pacific Highway San Diego, CA 92101-1745 (614) 544-5095
Midwest Research Institute (First Principles Models) 425 Volker Boulevard Kansas City, MO 64110-2299 (816) 753-7600 www.mriresearch.org Note: Group doing PEMS in MRI is in RTP, NC. MRI RTP office sold to RTI (www.rti.org) in June 2002.	Stegner Electric Controls 2155 Executive Hills Blvd Auburn Hills, MI 48326-2943 (248) 338-4100 www.stegner.cc
Pavilion Technologies, Inc. 11100 Metric Blvd., #700 Austin, TX 78758 (512) 438-1400 www.pavtech.com	Ultramax Corporation-Dynamic Process Optimization 1251 Kemper Meadow Drive Cincinnati, OH 45240 (513) 825-7794 www.umaxcorp.com
URS Houston, TX www.urscor.com (713) 914-6699	

VENDORS OF EXTRACTIVE SYSTEM COMPONENTS

Baldwin Environmental, Inc. 5401 Longley Lane #42 Reno, NV 89511 (701) 828-1300 www.bei-reno.com	Pace Environmental Products, Inc. 5240 West Coplay Road Whitehall, PA 18052 (800) 303-4532 www.pacecems.com
Cellex Mfg., Inc. 208 Thermon Drive San Marcos, TX 78667 (800) 800-8930	Perma Pure Inc. P.O. Box 2105 8 Executive Drive Toms River, NJ 08754-2105 (732) 244-0010 www.permapure.com

EPM Environmental, Inc. (Thermo Environmental) 834 E. Rand Road #6 Mt. Prospect, IL 60056 (847) 255-4494 www.epmenvironmental.com	PPM Systems Oy (TRS Convertor) Ruukinkuja 1 FIN-02320 Espoo, Finland 358-9-02 5200
Furon Company 1531 Commerce Creek Blvd. Cape Coral, FL 33909 (941) 995-8111	Restek 110 Benner Circle Bellefonte, PA 16823 (814) 353-1300 (800) 356-1688 www.restekcorp.com
KNF Neuberger, Inc. Two Black Forest Road Trenton, NJ 08691-9428 (609) 890-8600	Swagelok Co. 31400 Aurora Road Solon, OH 44139 (216) 349-5934
M&C Products 1879 Portola Road - Suite G Ventura, CA 93003 (805) 654-6970 www.mac-products.de	Technical Heaters, Inc./Thermolab 710 Jessie Street San Fernando, CA 91340 (818) 365-9435 www.Techheat.com
Millenium Instruments (Probes, Filters) 2402 Springridge Dr.-Unit A Spring Grove, IL 60081 (815) 675-3225 www.millinst.com	Unique Products International 29 East 8 Mile Road Hazel Park, MI 48030 (248) 542-7450
Mott Corp. (Filters) 84 Spring Ln. Farmington, CT 06032 (860) 747-6333 www.mottcorp.com	Universal Analyzers, Inc. 1771 South Sutro Terrace Carson City, NV 89706 (775) 883-2500 www.universalanalyzers.com

VENDORS OF ANALYZERS FOR MONITORING HYDROCARBONS AND VOLATILE ORGANIC COMPOUNDS

MANUFACTURERS OF ANALYZERS USING FLAME IONIZATION DETECTORS

Bernath Atomic GmbH Gottlieb Daimier Str. 11-15 D-30974 Wennigsen, Germany (49) 5103-7090	Photovac Monitoring Instruments 761 Main Avenue Norwalk, CT 06859-0211 (203) 761-5330
California Analytical Instruments, Inc. 1238 West Grove Avenue Orange, CA 92665 (714) 974-5560	Rosemount Analytical, Inc. 1201 N. Main Street Orrville, OH 44667 (216) 682-9010 www.emersonprocess.com
Dyna-Fid 131 Wallace Avenue, Suite 2 Downington, PA 19335 (610) 873-7824	Thermo Environmental Instruments Inc. 27 West Forge Parkway Franklin, MA 02038 (508) 520-0430 www.thermo.com/source
Eagle Monitoring Systems, Inc. 23 Mauchly-Suite 109A Irvine, CA 92718 (714) 754-7855	Mine Safety Appliances Co. Baseline Industries Subsidiary North Star Route, Box 649 Lyons, CO 80540 (800) 321-4665 (303) 823-6661

J.U.M. Engineering J.U.M. Lonestar Group 12900 FM3436 Dickinson, TX 77539 (281) 559-3366 www.jum.com	Questar Baseline North Star Route P.O. Box 649 Lyons, CO 80540 (303) 823-6661 www.baselineindustries.com

MANUFACTURERS OF ANALYZERS USING PHOTOIONIZATION DETECTORS

Foxboro Company 600 N. Bedford Street East Bridgewater, MA 02333 (508) 378-5400	Perkin-Elmer Corporation Photovac Monitoring Instruments 761 Main Avenue Norwalk, CT 06859-0211 (203) 761-5330
HNU Systems 160 Charlemont Street Newton, MA 02161 (617) 964-6690	Thermo Environmental Instruments Inc. (SO_2, NO_x, CO, NH_3, HCL, CO_2) 27 West Forge Parkway Franklin, MA 02038 (508) 520-0430 www.thermo.com/source
Mine Safety Appliances Co. Baseline Industries Subsidiary North Star Route, Box 649 Lyons, CO 80540 (800) 321-4665 (303) 823-6661	

PORTABLE ANALYZERS FOR INSPECTION/AUDIT

Air Quality Analytical, Inc. (FTIR) PO 204084 Austin, TX 78720 (512) 331-0073 www.airqa.com	Environmental Energy Systems (Megacom 9600) P.O. Box 871 (T&T Ingenieurgesellschaft mbH) Ridgefield, CT 06877 (203) 438-5442
California Analytical Instruments, Inc. (Fuji, IR Innova) 1238 West Grove Avenue Orange, CA 92865 (714) 974-5560 (800) 959-0959 www.gasanalyzers.com	Horiba Instruments Inc. (IR/Electrochem) 17671 Armstrong Ave. Irvine, CA 92714 (949) 250-4811 www.horiba.com
ECOM America (Electrochem.) 3075 Breckinridge Blvd. Suite 240 Duluth, GA 30136 (770) 806-0220 www.ecomusa.com	HNU Systems, Inc. (Photoioniz., GC) 160 Charlemont Street Newton, MA 02161-9987 (617) 964-6690
Energy Efficiency Systems, Inc. ("Enerac") (Electrochem.) 1300 Shames Drive Westbury, NY 11590 (800) 695-3637 www.enerac.com	Inficon (GC-Mass Spec) Two Technology Place East Syracuse, NY 13057 (315) 434-2520 www.inficon.com
Land Combustion 10 Friends Lane Newton, PA 18940 (215) 504-8000 www.landinst.com/comb/	Testo, Inc. (Electrochem./IR) 230 Route 206 Flanders, NJ 07836 (800) 227-0729

Photovac (Photoioniz.) 25-B Jefryn Boulevard West Deer Park, NY 11729 (516) 254-4199	Thermo Environmental Instruments Inc. (Photoioniz.) 27 Forge Parkway Franklin, MA 02038 (508) 520-0430
PPM Systems Oy Ruukinkuja 1 FIN-02320 Espoo, Finland 358-9-02 5200	

LOW-COST CEM SYSTEMS

AIR-World Environmental "AW-2K" Innovative Solutions "Mini-CEMS" Forney "CEMplicity" Land Combustion Inc. "FGA II"	

MERCURY MONITORS

ADA Technologies, Inc. (Solid state red/UV absorption) 8100 Shaffer Parkway, Suite 130 Littleton, CO 80127-4107 (303) 792-5615 www.adatech.com	Durag, Inc. (Solid State Reduction Unit) (Verewa Umwelt und Prozessmesstechnik GmbH) 1970 Christensen Ave. West St. Paul, MN 55118 (651) 451-1710 www. durag.com or www.durag.de
Apogee Scientific (Total Hg extractive system) 2895 West Oxford Avenue Suite 1 Englewood, CO 801100 (303) 783-9599 www.apogee-sci.com	EcoChem Analytics (Seefelder Messtechnik) (Hg-Mk 2)(UV) 22605 Valerio St. (Chem reduc./West Hills, CA 91307-1646 UV absorp.) (818) 347-4369 www.ecochem.biz www.seefelder-messtechnik.com
Cooper Environmental Services 14657 SW Teal Boulevard Beaverton, OR 97007 (503) 624-5730 www.cooperenvironmental.com	Envimeterics (Plasma Source/UV spec/solid Cat. Converter) P.O. Box 6 Pluckmin, NJ 07978 (908) 256-5033 www.envimetrics.com
Genesis Laboratory Systems (Quiksilver Sky 2527 Forsight Circle Grand Junction, CO 81505 (970) 241-0889 www.genlabsystems.com	Seefelder Messtechnik GmbH & Co. Muehlbachstrasse 20 D-8229 Seefeld Germany +49 (0) 8152 9939-0 www.seefelder-messtechnik.de
Mercury Instruments GmbH (solid state Liebigstrabe 11b reduction unit/ D-85757 Karlsfeld UV absorption) Germany 49 (0) 8131 50 57 20 www.mercure-instruments.de	Semtech Metallurgy AB (Hg 2000) (Wet Chem redu.) Ideon, Ole Römers väg 12 S-223 70 Lund, Sweden +46 46 182550 www.semtech.se/mercury
Nippon Instruments, Inc.(Gold collector Interlink Marketing Co. UV absorption) P.O. Box 260795 Plano, TX 75026 (972) 985-0883 www.smglink.com/nic	Sick Maihak.(MERCEM) (Au trap, UV abs) 6900 West 110th Street Bloomington, MN 55438 (952) 941-6780 www.sickmaihak.com

Ohio Lumex Co. (Zeeman type instrument) (216) 642-9700 www.headspace@oh.verio.com	PS Analytical Ltd (PSA) (Gold trap/UV Fluorescence) Arthur House, Unit 3 Crayfield Insdustrial Estate Main Road, St. Pauls, Cray Orptington Kent BR5 3HP United Kingdom +44 (0) 1689 891211 www.psanalytical.com
Lumex.Ltd 19, Moskovsky pr. St. Petersburg, 198005 Russia 7 (812) 315 0986 www.lumex.ru	ST2 Service Technologies 8550 West Ken Caryl Avenue Littleton, CO 80128 (303) 972-3740 www.mercury-instruments.de
Opsis (*In situ* UV AR 602 Z/600) (Hg 200-Extractive) 1165 Linda Vista Drive Suite 112 San Marcos, CA 92069 (760) 752-3005 www.opsis.se	Tekran, Inc.(Gold Film/UV Fluorescence) 330 Nantucket Boulevard Toronto, Ontario M1P 2P4 Canada (416) 449-3084 www.tekran.co

E
POP OUTS

Key O&M Cost Point

Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Section-Page	Topic	Key O&M Cost Point
2-3	*In situ* monitors	*In situ* monitors, as a class, require less maintenance than extractive systems when installed for appropriate applications. However, due to the sophistication of these monitors, when problems occur, a factory service representative most often must perform troubleshooting and maintenance.
2-10	Gas handling systems	Although gas handling systems are relatively simple, for the technician, they account for a considerable amount of the time spent working with CEM systems.
2-12	Dilution probes	Because dilution probes provide a wet-basis measurement; have a relatively low flow rate; do not draw large particles; and have fewer components, less maintenance is required when compared to source-level extractive systems.
2-19	Multipoint sample probes	Sample rakes or multi-point sampling probes will require more hardware to be placed in a stack or duct and may lead to more maintenance than a single probe.
2-20	Sample lines	Long lines tend to have more severe problems, which can lead to higher maintenance cost.
2-25	Nondisruptive ultraviolet	The simplicity of the NDUV designs allows for component replacement and is favored by source testers.
3-6	System performance	This in effect is what distinguishes good CEM systems from poor CEM systems—the level of effort and resources necessary to achieve acceptable performance.
3-9	Obsolete systems	When CEM system O&M costs and performance become unreasonable, it is often better to declare a system obsolete and purchase a replacement system.

Section-Page	Topic	Key O&M Cost Point
4-2	Calibration check	Taking longer than 30 minutes to perform a calibration check could result in having to report an hour of missing data to the EPA.
4-18	Dilution system	CEM system technicians must frequently recalibrate their dilution systems after a storm passes the plant.
4-21	Gas cylinder maintenance	To minimize cost associated with gas cylinders, it is essential that responsibility be given to some individual for the gas cylinder program.
5-3	Emission reporting	Low bias is not permitted in allowance trading programs, because the low bias would result in reporting emissions in tons per year that would be lower than true.
5-5	Source testing firms	Because the tests are expensive and are critical for determining whether a CEM system is in control or out-of-control, source testing firms should be selected carefully.
5-10	RAA testing	The RAA was intended to be a lower cost alternative to conducting a RATA. The difference in cost between a three-run and a nine-run RATA is not great. Consequently, this test is rarely performed.
9-1	System aging	When it becomes necessary to dedicate full-time technicians to the maintenance of a CEM system, it is time to consider changing the system.
9-2	Service life	Ten years is considered a reasonable service lifetime for most CEM systems.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Section-Page	Topic	Key Technical Point
2-2	Source-level systems	Source-level systems are more flexible in the choice of analytical techniques and more easily modified than dilution systems. They are used extensively in municipal and hazardous waste incinerators and in the process industries, such as petroleum refineries, pulp mills, and cement plants.
2-3	Path monitors	Path monitors, in particular, have difficulty in accommodating the daily calibration gas checks and quarterly gas linearity checks mandated in Part 75.

Section-Page	Topic	Key Technical Point
2-7	Out-of-stack probe	The out-of-stack design allows modification for the diversion of part of the undiluted sample gas stream to an oxygen analyzer. This offers an advantage for those who wish to measure flue gas oxygen.
2-10	Air-cleanup system	Although air-cleanup systems operate automatically, the system components require periodic maintenance
2-12	Calibration check	A weather front passing the plant, going from a plant shutdown to startup, or changing the calibration gas from a single-blend to a triple-blend gas, will all affect the pounds per hour measurement and the next calibration check.
2-16	Extraction system	Source-level extractive systems are inherently more flexible than dilution systems.
2-19	Extraction system	One advantage of source-level extractive systems is that in cases where the flue gas concentrations are severely stratified, sampling “rakes” or multi-point sampling probes can be designed to sample at multiple points in a stack or duct.
2-23	Hot-wet systems	Hot-wet systems are useful for monitoring gases such as hydrochloric acid, ammonia, or volatile organic compounds.
2-23	Hot systems	A hot system can also minimize the adsorption of gases on the internal surfaces and minimize the formation of compounds, such as ammonium chloride and ammonium sulfate, that can foul a system.
2-27	Moisture analyzer	Close-coupled moisture analyzers using dielectric techniques are now commercially available and provide an option to the complexity of the wet-dry oxygen monitoring method.
2-28	Part 75 limitations	Part 75 does not allow optional procedures for daily calibration checks or linearity tests. This limits the usefulness of *in situ* monitors for regulatory gas testing in the U.S.
2-36	Flow-to-load ratio test	Use of a Part 75 data validation technique, called the flow-to-load ratio test, can be a valuable tool in detecting problems in these systems.
4-3	Calibration	When requested to calibrate the instrument, the technician should know whether to check or to adjust the CEM instruments.

Section-Page	Topic	Key Technical Point
4-11	Protocol gases	If protocol gas has been stored between 12 to 36 months and/or the cylinder pressure falls below 150 psig (1034 kPa), the concentration may change and the cylinder should not be used.
4-12	New gas cylinders	Crosschecking new gas cylinders against the old cylinders and rejecting the new cylinder if it is out of tolerance should be part of the CEM QA Manual.
4-18	Recalibrate	CEM system technicians must frequently recalibrate their dilution systems after a storm passes the plant.
5-2	Relative accuracy test	The Part 75 semiannual requirement is for those systems or that part of the system whose last relative accuracy results were between 7.5% and 10.0%. If the results of the last test were less than 7.5%, only one test per year is required, providing an incentive to maintain the system or, at least, to optimize the performance of the system prior to the test.
5-12	Audit gases	It is possible to fail the audit if expired audit gases are used in the test.
7-1	System performance	If system failures are frequent after certification, the system may have some fundamental design problems or factors unique to the installation that may be affecting its performance.

Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent injury or damage or to ease completion of the task.

Section-Page	Topic	Key Human Performance Point
3-3	Trends	CEM systems tend to generate patterns of maintenance, where little things count and where memory is important.
4-11	Cylinder management	If cylinder gas pressures are not tracked and gases are not ordered on a timely basis, it is possible that cylinder gases appropriate for the system will not be available for the daily calibration checks.
4-13	Data acquisition	When replacing cylinder gases, remember to reconfigure the DAHS with the new gas concentration values of the replacement cylinder. If not, the DAHS will compute the calibration error from the previous cylinder value and the analyzer, or analyzers, may appear to be out-of-control.

Section-Page	Topic	Key Human Performance Point
4-21	Gas selection	When changing gas vendors, their technical capabilities, response capability, and performance in the EPA's gas audit program should be part of the selection process—not just cost.
7-4	System performance	The matter of pride also enters into such a problem—those who made the original engineering assessment and purchase decision may be unwilling to admit that they made a mistake and would rather that efforts be made to work with the equipment than to replace it.

Program:

Steam Turbines, Generators, and Balance-of-Plant

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