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An Introduction to Continuous Emission Monitoring Programs

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An Introduction to Continuous Emission Monitoring Programs

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ABSTRACT

This document provides a general introduction to continuous emission monitoring for those persons not previously involved in this field. Information is presented on continuous opacity monitoring, as well as instrumental and alternative monitoring techniques for SO_2 and NO_x (i.e., continuous wet-chemical measurement methods and fuel sampling and analysis methods). This document presents an outline and review of the fundamental concepts, terminology, and procedures used in a continuous emission monitoring program. Also presented are selected technical details necessary to understand the operation of emission monitors, the use of continuous emission monitoring data by air pollution control agencies, and references to other available documents which provide additional detailed information.

TABLE OF CONTENTS

	Page
I. Introduction	1
II. CEM Programs	7
Key Technical Elements of a CEM Program	7
CEM Data Quality Definitions and CEM Reliability	8
Installation and Location of CEMs	11
Instrument Design and Performance Specifications	13
Operation and Maintenance	15
Quality Assurance for CEMs	19
Reporting and Record Keeping Requirements	20
CEM Inspections and Performance Audits	22
Use and Interpretation of CEM Data	23
Alternative SO_2 and NO_x Continuous Monitoring Methods	25
III. Opacity Monitoring Systems	27
Basic Design and Operation Features of Opacity Monitors	27
Analyzer System	27
Sample Interface	32
Data Recorder	34
Calibration Mechanism	34
Design and Performance Specifications for Opacity Monitors	35
Transmissometer Installation Criteria	39
IV. Gas Continuous Emission Monitors	41
Gas Monitoring Systems and Monitoring Measurements	41
Basic Features of Gas Emission Monitors	44
Extractive Gas Monitors	45
In-situ Gas Emission Monitors	47
Performance Specifications for Gas Emission Monitors	51
Gas Monitor Installation Considerations	56

I.

INTRODUCTION

Continuous emission monitoring uses automatic instruments to provide semi-continuous measurement and recording of air pollutant emission levels (i.e., opacity, SO_2, and NO_x) at stationary sources. The term "continuous" applies to the on-going process of monitoring emission levels, rather than to the frequency of measurements. Depending on the type, design, and application of the continuous emission monitor (CEM), the sampling frequency may vary. Some instruments may provide an almost instantaneous or truly continuous record of emissions, while others may provide measurements taken at 10- to 15-minute intervals. In either case, the sampling frequency is generally sufficient to characterize variations in emission levels over time.

Alternative emission monitoring techniques are currently being developed. These techniques include the use of continuous wet-chemical SO_2 and NO_x measurement methods similar to those employed in Reference Methods and the use of various fuel sampling and analysis techniques for predicting SO_2 emission levels. Although the approval of these methods differs from that of the traditional CEM, it provides an essentially equivalent characterization of emission levels.

CEMs and alternative monitoring methods provide direct estimates of emission levels, control equipment collection efficiencies, and/or evaluation of process and control equipment operation and maintenance procedures. The obvious advantage over the more traditional compliance tools (e.g., source tests, source inspections, and visible emission observations) is that the CEM provides continual surveillance of source emissions.

Most CEMs in the United States are installed and operated to comply with Environmental Protection Agency (EPA), State, or local monitoring regulations. However, in some cases, CEMs are utilized by industry for process and/or control equipment operation. Currently, the EPA requires CEMs to be installed and operated at specified sources primarily through the New Source Performance Standards (NSPS). To date, some types of CEMs have been promulgated for 13 NSPS categories. Also, the EPA requires the use of CEMs through Prevention of Significant Deterioration (PSD) permits, Section 113 orders, Section 114 authority, and State Implementation Plans (SIPs). As a result, many states have now adopted CEM requirements for existing sources and have revised SIPs to include CEM regulations.

EPA and State monitoring regulations most often require the source owners and operators to monitor opacity, SO_2, and NO_x emissions. In addition, total reduced sulfur (TRS) or CO monitoring is required at some sources. Occasionally, at other sources where emissions cannot be measured directly, monitoring of velocity, pressure drop, temperature, and/or other process and control system parameters is required. (Figure 1-1 tabulates the various NSPS emission monitoring requirements.)

The use of CEMs and alternative monitoring techniques can provide significant benefits to the control agency and to the affected source owner/operator only when a comprehensive monitoring program is established. An effective CEM program requires that: (1) suitable and reliable instruments are used, (2) measurements representative of the entire effluent stream are obtained, (3) proper operation and maintenance of the monitors are performed, (4) an adequate quality control program is followed, (5) appropriate record

Figure 1-1. CONTINUOUS EMISSION MONITORING REQUIREMENTS FOR FACILITIES SUBJECT TO NEW SOURCE PERFORMANCE STANDARDS (NSPS)

Regulation 40CFR60 (Subpart)	Source Category	Affected Facilities	Emissions Requiring Monitoring						
			Opacity	SO_2	NO_x	O_2/CO_2	H_2S[1]	TRS[1]	CO[1]
D	FFFSG	>250 x 10^6 Btu/hr	X	X	X	X			
Da	FFFSG (Electric Utility)	>250 x 10^6 Btu/hr	X	X	X	X			
G	Nitric acid	Process equipment			X				
H	Sulfuric acid	Process equipment		X					
J	Petroleum refineries	FCCU	X						X
		FGC		X			X		
		Claus plants		X			X	X	
P	Primary copper smelters	Dryer	X						
		Roaster, smelting furnace, or copper converter		X					
Q	Primary zinc smelters	Sintering machine	X						
		Roaster		X					
R	Primary lead smelters	Blast or reverberatory furnace, sintering machine	X						
		Sintering machine, electric furnace, or converter		X					
Z	Ferroalloy production	Electric arc furnace	X						
AA	Iron and steel	Electric arc furnace	X						
BB	Kraft pulp mills	Recovery furnaces	X			X		X	
		Lime kilns, digester, washer, evaporator, condensate stripper, or black liquor oxidation system, smelt tanks				X		X	
DD	Grain elevators	Loading, unloading handling or dryers	X						
HH	Lime plants	Rotary lime kiln	X						

[1]Not effective until monitor performance specifications are proposed and promulgated.

keeping and reporting practices are utilized, and (6) appropriate procedures are used to interpret continuous monitoring results.

The degree to which each of the above activities must be performed and the corresponding complexity and detail of the CEM regulations depend directly on the intended use of the data. For instance, greater precautions and effort must be expended to achieve accurate results when the CEM data are used to determine compliance. However, when CEM data are employed as a relative indicator of source process/control system operation and maintenance practices, less effort need be expended.

The design of the CEM program must consider realistically the limitations of monitoring technology, methodologies, expertise, and manpower available to industry for complying with the regulations. Allowances must be made for unavoidable CEM malfunctions and inherent errors in CEM data.

CEM instruments vary widely in design and construction. In general, CEMs are inherently complex devices composed of a number of subsystems. They typically have complex physical-chemical analytical mechanisms, sophisticated electronic circuitry, and data recording systems ranging from simple strip charts to digital computer automatic data processors. The actual source conditions and situations often present additional problems which must be resolved on a case-by-case basis. In many situations, unforeseen specific applications problems are encountered, and the CEM user is required to expend significant time and considerable effort in their resolution.

Historically, the inherent complexity of many CEMs, the difficulties of applying relatively new technology to new situations, and the general lack of successful long-term demonstrations of CEM performance have affected significantly the implementation of CEM programs and have impeded the effective use of CEM data. However, in spite of the technical and administrative problems, the field of continuous emission monitoring has progressed very rapidly in recent years. Alternative monitoring methods are being developed, and CEMs are being applied to increasing numbers of source categories and new situations. Many CEM applications problems have been identified and resolved, and CEM instrumentation continues to evolve and improve. Much additional operating experience has been obtained, and effective quality assurance programs are being developed. In general, much more information is now available on achievable, long-term CEM performance.

Recent technical and methodological progress clearly aids the CEM user in obtaining high quality emission monitoring data. Existing regulations and procedures are being revised while new ones are being developed to establish more effective CEM programs which will facilitate the utilization of monitoring data in documenting pollutant emission levels from stationary sources. Current efforts by CEM manufacturers, industrial CEM users, and control agencies will further improve the technological feasibility and cost-effectiveness of continuous emission monitoring, thereby culminating in more effective measurement, regulation, and control of air pollution from stationary sources.

II.

CEM PROGRAMS

This section presents an overview of CEM program implementation. The key elements of a CEM program are delineated, followed by brief discussions of basic CEM data quality definitions, reliability, and the key elements of conventional CEM instrumentation. Finally, a brief summary is provided of the status of alternative SO_2 and NO_x continuous monitoring techniques (i.e., continuous wet-chemical measurement methods and fuel sampling and analysis methods for estimating SO_2 emission levels). Throughout this section, references to other documents are included that provide additional information and/or in-depth discussion of particular subject areas.

Key Technical Elements of a CEM Program

Successful implementation of any CEM program or alternative monitoring methodology depends upon a number of key program elements encompassing a range of activities and regulatory provisions, from the selection of CEM measurement locations to the utilization and interpretation of monitoring results. These key elements include appropriate procedures to ensure:

1. Representative measurements of the entire effluent stream.
2. Proper performance testing of monitoring instrumentation and adequate criteria to ascertain the acceptability of monitoring instrumentation.
3. Proper operation and maintenance of monitoring equipment.
4. Adequate quality assurance that data quality levels are consistent with the intended use of the data.

5. Acceptable reporting and recordkeeping practices.

6. An effective control agency inspection-audit program to provide independent validation of the accuracy of reported measurements.

7. Correct interpretation of CEM (and alternative method) data to facilitate the initiation of follow-up activities.

All of the above program elements are interrelated and interdependent, and none can be neglected or eliminated without seriously diminishing the effectiveness of the entire CEM program. Conversely, excessive emphasis directed at any one (or all) of the elements may surpass the needs of the source owner/operator and the control agency, thereby resulting in excessive CEM program implementation costs.

CEM Data Quality Definitions and CEM Reliability

CEM data, like any other scientific measurements, are estimates of the actual or "true" values. The accuracy and/or errors associated with the data must be considered to arrive consistently at valid and supportable conclusions. Thus, to be useful, the quality of the data must be maintained within reasonable limits. The confidence level associated with CEM data is directly proportional to the degree of data quality.

CEM data reliability is indicative of the overall data quality and is generally defined in terms of accuracy, precision, representativeness, and availability. Because confusion often results from the practical application of these terms, they are defined for this document as follows:

accuracy - the closeness of the measured value to the true value (usually the degree of closeness of the mean of a data set to the mean of the corresponding true emission values).

precision - the repeatability of the data obtained by the measurement system (consistency of the relationship between measured values and true values).

representativeness - the degree to which the effluent samples obtained represent the entire effluent stream, and the degree to which the measured values are indicative of the parameters of interest.

availability - the portion of source operating time for which CEM data is obtained (% of time monitor is actually operating and providing data, with respect to the total time the monitor is required to operate).

CEM "reliability" represents the degree to which CEM data yield consistent and valid opacity, SO_2, and NO_x measurements.

For any particular emission measurement to be meaningful, three fundamental criteria must be met: (1) samples must be representative of the entire effluent stream, (2) sampling must be conducted with the maximum accuracy obtainable under the existing test conditions, and (3) sufficient sampling and analysis must be conducted to minimize the effects of test site parametric variations and the imprecision of the measurement method. While these criteria provide a basis for evaluating the validity of a given set of emission measurement data, the time-dependent characteristics of the data must be considered.

Historically, CEM reliability and long-term level of performance have been the center of much controversy, because of the lack of available information.

Recently, however, several studies characterizing long-term CEM performance have been completed, and additional studies are on-going. Information relevant to the performance of SO_2 and NO_x monitors is included in "A Compilation of SO_2 and NO_x Continuous Emission Monitor Reliability Data Information," SSCD CEM Report Series No. 340/1-83-012 (J. W. Peeler, Entropy Environmentalists, Inc., Contract No. 68-01-6317, Task No. 29). Information regarding the performance of continuous opacity monitoring systems is included in "A Compilation of Opacity Monitor Performance Audit Results," SSCD CEM Report Series No. 340/1-83-011, (Entropy Environmentalists, Inc., Contract No. 68-01-6317, Task No. 29).

Installation and Location of CEMs

Installation and location criteria specify how and where CEMs are to be installed. The purpose of these requirements is to reduce the possibility that a poor monitor location will adversely affect the representativeness of the monitoring data. Two distinct issues must be addressed.

First, because a CEM samples only a very small portion of an effluent stream, the samples must be consistently representative of the entire effluent stream at the measurement site. Stratification (i.e., variations in the pollutant concentration across the duct or stack cross section) at the selected monitoring location must be considered to ensure that CEM samples have the same pollutant concentration as the average of the total effluent stream. Stratification tests are sometimes required to determine whether particular monitor locations will provide representative measurements.

Second, the CEM data must represent the effluent exit stream. For example, consider a coal-fired steam generator with twin electrostatic precipitators (ESPs) and a common exhaust stack. An opacity monitor can be located in the ductwork following each precipitator, or a single opacity monitor can be located in the stack. The final decision depends on whether the opacity monitors are intended to monitor control equipment operation and maintenance practices (in which case a monitor should be installed in each duct), or whether the opacity monitor is intended to provide data on the opacity of the effluent discharged to the atmosphere (in which case a single opacity monitor should be installed in the stack). Thus, the choice of the monitor location is dependent on the monitoring program goals.

Other factors which should be addressed in locating the CEM include: (1) accessibility for monitor maintenance, (2) environmental conditions (i.e., ambient temperature, exposure to weather, presence of vibrations, etc.), and (3) effluent conditions (i.e., temperature, pressure, moisture content, etc.). All of these factors will affect the degree of maintenance required and CEM data availability.

The monitoring requirements of 40 CFR 60.13 include a general requirement for obtaining representative measurements; specific installation and location criteria are included in the Performance Specifications of Appendix B. Additional location criteria are provided in the applicable subparts of Part 60 for some source categories.

The proposed revisions to Performance Specification 1 for opacity monitors (published in the October 10, 1979 Federal Register) will provide improved guidance in selecting and evaluating opacity monitoring installation locations. In addition, revisions to Performance Specifications 2 and 3 for SO_2, NO_x, CO_2, and O_2 monitoring systems (first proposed in the October 10, 1979, Federal Register and subsequently reproposed in the January 26, 1981, Federal Register) will affect the choice and evaluation of gas CEM installation locations. Until the final revisions are promulgated, it is not possible to determine the impact of these new requirements on CEM test parameters and methodology. However, it is expected that revisions to Performance Specifications 2 and 3 will clarify the source operator's responsibility for the selection of representative monitoring locations.

Existing NSPS monitoring requirements do not provide procedures for conducting stratification tests to determine the representativeness of gas CEM monitoring locations. Draft procedures have been developed, however, and may be found in "Transportable Continuous Emission Monitoring System Operational Protocol: Instrumental Monitoring of SO_2, NO_x, CO_2, and O_2 Effluent Concentrations," SSCD CEM Report Series No. 340/1-83-016, (G. D. Deaton and J. W. Peeler, Entropy Environmentalists, Inc., Contract No. 68-01-6317, Task No. 31).

Instrument Design and Performance Specifications

Instrument specifications are necessary to ensure that CEMs are capable of providing data of sufficient quality to fulfill the requirements of the monitoring program. Instrument specifications are classified in two categories: performance specifications and design specifications.

Performance specifications prescribe operational criteria, such as response time, accuracy, drift, etc. The performance of the instrument in terms of these parameters is verified according to prescribed evaluation procedures. Performance specifications do not dictate specific instrument design criteria, but instead provide latitude in the instrument design, requiring only that the instrument be capable of being evaluated.

Design specifications, in contrast, prescribe physical design and construction details. The assumption is that if an instrument complies with specific design criteria, then it will perform satisfactorily.

Performance specifications are generally preferred to design specifications because the desired instrument operating characteristics are verified directly through testing of the monitor. Design specifications are generally utilized where testing of instrument performance is not practical or feasible. CEM regulations usually contain both design and performance specifications. EPA instrument specifications (both design and performance specifications) for opacity, SO_2, NO_x, O_2, and CO_2 monitors are contained in Performance Specifications 1, 2, and 3 of Appendix B, 40 CFR 60. These regulations specify performance test procedures and design criteria for evaluating the acceptability of CEM instrumentation.

Instrument specifications ensure only that CEMs are capable of accurately analyzing effluent samples. They do not ensure the validity of monitoring data, except when the monitors are demonstrated to comply with the performance specifications during the actual testing periods. (Instrument design and performance specifications are discussed in greater detail in Sections III and IV of this document for opacity monitors and gas emission monitors, respectively.)

NSPS monitoring regulations and most state CEM regulations require source owners/operators to conduct field tests in accordance with the procedures specified in Performance Specifications 1, 2, and 3, which require that the control agency be notified in advance of such tests. The control agency should then designate a representative to observe the monitor performance tests. A manual for use by control agency observers has been prepared, entitled, "Guidelines for the Observation of Performance Specification Tests of Continuous Emission Monitors," SSCD CEM Report Series No. 340/1-83-009, (Entropy Environmentalists, Inc., Contract No. 68-01-6317, Task No. 28). An additional manual, which addresses the review and evaluation of CEM Performance Specification test reports submitted to the agency, has also been prepared, entitled "Performance Specification Tests for Pollutant and Diluent Gas Emission Monitors: Reporting Requirements, Report Format, and Review Procedures," SSCD CEM Report Series No. 340/1-83-013, (G. B. Oldaker III, Entropy Environmentalists, Inc., Contract No. 68-01-6317, Task No. 28).

Operation and Maintenance

Proper operation and maintenance procedures are vitally important for the successful CEM application. Improper operation and/or lack of maintenance is often the cause of invalid monitoring data and excessive monitor downtime. The appropriate procedures for operating and maintaining CEMs are very monitor- and source-specific. Thus, it is difficult to prescribe general guidelines.

For NSPS, minimum operating requirements for CEMs are included in 40 CFR 60.13; these include specification of the sampling frequency and minimum procedures for checking CEM calibration on a daily basis. In addition, the span value (upper limit of the CEM measurement range) is specified for each source category in the applicable subpart of 40 CFR 60. Also, Subpart Da for electric utility steam generators specifies a minimum data capture rate (minimum acceptable monitor availability).

CEM regulations generally specify only that proper maintenance practices be followed and that the CEM user follow the manufacturer's written instructions. Thus, the adequacy and completeness of the manufacturer's instructions become an integral part of the CEM program. It must be kept in mind that monitor vendors are somewhat hesitant to specify more than minimum maintenance procedures, because an apparently extensive operation and maintenance program would affect a potential user's decision to purchase a particular continuous emission monitor.

The routine calibration of CEMs is probably the most important aspect of operation and maintenance procedures. Calibration involves a check of monitor system operation by introducing known input conditions to the monitor and observing the resultant instrument responses. Routine calibration checks are generally performed at the zero value and at one upscale value. The known conditions are simulated by the use of devices or materials (i.e., calibration standards) for which there is some assurance of the equivalent value in units of the monitoring measurement. Filters that attenuate a known quantity of light are used to calibrate opacity monitors. Calibration gas mixtures containing known quantities of the gas of interest are often used to calibrate gas emission monitors.

Calibration of a monitoring system allows the operator to adjust the monitor to obtain the correct monitor response to the calibration standards. Thus, the validity of the monitoring data is directly dependent on the calibration procedure and on the accuracy of the calibration standard values. For example, if the values of the calibration standards are in error, then the monitoring system will be misadjusted and errors will be introduced into the monitoring data. Similarly, where a particular calibration procedure fails to check the entire monitoring system, errors arising from the unchecked portion of the system may affect the validity of the monitoring data, even though the monitor is apparently calibrated correctly. The latter situation has occurred far too frequently, particularly for in-situ gas CEMs. It is anticipated that more attention will be directed at the validity of calibration procedures as effective quality assurance procedures are developed and as additional CEM operational experience is obtained.

Quality Assurance for CEMs

Quality assurance (QA) consists of procedures and practices to ensure an adequate level of monitor data accuracy, precision, representativeness, and availability. Generally, monitor location criteria, instrument design and performance specifications, monitor operation procedures, and maintenance procedures can all be considered as QA procedures. However, in common usage, QA is usually considered to mean the procedures and practices employed in addition to the above criteria to ensure valid and reliable CEM data. To date, QA procedures for CEMs have not been included in the EPA monitoring regulations. Efforts are currently underway, however, to develop Appendix F of 40 CFR 60 to fulfill the need for QA procedures for CEMs at NSPS sources.

The need for CEM QA procedures is apparent from the past experience of CEM operation at industrial sources. Although the performance specification test shows that a particular monitoring system can produce valid data and although the rather general requirements for operating and maintaining CEMs should ensure that the CEM data will fall within some error range, it has been very difficult to address the reliablity or accuracy of CEM data over any extended period of time.

QA procedures may be divided into two distinct areas: quality assessment and quality control. Quality assessment procedures provide methods for estimating the accuracy and precision of monitoring data. Quality control consists of specific procedures and corrective actions taken to improve data quality. These procedures are implemented when quality assessment procedures indicate that data quality is inadequate.

Because CEMs vary widely in design and application, general QA procedures are difficult to devise. Efforts are currently underway to develop monitor-specific and source-specific QA procedures. Specifically, Appendix F, Procedure 1, will apply to SO_2 and NO_x emission monitors used to determine compliance with emission limitations. It is anticipated that this procedure will contain relatively general quality assessment procedures, including daily precision estimates based on calibration data and periodic relative accuracy tests (comparisions of monitoring data with independent measurements of the pollutant emission levels). Appendix F will require that each CEM user develop a specific set of quality control procedures.

Additional information regarding QA procedures for gas CEMs is contained in "A Compilation of Quality Assurance Procedures for SO_2 and NO_x Continuous Emission Monitoring Systems," SSCD CEM Report Series No. 340/1-83-014, (J. W. Peeler, Entropy Environmentalists, Inc., Contract No. 68-01-6317, Task No. 27). Furthermore, the results and conclusions presented in "Transmissometer Field Audit Results" (see previous citation) provide information relevant to appropriate QA practices for opacity monitoring systems.

Reporting and Record Keeping Requirements

Reporting and record keeping requirements are of fundamental importance to any CEM program. Obviously, if CEMs are to provide any benefit for either the control agency or the source, then adequate data records must be maintained and specific information must be reported to the control agency.

Basically, records of all emission measurements and information documenting monitor performance and operation should be maintained. The second category should include records of: (1) monitoring system performance evaluations, (2) calibration data, (3) adjustments and maintenance performed on the monitoring system, and (4) all periods of monitor malfunction or downtime.

The type of information that should be reported to the control agency by the CEM user depends directly on the intended utilization of the data. For example, under "never to be exceeded" emission standards, reporting only periods of excess emissions (periods when the standards are exceeded) is appropriate. In contrast, for 30-day rolling average standards, reporting daily averages of pollutant emission levels is probably more appropriate. In either case, the agency should require only the information necessary to decide whether additional action is necessary within the overall context of the particular monitoring program to be reported. For additional information, the agency should rely on the records maintained by the source.

Reporting and record keeping requirements for CEMs installed to comply with NSPS are contained within Part 60.7 of 40 CFR 60. Reporting requirements include: (1) the magnitude and duration of all periods of excess emissions, (2) identification of each excess emission period that occurs during startup, shutdown, or malfunction of the affected facility, (3) the nature and cause of each malfunction and the corrective action taken, and (4) all periods when the monitoring system was inoperative. These reporting requirements provide a basis for determining whether proper process/control system operation and maintenance practices are followed by the affected source, and for initiating appropriate follow-up activities by the control agency.

CEM Inspections and Performance Audits

Control agency inspections and performance audits comprise a critical element of any CEM program. They provide an independent means (not subject to the control of the source operator) for determining the validity of the data reported to the agency, the adequacy of monitor operation and maintenance procedures, and compliance with various monitoring regulations.

Performance audit procedures for opacity monitors are presented in "Performance Audit Procedures for Opacity Monitors," SSCD CEM Report Series No. 340/1-83-010, (Entropy Environmentalists, Inc., Contract No. 68-02-3431, Tasks No. 40 and 166, and Contract No. 68-01-6317, Task No. 28). These procedures afford a quantitative measure of monitor performance and indicate whether a source is utilizing proper monitor operation and maintenance procedures. Over 100 audits have been conducted to date, providing an extensive data base for evaluating opacity monitor performance. The results of the opacity monitor performance audit program are presented in Transmissometer Field Audit Results" (see previous citation).

Performance audits of SO_2 and NO_x CEMs quantitatively determine compliance with both monitoring regulations and emission limitations. Audit procedures that include traditional reference method testing and transportable extractive monitors are delineated in two manuals: "Performance Audit Procedures for SO_2, NO_x, CO_2, and O_2 Continuous Emission Monitors," SSCD CEM Report Series No. 340/1-83-015, (J. W. Peeler and G. D. Deaton, Entropy Environmentalists, Inc., Contract No. 68-01-6317, Task

No. 31), and "Transportable Continuous Emission Monitoring System Operational Protocol: Instrumental Monitoring of SO_2, NO_x, CO_2, and O_2 Effluent Concentrations" (see previous citation). The results of gas CEM performance audits are included in "A Compilation of SO_2 and NO_x Continuous Emission Monitor Reliability Data" (see previous citation).

Use and Interpretation of CEM Data

Throughout the foregoing discussions, there have been numerous references qualifying other requirements and activities in terms of the intended use of CEM data. Although, too often, the use and interpretation of the monitoring data is the least discussed and least well-defined aspect of continuous emission monitoring, the applicability and appropriate level of effort for other aspects of a CEM program hinge on the intended use of the data.

Two major categories of CEM data utilization are included in the existing NSPS: (1) the use of CEM data as an indicator of process and control systems operation and maintenance practices (40 CFR 60.11d), and (2) the use of CEM data to determine compliance with emission standards (Subpart Da). The original promulgation of NSPS monitoring requirements (October 5, 1975, Federal Register) employed CEMs to assess a source's process/control system operation and maintenance practices. As such, CEMs are required to provide only a relative indication of emission values; the absolute accuracy of the data is not of fundamental concern. For example, if the opacity monitor indicated levels significantly above those measured during the last particulate performance test and no malfunction of the process or control system was apparent, then it may be appropriate to require a new particulate emission test to determine whether the source is still in compliance with the particulate emission standards. In this situation, the CEM is used to indicate a relative change in emission levels, rather than to provide an absolute value.

The second use of CEM data within NSPS is contained in the recently promulgated NSPS for electric utility steam generators, Subpart Da. These regulations require the use of SO_2 and NO_x CEM data to determine compliance with SO_2 and NO_x emission standards, and the use of SO_2 CEM data to determine compliance with SO_2 percent removal requirements. Subpart Da requires that these compliance determinations be made on a 30-day rolling average basis. Although the Subpart Da promulgation does not specify procedures to be used by the control agency to interpret and to evaluate the CEM data, it does require that affected sources report the appropriate 30-day rolling average values. Subpart Da also specifies alternative calculation procedures for use in reporting CEM results where the required minimal data capture rates are not achieved.

Some control agencies are reluctant to discuss specific procedures used to evaluate CEM data because such procedures are expected to vary between Regions and States to reflect local policies and control strategies. Efforts currently underway should enhance the basis for establishing the error band associated with CEM data, and thus, should enhance appropriate procedures for interpretating CEM results. Also, the promulgation of improved monitor performance specifications and quality assurance procedures should reduce the potential error band associated with CEM data. In addition, procedures using quality assessment to interpret CEM data are being developed. Draft procedures for interpretating continuous opacity monitoring results for NSPS sources have been developed but are still being evaluated by the EPA. These procedures focus on the relationship of opacity monitoring results to: (1) proper control system operation and maintenance practices, (2) visible emission observations, and (3) particulate emission levels.

Alternative SO_2 and NO_x Continuous Monitoring Methods

An alternative SO_2 monitoring method (i.e., proposed Method 6B) is currently under development by the EPA's Emissions Measurement Branch, Quality Assurance Division, and Stationary Source Compliance Division. A limited quantity of field testing has been conducted to demonstrate and evaluate the feasibility of this monitoring technique when emission standards are expressed in terms of 24-hour and longer averaging periods. Promulgation of Method 6B is expected fairly soon; this method should prove to be a relatively low cost, highly reliable SO_2 emission monitoring technique. A current assessment of the status of Method 6B is provided in "An Update and Discussion of the Critical Aspects of Proposed EPA Reference Method 6B," SSCD CEM Report Series No. 5-411-11/82, (G. B. Oldaker III, Entropy Environmentalists, Inc., Contract No. 68-01-6317, Task No. 28).

A method similar to proposed Method 6B, referred to as the "permanganate method," is also being developed. This method will provide for concurrent measurement of SO_2, NO_x, and CO_2 effluent concentrations, and together with proposed Method 6B, will provide industry with increased flexibility in meeting SO_2 and/or NO_x monitoring requirements, thereby reducing the cost of conducting a CEM program.

Coal sampling and analysis (CSA) procedures for determining flue gas desulfurization (FGD) inlet SO_2 levels have been promulgated in Method 19, Appendix A, 40 CFR 60. CSA procedures for non-FGD equipped steam generators are currently under development. A number of alternative CSA approaches are being considered, spanning the range of "as received" to "as fired" sampling. A preliminary protocol has been developed to allow source operators to demonstrate the adequacy of existing CSA procedures in lieu of utilizing SO_2 CEM. A limited amount of field testing has been conducted, and further development of CSA methods is expected to provide industry with increased flexibility in meeting SO_2 monitoring requirements while reducing the costs of conducting a CEM program.

III.

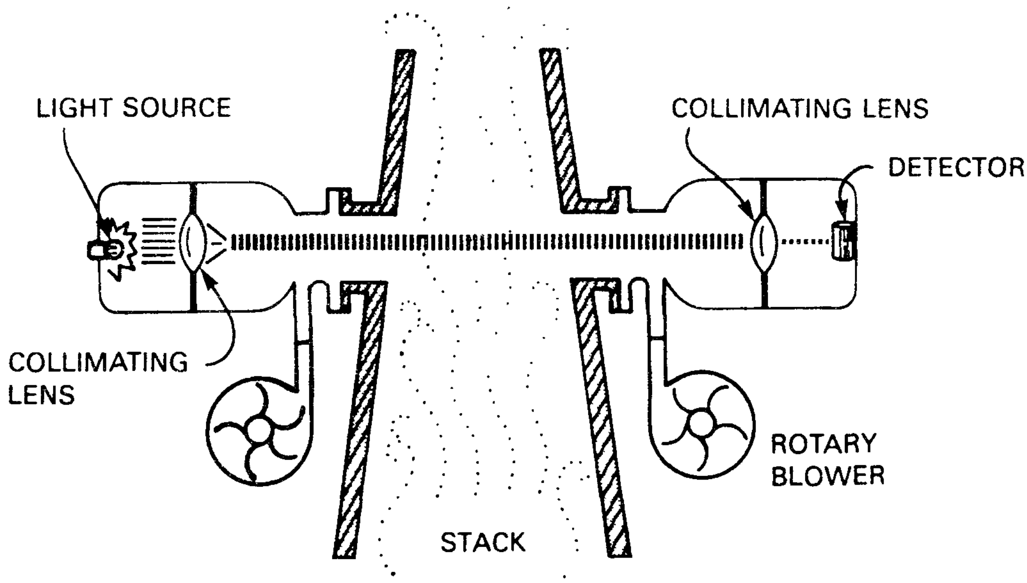
OPACITY MONITORING SYSTEMS

Basic Design and Operation Features of Opacity Monitors

Continuous opacity monitoring systems use transmissometers to determine the in-stack opacity of an effluent stream. The transmissometer operates on the principle of light attenuation by the particulate matter in the stack effluent. The transmissometer generates a light beam, projects it across the stack effluent, and detects the amount of light transmitted across the stack effluent relative to the amount of light generated by the light source. (Figure 3-1 shows typical transmissometer configurations.) The basic components of the opacity monitoring system are the analyzer, sample interface, data recorder, and calibration mechanism. Each of these system components is discussed separately in the following paragraphs.

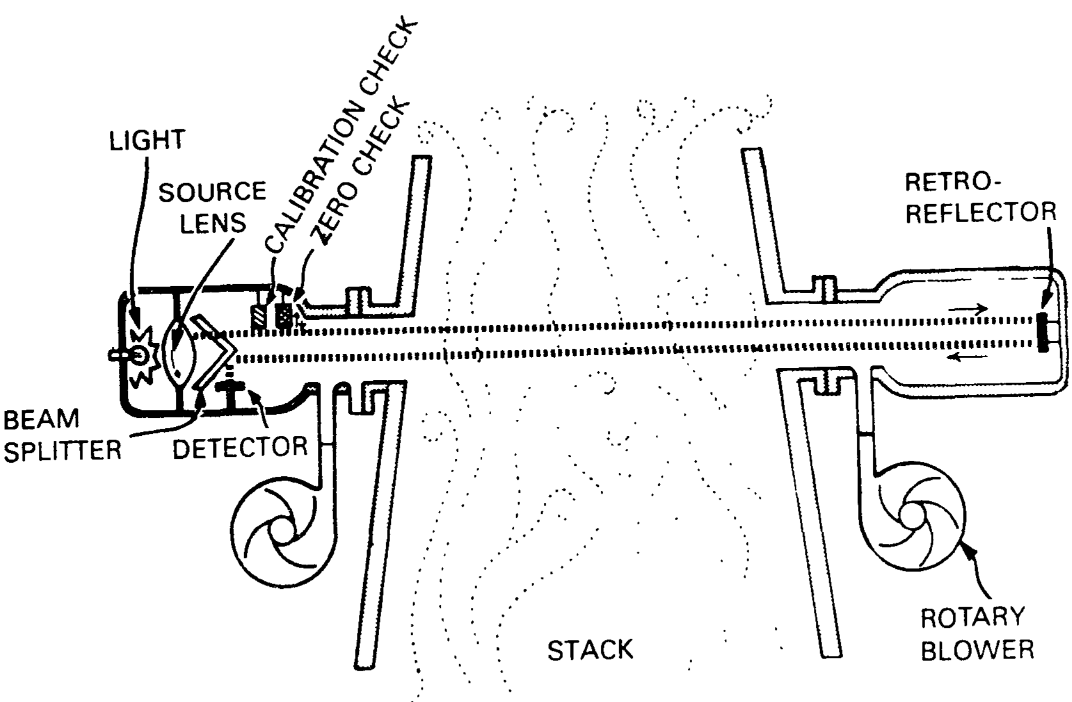
Analyzer System

The analyzer system contains the light source, detector, and signal generator, and measures the amount of light attenuated (i.e., absorbed and scattered) by the stack effluent. The percentage of visible light attenuated is defined as the opacity of the emission. Transparent stack emissions will have a transmittance of 100%, or an opacity of zero percent. Opaque stack emissions that attenuate all of the visible light will have a transmittance of zero percent, or an opacity of 100%.



SINGLE PASS TRANSMISSOMETER

(Many single pass opacity monitoring systems do not conform with EPA continuous monitoring requirements)



DUAL PASS TRANSMISSOMETER

Figure 3-1. Typical Transmissometer Configuration

The opacity of an effluent stream is a function of the light beam path length: the longer the measurement path length, the greater the resulting opacity for a given particulate concentration. The measurement path length at the transmissometer installation may not be the same as the stack exit diameter. However, existing opacity monitoring regulations usually require the correction of opacity measurements to the stack exit diameter. The following equation is used for this calculation.

$$\log (1 - Op_1) = \frac{L_1}{L_2} \log (1 - Op_2)$$

where: Op_1 = opacity at the stack exit

L_1 = stack exit diameter

L_2 = monitor pathlength

Op_2 = opacity based on L_2

The light attenuation characteristics of a particulate laden stream are dependent on the wavelength of the light passing through the effluent. In traditional visual opacity measurement, the in-stack opacity represents the attenuation of visible light. This convention restricts the optical characteristics of the transmissometer. Visible light encompasses the region of the electromagnetic spectrum between 0.3 and 0.7 microns (see Figure 3-2). Consequently, the transmissometer system must be designed for peak response within this range. Most transmissometers use a tungsten filament lamp as a light source. Figure 3-2 shows that the tungsten lamp's output encompasses a broader range than the visible spectrum. Part of the tungsten lamp's emission is also in the region where water vapor absorbs light strongly. Therefore, transmissometers must optically filter the lamp's output before it crosses the

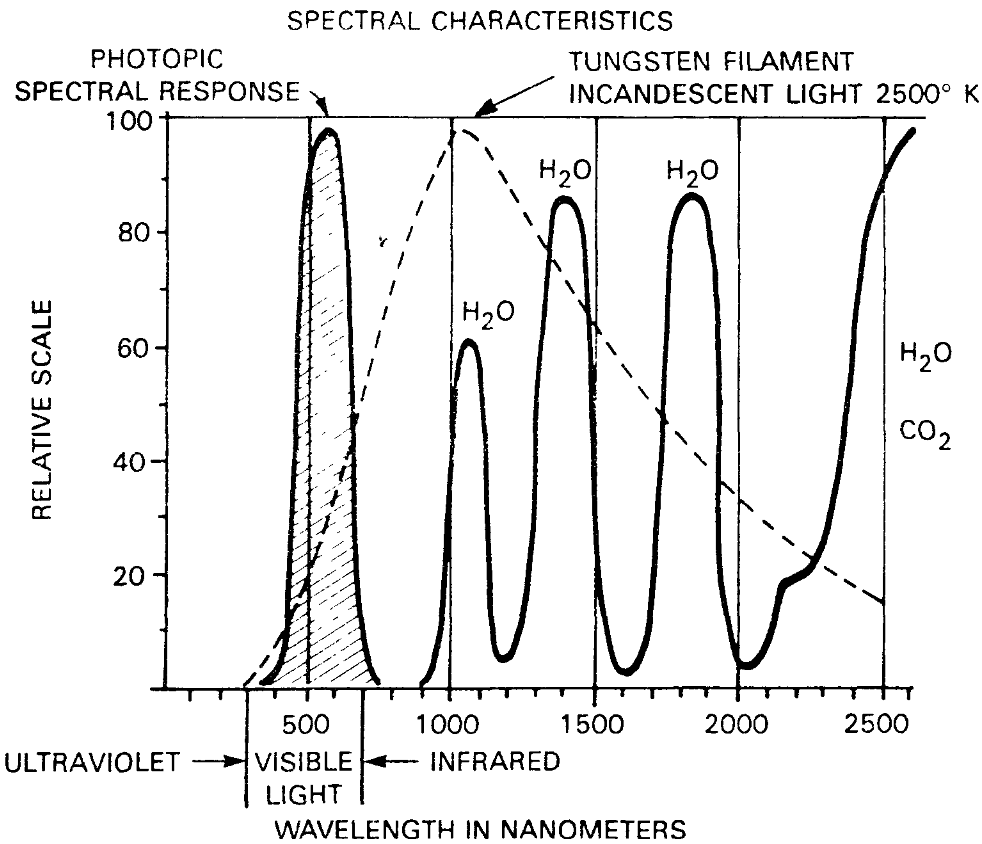


Figure 3-2. Electromagnetic Spectrum

stack effluent, both to eliminate water vapor interference and to provide a light beam of the proper spectral characteristics. The optical system for both the light source and the detector must be designed such that the peak and mean spectral responses are within the visible light range, as previously described, to minimize the adverse effects of water vapor and CO_2.

Most transmissometers use either a single- or dual-pass beam to determine the amount of light transmitted across a stack effluent relative to the amount of light emitted by the light source. Some dual-pass instruments use a multilobed, perforated, rotating disc, which alternately gates the light between measurement and reference signals. The reference beam is projected internally to the detector, with measurement and reference beams being compared on the same detector using time-shared optics.

Single-pass transmissometers cannot use the same techniques for generating the reference beam. Fiber optic cables may be employed to transmit a reference signal to the detector. Fiber optics are flexible "light pipes" that transmit light with minimal spectral distortion and reduction in intensity. With these cables it is possible to transmit a reference beam generated by a beam splitter around the outside of the stack and couple the light beam to the detector.

As with any line of sight optical measurements, optical alignment is important. The light source and detector must be aligned so that the light beam falls squarely on the detector. The transmissometer alignment must be carried out under actual stack conditions because of thermal expansion effects occurring when the stack is heated. Long slotted tube transmissometers are not practical if sagging occurs because of excessive tube length. Some dual-pass transmissometers employ special reflectors to reflect the light beam parallel to the incident light path independent of small variations in reflector alignment.

The transmissometer's optical system must be sensitive only to light actually transmitted through the stack effluent. Slotted tube transmissometers must be designed so that no light is reflected off the walls of the pipe and into the detector. The optical system of all transmissometers must be insensitive both to ambient light and to scattered light. Modulation of the light source may be used to eliminate the detection of ambient light. In this approach, the detector system is designed to respond only to light at the modulation frequency, thereby eliminating responses to ambient light. In order to avoid detection of scattered light, the light beam must be properly collimated. Simply put, collimation is the focusing of the light beam using lenses and apertures to prevent scattered light from reaching the detector. Figure 3-3 shows a typical collimation method. Collimation of transmissometers is characterized in terms of the angle of projection and angle of view of the instrument. The angle of projection is the total included angle which contains 95% of the light radiated from the lamp. The angle of view is the total included angle for which the detector has greater than a 5 percent response.

Sample Interface

The transmissometer's optical surfaces must be protected from the stack effluent. Particulate matter deposited on the optical surfaces can cause erroneously high opacity readings. The sample interface generally provides a constant flow of highly filtered air (purge air) across the optical surfaces to prevent particulate accumulation on the exposed surfaces. In addition, a method for isolating the optical surfaces in the event of a loss of filtered air should be provided. Some transmissometer models provide an automatic protection device that is actuated when a loss of filtered air is detected.

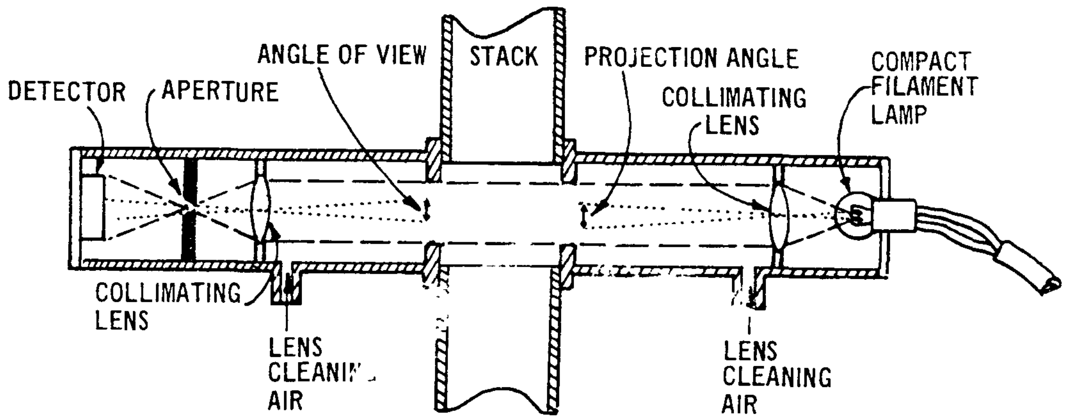


Figure 3-3. Transmissometer with Collimating Features.

Data Recorder

The data recorder provides a hard copy record of the analyzer output. Data recorders may range in complexity from strip chart recorders to mini-computers. The opacity may be recorded as the instantaneous value, the integrated value, or some combination of the two. Some systems provide a summary of excess emissions for each 1-hour or 24-hour period. It is important that the data recorder have sufficient resolution to permit proper calibration of the instrument. The recorder must be sensitive enough to enable the performance tests to be carried out, and should have a resolution of approximately 0.5% opacity.

Calibration Mechanism

EPA monitoring regulations require that the calibration of opacity monitors be checked daily (and adjusted if necessary) at the zero opacity level and at a prescribed upscale opacity level. These checks are referred to as zero and span checks. Most commercially available transmissometers provide an automated method of performing the zero and span checks. The most commonly encountered approach to performing a zero check for dual-pass instruments uses a mirror (located on the effluent side of the window separating the analyzer from the effluent) which can be rotated in and out of the light path. During the zero check, the mirror is automatically positioned in the light path, and it returns the same level of light to the analyzer as would be returned by the stack mounted reflector under clear stack conditions. The span check is accomplished by inserting both a calibrated filter and the zero mirror into the light path simultaneously to produce a simulated upscale opacity condition.

Design and Performance Specifications for Opacity Monitors

Instrument design and performance specifications for opacity monitors are contained in Performance Specification 1 of Appendix B, 40 CFR 60. The existing specifications were promulgated on October 5, 1975. Revisions to Performance Specification 1 were proposed October 10, 1979; however, final revisions to the specifications have not yet been promulgated. For the purposes of this discussion, the existing specifications will be used.

Performance Specification 1 includes design specifications for peak spectral response, mean spectral response, angle of view, and angle of projection. The peak and mean spectral response criteria require that transmissometers measure the attenuation of visible light. These specifications are important in ensuring the accuracy of transmissometer measurements, because the attenuation of light by a particulate laden stream is wavelength dependent. The angle of view and angle of projection specifications (i.e., collimation specifications) ensure that the accuracy of the measurements obtained by an instrument meeting these specifications will be relatively unaffected by scattered light. Performance Specification 1 includes general procedures for demonstrating that a particular instrument complies with the design specifications. However, because compliance with these specifications is essentially a design feature of the monitors, instrument manufacturers are only required to test one instrument from each month's production. Performance Specification 1 also includes performance specifications and compliance test procedures for calibration error, response time, zero drift, calibration drift, and an operational test period.

The calibration error test provides an evaluation of the accuracy, precision, and linearity of the analyzer portion of the transmissometer. This test is performed before the instrument is installed at the source, and is most often performed at the instrument manufacturer's facility. This test involves inserting calibrated neutral density filters into the light path of the transmissometer and comparing the instrument response to the known filter values. Three different filter values, spaced over the operating range of the instrument, are used, and five measurements are obtained with each filter. For each set of 5 measurements, the mean difference (a measure of accuracy) and the 95% confidence interval of the data set (a measure of the precision) are calculated. The calibration error for each filter is the sum of the mean difference and confidence interval, and must be less than 3% opacity.

The response time is defined as the time required for an instrument to reach 95% of the final value in response to a step change in the monitored value. The response time specification is 10 seconds for transmissometers; this ensures that opacity monitors will be able to track the relatively rapid changes in effluent opacity which are typical of many particulate emission sources.

Transmissometers are required to operate in the "normal operating manner" without malfunction or repair, first for a 168-hour conditioning period, and then for a 168-hour operational test period. Both of these requirements ensure that the transmissometer is capable of operating for sufficient periods of time to provide a useful amount of data.

During the 168-hour operational test period, the tests for zero drift and calibration drift are conducted. These tests involve an initial calibration of the transmissometer at the zero value and at an upscale value, followed by subsequent calibrations at 24-hour intervals during the 168-hour operational test period. The difference in zero readings at 24-hour intervals and the difference in span readings at 24-hour intervals are used to calculate the zero and span drift, respectively. Thus, the zero and calibration drift tests evaluate the stability of the instrument calibration over time.

Performance Specification 1 as initially promulgated does not contain an accuracy specification. This provision was omitted because of the absence of an independent method to measure in-stack opacity other than the use of transmissometers. Together, the prescribed design and performance specifications for transmissometers attempt to ensure the accuracy and validity of opacity monitoring data by limiting critical instrument design criteria and by requiring those performance tests that are feasible for transmissometers. Nonetheless, there is no means available for checking the absolute performance of the entire transmissometer system after it is installed on the stack except when the source is not operating. When clear stack conditions do exist, performance audit techniques (described in "Performance Audit Procedures for Opacity Monitors," cited previously) can be used to evaluate the performance of the opacity monitoring system.

Transmissometer Installation Criteria

An ideal transmissometer installation location would provide representative measurements of the effluent stream and easy access to the instrument for routine servicing and maintenance. Although both of these criteria are important, compromises must often be made.

Installation criteria for transmissometers are provided in Performance Specification 1. Generally, the transmissometer must be installed such that the flow of particulate material through the optical volume of the transmissometer is representative of the flow of the particulate matter through the entire duct or stack. Additional location criteria specified by Performance Specification 1 require that the transmissometer be installed: (1) downstream of all particulate control devices, (2) as far from bends and flow obstructions as possible, (3) in the plane of the bend when it is necessary to be located after a bend or turn, and (4) in accessible locations.

The above criteria provide only the most general framework for selecting a transmissometer installation location. In practice, proposed locations must be evaluated on a case-by-case basis. It must be kept in mind that almost all effluent streams are stratified with respect to particulate matter concentration. However, because relatively small effluent stream particles are responsible for the opacity of the effluent as measured by a transmissometer and because small particles tend to remain fairly well mixed and evenly distributed throughout the effluent stream, the effects of particulate stratification on opacity measurements are generally minimal.

When a particular transmissometer location is suspected of being non-representative, Performance Specification 1 allows the agency to require the source to conduct an examination of the opacity profile at the monitoring location. This type of test, usually performed with a portable transmissometer, facilitates a determination of whether a particular monitoring location is acceptable. The feasibility of conducting these opacity profile examinations has not been demonstrated, and specific procedures for conducting this type of test are not included in Performance Specification 1.

IV.

GAS CONTINUOUS EMISSION MONITORS

This section introduces the terminology and outlines some of the important measurement concepts associated with continuous emission monitoring of gaseous pollutants. A general discussion of monitoring systems and monitoring measurements is followed by discussions of basic monitor design and operation features, performance specifications, and installation considerations for gas CEMs. The variety and complexity of gas emission monitoring analytical techniques, combined with the wide variety of adaptations of these techniques to emission monitoring, prohibit an extensive discussion of technical details contained in other literature and in specific source testing regulations.

Gas Monitoring Systems and Monitoring Measurements

Monitoring of emission levels of gaseous pollutants is required at many sources. Almost all gas emission monitoring regulations require measurements in the units of the applicable standard, which are generally specified in units of concentration, mass emission rate, or production rate (i.e., mass of pollutant emitted per unit of product or mass of pollutant emitted per unit of heat input).

Individual emission monitors provide measurements of a particular gas constituent in units of concentration, usually expressed in ppm (parts per million). Thus, monitoring of other parameters in addition to pollutant concentration is required to determine emissions in units of the standards.

For example, to monitor mass emission rates of SO_2, both the concentration of SO_2 and the effluent volumetric flow rate must be measured. In some cases, monitoring of process or production rate parameters is required in addition to monitoring of pollutant concentrations.

Monitoring emissions of SO_2 and NO_x in units of mass of pollutant per unit of heat input ($lbs/10^6Btu$) at fossil fuel-fired steam generators presents a special case which deserves attention because of the frequency with which it is encountered. At steam generators, a pollutant monitor (measuring SO_2 or NO_x concentrations) and a diluent monitor (measuring O_2 or CO_2 concentrations) are used in conjunction with the F-Factor to calculate emissions in units of $lbs/10^6Btu$. In this situation, the accuracy of the SO_2 or NO_x monitor and that of the O_2 or CO_2 monitor directly affect the accuracy of the measured emission levels.

The F-Factor method of calculating emissions in units of $lbs/10^6Btu$ is included in the NSPS for steam generators, Subpart Da, and in the more recently promulgated Method 19, "Determination of Sulfur Dioxide Removal Efficiency and Particulate Sulfur Dioxide and Nitrogen Oxides Emission Rates from Electric Utility Steam Generators." There are a number of formulations of the F-Factor approach. The appropriate equation to be used depends on: (1) whether O_2 or CO_2 measurements are obtained, and (2) whether pollutant and diluent concentrations are obtained on a wet or a dry basis. The two equations which are applicable when all concentrations measurements are on a dry basis are:

$$E = CF \frac{20.9}{20.9 - \%O_2}$$

$$E = CF_c \frac{100}{\%CO_2}$$

where: E = emissions in $lbs/10^6 Btu$

C = pollutant concentration

F, F_c = constants for various types of fuels

$\%O_2$ = oxygen concentration

$\%CO_2$ = carbon dioxide concentration

The above equations show that errors in either the pollutant or diluent concentration measurements will affect the calculated emission values. Therefore, in assessing the accuracy of the emission monitoring data, the error contribution of both measurements must be considered.

CEMs may provide concentration measurements on either a wet or a dry basis. Wet concentrations measurements are equivalent to the ratio of the volume of pollutant to the total volume of effluent gases including water vapor. In contast, dry concentration measurements exclude the volume occupied by the water vapor and are, therefore, equivalent to the ratio of the volume of pollutant to the volume of dry effluent gases. For an effluent stream containing water vapor, wet basis measurements yield lower concentration values than dry basis measurements. At most sources, a significant fraction of the effluent gases is attributable to water vapor, and therefore, the distinction between wet and dry basis measurements is important. Care must be exercised when gas emission monitoring data are converted to units of the standard, or when CEM data are compared to Reference Method sampling values, to ensure that all measurements are expressed on the appropriate moisture basis.

The term "system" as it applies to gas emission monitoring often causes confusion. For example, an SO_2 monitor is composed of a number of components which function together to sample, analyze, and record effluent SO_2

measurements. The aggregate of the various components is typically referred to as a "monitoring system." It should be remembered that the proposed revisions to the performance specifications and corresponding test procedures for gas emission monitors evaluate the performance of the system, rather than the components within the system. At steam generators, where both a pollutant monitor and a diluent monitor are required, the term "system" may be used to refer to the combined monitoring system composed of the two monitors, or it may be used to refer to either monitor separately. Both usages are quite common, and it is often important to distinguish between the two usages in discussing monitoring at steam generators. The proposed revisions to the CEM performance specifications (October 10, 1979, Federal Register) redefine "system" to include both the pollutant and diluent monitors at steam generators. However, some of the performance specifications of the proposed revisions apply to each monitor separately, while others apply to the combined monitoring system.

Basic Features of Gas Emission Monitors

Gas emission monitors may be categorized into two general groups: extractive monitors and in-situ monitors. Extractive monitors withdraw a sample of the effluent stream and transport the sample to an analyzer at another location. In-situ monitors measure the gas concentration at the effluent stream sampling location: a sample is not removed. Both extractive and in-situ monitors are composed of subsystems performing separate functions. The major monitoring system components are the sample interface, the analyzer, and the data recorder. The nature of these components varies greatly between extractive and in-situ monitors.

Extractive Gas Monitors

The analyzer is the portion of the monitoring system that senses the gas component of interest and generates an output signal proportional to the concentration of that component. A wide variety of analyzers for SO_2, NO_x, CO_2, and O_2 are available for use in extractive monitoring systems. Commonly encountered analytical methods include such diverse techniques as: nondispersive infrared spectroscopy, differential absorption spectroscopy, chemiluminescence, pulsed fluorescence, electrocatalysis, and paramagnetism. Fortunately, NSPS performance specifications typically require evaluation of only the overall system performance, which allows monitor performance evaluations to be conducted without requiring familiarity with or knowledge of the above analytical techniques. Selection of the most appropriate analyzer is usually dependent on the source-specific conditions encountered and the gas components to be monitored.

Frequently, a single analyzer is used to determine concentrations of more than one gas component. For example, many analyzers employing ultraviolet differential absorption are used to monitor both SO_2 and NO_x concentrations. In some cases, a single analyzer processes samples obtained at several monitoring locations. Thus, the analyzer is time-shared between several sampling locations and costs are greatly reduced where monitoring of several emission points or effluent streams is required at a single facility. Although some manufacturers of CEM gas analyzers provide only the analyzer, others provide complete systems, including the sample interface, analyzer, and data recording components.

The sample interface for extractive monitoring systems performs three basic functions: (1) sample acquisition; (2) sample transport; and (3) sample conditioning. Samples are extracted from the effluent stream using either a single point or multi-point sampling probe. Particulates are usually removed from the sample stream by filtration. In all cases, the condensation of water vapor in either the sample transport lines or in the analyzer must be prevented. Therefore, where water is not removed at the sampling probe outlet (i.e., as a function of the conditioning system), heated sample transport lines are used to prevent condensation.

Most gas analyzers require that specific sample conditions at the analyzer inlet be maintained. Thus, sample conditioning systems are usually employed to remove particulates and water vapor from the sample stream and to ensure that the samples are within the temperature and pressure operating limits of the analyzer. The degree of water vapor removal is dependent on the analytical technique employed by the analyzer. For some instruments, removal of enough water vapor to prevent condensation within the analyzer is sufficient. For other instruments, water vapor severely impedes the measurement process, and essentially all of the water vapor must be removed. Water is usually removed by refrigeration of the sample and separation of the resulting condensate, or by permeation tube dryers.

Regardless of the design or configuration of the sample interface system, the sample interface must not affect the concentration of the gas constituent of interest. The two most common problems are absorption-adsorption of pollutant gases and dilution of the sample stream by air in-leakage into the system. In the case of absorption-adsorption, the sample stream gas concentrations are changed when constituent gases are trapped in the sample interface system prior to entering the analyzer. In contrast, sample stream dilution by air infiltration results in an erroneously low concentration of pollutant gases reaching the analyzer.

The proper calibration of an extractive monitoring system is verified by introducing calibration gas into the system. Calibration gases are quantitatively known mixtures of the gas of interest in an appropriate diluent gas. A zero gas (usually nitrogen or "clean" air) and a span gas (gas mixture with a concentration of approximately 90% of the maximum concentration which can be measured by the monitor) are used to verify proper instrument performance. For extractive monitors, the calibration gases must be introduced as near to the sampling probe as possible to provide a check of both the sample transport/sample conditioning system and the analyzer. If gases are introduced at the analyzer, as happens too frequently, then dilution or absorption effects in the sample interface may go undetected, resulting in errors in the monitoring data.

In-Situ Gas Emission Monitors

In-situ monitors analyze the gas concentration within the effluent stream. Most in-situ analytical techniques utilize optical analytical methods, in which the interaction of light with the gas component of interest is employed to generate an output signal proportional to the particular gas component concentration. Analytical techniques employed for in-situ monitoring include: ultraviolet differential absorption, second derivative ultraviolet spectroscopy, nondispersive infrared correlation spectroscopy, and electrocatalysis. Again, because the applicable monitoring regulations include only system performance specifications, monitoring systems can be adequately evaluated in most cases with little knowledge of these techniques.

With the exception of electrocatalytic monitors (used for O_2 measurements only), in-situ monitors project a beam of light across the duct (referred to as a path monitor) or project the light beam through a shorter segment of the effluent (limited path or point monitor). If the light source and detector are located on opposite sides of the effluent stream, the monitor is a single-pass instrument. If the light source and the detector are located on the same side of the effluent stream and a reflector is used to return the light source radiation to the detector, then the instrument is referred to as a dual-pass instrument (i.e., the light traverses the effluent twice). The distinction between single-pass and dual-pass in-situ monitors is important in determining the applicability of some instrument specifications. Dual-pass instruments are somewhat easier to deal with, because both of the critical components (light source and detector) are located at the same place and because the calibration procedures are generally simplified.

In-situ monitors are typically calibrated using calibration gas cells that contain known quantities of the gas constituent(s) of interest. These cells are placed in the light beam of the instrument during calibration. Difficulty has been encountered in calibrating some in-situ monitors, because the calibration procedure devised by the manufacturer does not always check the entire monitoring system. For single-pass instruments, the interference of the other stack effluents cannot be eliminated to provide a check of the instrument zero value.

The chief advantage offered by in-situ monitors, as compared with extractive monitors, is the virtual elimination of the sample interface system and of the corresponding sample handling problems. Disadvantages include the restriction that an in-situ monitor cannot be time-shared between several locations, calibration is more difficult, and effluent stream conditions are not always suitable for their use.

Performance Specifications for Gas Emission Monitors

The existing regulations for gas emission monitors (Performance Specification 2 for SO_2 and NO_x instruments, and Performance Specification 3 for O_2 and CO_2 instruments) were promulgated October 5, 1975. Proposed revisions to the Performance Specifications were included in the October 10, 1979, Federal Register. Since then, additional and extensive revisions have been considered. For the purposes of this discussion, the existing specifications are generally cited as examples, and where significant revisions are expected, they are pointed out.

The Performance Specifications for SO_2, NO_x, CO_2, and O_2 monitors are indeed performance specifications. The regulations do not mandate the use of any particular analytical technique or design criteria. Thus, the regulations allow a great deal of freedom in the analytical technique employed and in the electro-mechanical configuration of gas monitoring systems. Essentially, the only design specifications contained in Performance Specifications 2 and 3 are the implicit requirements that the monitors can be tested according to the prescribed methods.

The performance specifications applicable to SO_2 and NO_x monitoring systems are:

Relative Accuracy	$\leq$ 20%
Calibration Error	$\leq$ 5%
Response Time	$\leq$ 15 minutes
24-Hour Zero Drift	$\leq$ 2%

24-Hour Calibration Drift	≤ 2.5%
2-Hour Zero Drift	≤ 2%
2-Hour Calibration Drift	≤ 2%
Conditioning Period	168 hours
Operational Test Period	168 hours

The requirements for diluent monitors are similar to those listed above. Performance Specifications 2 and 3 also prescribe test procedures for determining compliance with the performance specifications. Each individual monitor must be tested to determine compliance with the specifications. Approval of a particular monitor design cannot be granted in place of the testing requirement, because of the source-specific problems and conditions that may affect monitor performance.

After a CEM is installed at a source, the monitor must first complete a 168-hour conditioning period. The purpose of the conditioning period is to ensure that the monitor can operate continuously in the "normal operating manner" for at least a week without requiring non-routine maintenance.

After the conditioning period is successfully completed, a 168-hour operational test is conducted. During this period, conformance with the other performance specifications is determined. The existing specifications allow the calibration error test to be performed either in the field or in the laboratory, and therefore, the calibration error test is not necessarily conducted during the operational test period.

During the operational test period, the monitor must again operate without failure or malfunction. Only routine maintenance can be performed during this period. Both the conditioning period and the operational test period serve to ensure that monitors that comply with the Performance Specifications can operate reliably and can achieve sufficient data availability to fulfill the purposes of the monitoring program.

The relative accuracy of gas CEMs is determined by conducting Reference Method sampling of the effluent stream and comparing the sampling results to concurrent CEM data. Under the existing specifications, the relative accuracy of SO_2 and NO_x monitors is determined in units of concentration by conducting a series of nine measurements using Reference Method 6 for SO_2 and Method 7 for NO_x. Concurrent moisture sampling is also conducted where the CEM provides wet basis measurements. The moisture sampling results may be used to adjust either the wet basis CEM data or the dry basis Reference Method data, so that the two sets of concentration data are expressed on the same moisture basis. The relative accuracy is computed from the differences between the 9 pairs of concurrent monitor/manual sampling results. The relative accuracy is calculated as the sum of (1) the absolute value of the mean difference and (2) the two-sided 95% confidence interval, divided by the mean Reference Method value (to express the relative accuracy as a percentage). The relative accuracy calculated using this procedure is actually expressed in terms of error; smaller calculated relative accuracy values indicate better monitor performance.

The results of the relative accuracy test will be affected by errors in the CEM data or by errors in the Reference Method sampling results. The Reference Methods are neither totally accurate nor totally precise; therefore, a portion of the allowed relative accuracy is attributable to the inherent variability of Reference Method sampling results. Although the relative accuracy test provides a direct measure of the accuracy of the monitoring data, the results of the test may be representative only at the effluent conditions encountered during the test.

The existing Performance Specifications do not require a relative accuracy test to be conducted for diluent monitors, even when a pollutant and a diluent monitor are employed to provide emissions data in units of lbs/10^6Btu at steam generators. Also, the existing specifications do not require a system relative accuracy test in which Reference Method sampling results expressed are compared to CEM data. However, the proposed revisions to the Performance Specifications do require a system accuracy. Thus, a measure of the accuracy of the CEM data in units of the standards will be available.

The calibration error test is a check of an instrument's accuracy, precision, and linearity in response to a range of calibration standards. The calibration error test for extractive gas monitors is performed by introducing into the monitoring system calibration gases equal to 0, 50%, and 90% of the span value. For in-situ monitors, calibration gas cells are utilized instead of calibration gases. The calibration error, a measure of the difference between the monitor response and the value of the calibration standard, is computed from the 5 measurements obtained using each gas.

Zero and calibration drift tests must be conducted on both a 2-hour and 24-hour basis. For this discussion, zero drift is defined as the change in the measurement system output over a stated period of time when the pollutant concentration at the time of the measurements is zero. Similarly, span drift is the change in the measurement system output over a stated period of time when the pollutant concentration at the time of the measurements is the same upscale value. Calibration drift is equivalent to span drift with the effects of zero drift removed from the upscale value measurements. For the 2-hour drift test, 15 sets of zero and span drift measurements are obtained over 2-hour intervals. For the 24-hour drift tests, 7 sets of drift measurements are obtained over 24-hour intervals. For all drift measurements, the parameter of interest is the change in the zero or span values over time. Thus, the 2-hour and 24-hour drift tests provide a basis for evaluating the stability of the instrument calibration over the short and long term.

Response time is defined as the time interval from a step change in pollutant concentration at the input of the measurement system to the time at which 95% of the final monitor output value is reached. The response time specification for pollutant gas monitors is 15 minutes; the response time specification for diluent monitors is 10 minutes. According to the existing specifications, the response time is determined by alternately injecting zero gas and 90% span gas into the monitoring system and measuring the time required for the monitor to reach 95% of the final response. For in-situ monitors, the alternation between the simulated zero conditions and the upscale calibration value determines the response time. According to the proposed revisions to the specifications, the response time would be determined by alternately switching from the zero value to monitoring the effluent for upscale response time determinations, and switching from the upscale calibration values to monitoring the effluent for downscale response time determinations. The change in the test procedure reflects the fact that the response time observed during the calibration procedures is not always representative of the response time associated with changes in the effluent concentration. The proposed method would provide a more realistic determination of response time.

Gas Monitor Installation Considerations

Obviously, from a data quality point of view, the location of gas CEMs is of fundamental importance. The accessibility of the location is also very important, however, because service and maintenance of the monitoring system is vital to achieving acceptable monitoring data availabilty. Often a trade-off between the most representative location and the most practical location is required.

Performance Specifications 2 and 3 prescribe monitor installation location criteria for pollutant and diluent monitors. Location criteria are particularly important where stratification exists. Stratification usually exists when the mean concentration and the concentration at any point more than 1 meter from the duct wall differs by more than 10%. Stratification of gaseous constituents may occur following any point in the effluent handling system where the mean concentration of the effluent stream is expected to change. Examples of situations where gaseous stratification may occur are: (1) following a point where two effluent streams having different concentrations are combined; (2) after a flue gas desulfurization (FGD) device; or (3) after points where air infiltration exists.

Where only a pollutant monitor is employed, the monitor must be located to sample a portion of the effluent stream where the concentration of the samples are equivalent to the mean concentration of the entire effluent stream. When both a pollutant monitor and a diluent monitor are required, the two monitors should be located so as to sample essentially the same portion of the effluent stream. Stratification due to air infiltration will not affect emission monitoring results expressed in terms of lbs/10^6Btu where both the pollutant and diluent monitors sense the same quantity of air infiltration, because the F-Factor method of computing emissions will cancel out the biases associated with dilution of the effluent stream by ambient air.

Where monitoring location stratification cannot be determined according to the prescribed criteria, tests may be required to determine whether stratification exists and/or whether particular sampling points will provide representative measurements. Specific procedures for conducting these tests have not been prescribed; the only practical method of performing the tests utilizes portable extractive monitoring equipment. An important aspect of this type of test is to ensure that the monitoring location is non-stratified and is representative at all processs operating conditions, because the concentration profile of the gas constituent(s) of interest may vary with process operating conditions. The need for consistent CEM measurement representativeness must be balanced against the ccst and feasiblity of performing numerous stratification tests. Realistically, stratification tests at two process conditions (80-100% and 40-60% of the maximum production rate) should suffice.

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16. ABSTRACT

This document provides a general introduction to continuous emission monitoring for those persons not previously involved in this field. Information is presented on continuous opacity monitoring, as well as instrumental and alternative monitoring techniques for SO_2 and NO_x (i.e., continuous wet-chemical measurement methods and fuel sampling and analysis methods). This document presents an outline and review of the fundamental concepts, terminology, and procedures used in a continuous emission monitoring program. Also presented are selected technical details necessary to understand the operation of emission monitors, the use of continuous emission monitoring data by air pollution control agencies, and references to other available documents which provide additional information.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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