

Compliance Monitoring Using Continuous Emissions Monitoring Systems (CEMS)

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List of Abbreviations

% VOL	percent volume
BLD	bag leak detector
CEM	continuous emissions monitor
CEMS	continuous emissions monitoring system
CGA	cylinder gas audit
Cl ₂	chlorine
CO	carbon monoxide
EAD	Environment Agency–Abu Dhabi
EE	excess emission
EAP	environmental action plan
EER	excess emission report
ESP	electrostatic precipitator
HCl	hydrogen chloride
HF	hydrogen fluoride
Hg	mercury
kg/cm ²	kilogrammes per square centimetre
mg/Nm ³	milligrammes per normal cubic metre
m ³	cubic metre
MDT	monitor downtime
MW	megawatt
MWH	megawatt-hour
Nm ³ /h	normal cubic metres per hour
NO	nitric oxide
NO ₂	nitrogen dioxide
NO _x	nitrogen oxides
O ₂	oxygen
PM	particulate matter
QA	quality assurance
QC	quality control
RAA	relative accuracy audit
RATA	relative accuracy test audit
Sm ³	standard cubic metre
SO ₂	sulphur dioxide
SOP	standard operating procedure
TSP	total suspended particles

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Definitions of Terms

Calibration Drift—Calibration drift (zero and span checks) is the value obtained by subtracting the known standard or reference value from the raw response of a Continuous Emissions Monitoring System (CEMS).

Continuous Emissions Monitoring System—Equipment used to sample and condition, analyse, and provide permanent record of emissions or process parameters.

Cylinder Gas Audit—This type of audit is an alternative relative accuracy test of a CEMS to determine its precision using certified gases. A cylinder gas audit (CGA) applies to gaseous pollutant or diluent CEMS and is not intended to audit other types of monitors associated with the CEMS such as flow or temperature monitors.

Data Acquisition and Handling System—Equipment used to record and report the data produced by an analyser in a CEMS.

Excess Emissions—The amount by which recorded emissions exceed those allowed by regulations, operating permits, and other applicable requirements.

Excess Emission Report—A report documenting the date, time, and magnitude of each excess emission episode occurring during the reporting period.

Monitor Malfunction—Any interruption in the collection of data as a result of the failure of any component of the CEMS to operate within specifications of the manufacturer or performance specifications.

Monitoring Plan—A plan submitted prior to actual installation of a CEMS that outlines information such as sampling location and instrument specifications.

Performance Audit—This type of audit is a quantitative evaluation of a CEMS operation.

Relative Accuracy Audit—This type of audit is an abbreviated version of a relative accuracy test audit, which was originally intended for auditing CEMS that were not designed to accept CGAs.

Relative Accuracy Test Audit—This type of audit is the primary method for determining the correlation of CEMS data to simultaneously collected reference method test data.

Summary Report—This report is a summary of all monitor and excess emissions information that occurred during a reporting period.

Systems Audit—This type of audit is a qualitative evaluation of a CEMS operation.

Purpose of This Guidance Document

This document has been prepared to assist entities in Abu Dhabi Emirate in evaluating and reporting Continuous Emissions Monitoring System (CEMS) data. CEMS provide data on the emissions of air pollutants and are typically located at plants that are large sources of criteria pollutant emissions and/or facilities that require accurate measurement of emissions over extended periods of time. This document provides information on CEMS equipment and the pollutants that are typically continuously monitored, the development of a Quality Assurance (QA) Plan, and reporting requirements.

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Section I. Background Information

This document provides guidance on the use of CEMS for the continuous monitoring and measurement of air pollutants. Environmental compliance air monitoring may be required in a project or facility's Construction Environmental Management Plan, Operation Environmental Management Plan, Decommissioning Environmental Management Plan, or operating permit.

1. Definition of the CEMS

A CEMS is an integrated system for continuously measuring pollutant concentrations or emissions rates and generally consists of a sample interface, pollutant analyser, data recorder, the associated electrical wiring, and other hardware. The CEMS includes the following major subsystems:

- Sample Interface—Used to perform one or more of the following tasks: sample acquisition, sample transportation, and sample conditioning, or the protection of the monitor from the effects of the stack effluent
- Pollutant Analyser—Senses the pollutant gas and generates an output proportional to the gas concentration
- Flow Rate Monitor (where applicable)—Senses the stack (duct) gas velocity, which is used in conjunction with the pollutant concentration to determine the mass emissions rate of the pollutant
- Data Acquisition and Handling System—Electronically records all measurements and automatically calculates and records emissions and heat input (where applicable) in the required units of measure.

2. Purpose of the CEMS

CEMS are used to measure air pollution emissions and other parameters (i.e., diluent gases and volumetric flow) from a variety of industrial sources. CEMS are typically used to

- Monitor compliance with air pollution emissions limits
- Provide data for emissions inventory applications
- Indicate a control system's performance.

3. Pollutants Monitored

The air pollutants typically monitored with CEMS are listed in **Table 1**. It has historically been more common to monitor criteria pollutants such as NO_x, CO, and SO₂. Only recently have continuous monitors for hazardous pollutants such as mercury (Hg), hydrogen chloride (HCl), and hydrogen fluoride (HF) been developed and begun to be deployed.

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Table 1. Air Pollutants Monitored with CEMS

Pollutant Name	Abbreviation	Effects of Pollutant (Cooper and Alley, 1986)
Nitrogen oxides	NO _x	NO _x contributes to smog; are injurious to plants, animals, and human health; and contributes to acidic deposition. NO _x reacts with reactive volatile organic compounds in the presence of sunlight to form photochemical oxidants (Cooper and Alley, 1986).
Sulphur dioxide	SO ₂	SO ₂ is associated with human health problems, damage to plants and animals, smog and haze through the formation of acid mists, and corrosion of materials (Cooper and Alley, 1986).
Carbon monoxide	CO	CO can cause harmful health effects by reducing oxygen delivery to the body's organs, such as the heart and brain, and tissues. CO also contributes to the formation of smog, which can trigger serious respiratory problems (Cooper and Alley, 1986).
Particulate matter	PM	PM damages human and animal health, retards plant growth, reduces visibility, soils buildings and other materials, and alters local weather (Cooper and Alley, 1986).
Total hydrocarbons	THC	THC reacts with NO _x in the presence of sunlight to form photochemical oxidants. THC is also measured as a surrogate for hazardous organic pollutants.
Opacity	Opacity	An opacity monitor is not technically a continuous emissions monitor (CEM) because it does not directly measure emissions. Rather, opacity has historically been used as a surrogate for particulate because opacity monitors are a relatively simple, inexpensive technology, whereas PM CEMS are more expensive and require much more maintenance.
Bag leak detector (BLD)	BLD	A BLD is also not technically a CEM because it does not directly measure emissions. Rather, a BLD is typically used because it is relatively low in cost, and it can measure changes in particulate concentrations at levels below the capability of most opacity monitors. Multiple BLDs can be used to more quickly locate leaks in fabric filter bags than a single BLD located at the outlet of a baghouse (fabric filter).
Mercury	Hg	The most dangerous form of Hg is methylmercury, which is typically produced when mercury is transformed by microbial activity. Methylmercury bioaccumulates, which means methylmercury gets more concentrated higher up in the food chain (e.g., algae to fish to humans) (USGS, 2009).
Hydrogen chloride	HCl	HCl is an acid gas. Acute exposures to hydrogen chloride can cause coughing and immediate burning or itching of the eyes, nose, throat, and/or the respiratory system.
Hydrogen fluoride	HF	HF is highly corrosive. Mild clinical effects include mucous-membrane irritation and inflammation, coughing, and narrowing of the bronchi. Severe clinical effects include almost immediate narrowing and swelling of the throat, causing upper airway obstruction. Emitted fluoride can be taken up from vegetation, soil, and drinking water and can cause fluorosis, which results in damage to teeth and bones.

Table 2 lists several industries where CEMS are used, including the pollutants measured by the CEMS. Table 2 is intended to represent “international best practices” for large facilities. That is, the CEMS that are checked would typically be used at some of the best large international facilities within that industry, but would not be used at all facilities within that industry. Note that Table 2 only focuses on continuous emissions monitoring; it does not deal with periodic monitoring or periodic stack testing. For example, annual or periodic stack testing for particulate matter (PM) and dioxins/furans is required for some industries (e.g., medical waste incinerators). Also note that the electrical generation units listed in Table 2 are units burning natural gas (rather than coal or oil); electrical generation units firing natural gas typically have fewer CEMS than units firing coal or oil. Table 2 shows that, of the industries presently in the the United Arab Emirates (UAE), cement kilns operating according to “international best practices” have the widest array of CEMS.

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Table 2. International Best Practice Usage of CEMS for Various Industries

Industry	CO	NO _x	SO ₂	THC	Opacity	PM	BLD	Hg	HCl	HF	CH ₄	Flow	CO ₂ or O ₂
Electrical generation (natural gas)	✓	✓										✓	✓
Cement kiln	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
Primary aluminum							✓			✓			
Electric arc furnace	✓				✓		✓						
Medical waste incinerator	✓	✓	✓		✓		✓		✓				✓
Municipal waste incinerator													
Sewage sludge incinerator													
Landfill											✓	✓	

4. Monitoring Locations

CEMS are most commonly located in an exhaust stack or vent. However, CEMS may also be used for fugitive emissions monitoring (e.g., emissions from building openings that do not have stacks or exhaust fans).

5. Monitoring Equipment

There are many systems for continuous monitoring commercially available. Many factors should be considered to determine the best equipment for a specific source. These factors include, but are not limited to, the type of system required, design characteristics, environmental requirements, maintenance and operational considerations, and Environment Agency–Abu Dhabi (EAD) requirements.

CEMS may be *extractive* or *in situ*. With *extractive gas monitoring systems*, gas is extracted from a duct or stack and transported to analysers for the measurement of pollutant concentrations. Extractive analysers are designed to monitor source-level gas concentrations, or they can be combined with dilution systems to measure lower pollutant concentrations. The choice of gas analysers for an extractive CEMS is important because some analytical techniques perform better than others in a specific source application or system design. One of three analytical methods is generally used to determine these concentrations: absorption spectroscopic, luminescence, and electroanalytical.

In situ gas monitoring systems consist primarily of an analyser that uses some type of sensor to measure the gas directly in the stack. There are two types of in situ gas monitoring systems currently in use. The first type is an across-stack (or path in situ) system that analyses the effluent that passes by a specific “line of sight” of the monitor, typically ranging from a few feet, to the full distance across the interior diameter of the stack or duct. The second type is a point in situ instrument, which analyses the effluent at one specific point or along a short path in the stack or duct.

Technical details on the application of CEMS at thermal power plants and associated emissions monitoring technologies are provided in **Annex 1**.

6. Quality Assurance Plan Requirements

A QA program is a type of management system that ensures quality control (QC) activities are performed. Examples of QC activities include preventive maintenance, daily calibrations, and quarterly audits. QC activities certify that generated data are

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complete, representative, accurate, and precise. Appropriately, all QA/QC program elements should be incorporated into a facility QA Manual. An outline for a CEMS QA Manual is provided in **Annex 2**.

The QA program, which is typically specified in a plant- or source-specific QA Plan, is the basis for assessing and maintaining the quality of CEMS data. A QA program has the following two distinct and equally important functions:

1. Assessment of data quality (accuracy and precision)
2. QC, which involves activities used to maintain or improve data quality.

These two functions form a control loop. When the assessment function indicates that data quality is inadequate, the QC function should be applied until data quality is acceptable. The quality and quantity of valid data dictate the amount or degree of QC to be used in the monitoring program.

The QA Plan is a valuable tool for the evaluation and improvement of the monitoring system by the source and regulatory personnel. The QA Plan should provide detailed written descriptions of all current QC activities. In this plan, the procedures used to set up the QA program should be stated as a clearly defined set of activities. These activities, or standard operating procedures (SOPs), should also be incorporated into the QA Plan. SOPs provide monitoring descriptions, company QA policies, monitoring system QC procedures, audit procedures, and recordkeeping and reporting requirements.

A well-written QA Plan, along with the equipment manufacturer's operation manuals, provides the CEMS Owner or Operator with most of the necessary information needed for proper monitor operation, maintenance, and QC. Additional information, such as the plant personnel's experience with the system, should also be incorporated into the QA Plan.

When updates or changes to any activities are necessary, the QA Plan should be revised to reflect those changes. This plan should be reviewed and revised by the CEMS Owner or Operator when changes are made to the CEMS procedures (ranging from operation to reporting).

7. Quality Control Requirements

A CEMS will provide valid, reliable data when the system is properly maintained and operated. This system should be maintained at regular intervals to ensure that it is operating within prescribed limits. Accordingly, each source Owner or Operator should develop and implement written QC protocols that describe in detail, complete, step-by-step procedures and operations for each of the following activities:

- Calibration of the CEMS
- Calibration drift determination and adjustment of the CEMS
- Preventive maintenance of the CEMS, including a spare parts inventory
- Data recording, calculations, and reporting
- Accuracy audit procedures, including sampling and analysis methods
- Program of corrective action for a malfunctioning CEMS.

QC activities are generally performed on a routine basis by the CEMS Operator or are automatically initiated by the CEMS. In either case, the Operator or some other designated individual should promptly review the results of all QC checks and take appropriate follow-up actions to correct any problems. The QA/QC evaluations of CEMS typically include the following:

- Daily checks
 - Calibration drift assessment—This type of assessment is used for zero/low-level and upscale/high-level calibration checks of the monitoring system.
- Periodic checks
 - Performance audit—This type of audit is used to check all of the individual CEMS components and factors affecting the precision and accuracy of monitoring data. Examples of performance audits include the following: cylinder gas audit (CGA), relative accuracy test audit (RATA), and relative accuracy audit (RAA). The RATA is typically performed by a third party, which brings its own measurement equipment to the site to perform a side-by-

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side comparison with the installed equipment, according to the testing reference method used to determine compliance with the standard.

- Systems audit—This type of audit is a systematic qualitative review of facilities, equipment, training, procedures, record-keeping, validation, and reporting aspects of a total QA system to determine the system’s capabilities.

Other frequent checks (operational or preventive maintenance) may be required depending on the CEMS manufacturer’s instructions and the Operator’s experience with the system. The Owner or Operator should include all additional checks on the daily/weekly/monthly logs. Logs may be either kept on paper or by computerised records. A useful way to chart the type and frequency of operational and maintenance checks is to create an activity matrix. The CEMS manufacturer’s manual is useful in creating this matrix. An example of this type of matrix is presented in **Table 3**.

Table 3. Example of a CEMS QC Activity Matrix

Activity	Frequency
1. Check system zero and span check results	Daily
2. Check cylinder pressures	Weekly
3. Check for alarms and any malfunction	Daily
4. Check components of dilution system on the CEMS (if applicable)	Bi-weekly
5. Check filters, desiccants, and dryers	As recommended by the manufacturer
6. Conduct performance audit	Quarterly
7. Check shelter temperature of the CEMS	Daily

Section II. CEMS Monitoring Reports

1. Format and Content of Reports

1.1 Emissions Data

Hourly, daily, and annual emissions data should be provided for each pollutant. Hourly data for each month should be reported in one data table (i.e., for a month with 30 days, there would be 720 hourly values in one table). Daily data should also be provided in one table (i.e., for a month with 30 days, there would be 30 daily values in one table). Annual data should be provided on a spreadsheet, with each monthly total as one line. Therefore, a complete report for 1 year would have 25 tables as outlined below:

- 12 hourly tables (one for each month), with approximately 720 rows each
- 12 monthly tables, with approximately 30 rows each (one for each day)
- 1 annual table, with one line for each of the 12 months.

Annex 3 contains an example workbook with spreadsheet templates of the various report tables oriented towards natural gas-fired power plants for the three different time intervals described:

1. **Annex 3a**—Example of a CEMS Hourly Emissions Report
2. **Annex 3b**—Example of a CEMS Daily Emissions Report
3. **Annex 3c**—Example of a CEMS Annual Emissions Report.

As noted in the example of a CEMS hourly emissions report, periods of instrument calibration or malfunction should be noted in the “Remarks” column. For periods of instrument malfunction or calibration, values entered into this table should be the average of those in the nearest 4 hours before and the nearest 4 hours after instrument malfunction or calibration, provided the plant

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power during those hours is equal to the power during instrument malfunction, $\pm 10\%$ of the rated power. **Annex 3d** provides examples on how to calculate values during instrument malfunction or calibration. For calibrations lasting 30 minutes or less, the average values for the remainder of that hour can simply be used (there is no need to calculate averages 4 hours before and 4 hours after).

If emissions standards for combustion sources are in the form of an exhaust stack concentration, they typically include the oxygen (O_2) level for which the measurements should be reported. This prevents compliance with the standard from being achieved simply by adding more excess air to the process or allowing ambient air in-leakage into the exhaust duct. **Annex 4** describes how pollutant concentration measurements are adjusted to conform to O_2 levels specified in the standard.

1.2 Quarterly Reporting

Presently, electrical generating units report quarterly to EAD. It is recommended that other industries that are similarly large sources of air pollution (e.g., primary aluminium smelters, large cement kilns, electric arc furnaces) also report quarterly. Quarterly reports that are to be submitted to EAD should include the following information:

- Facility information
- Monitoring Plan, which includes information and drawings with regards to monitor specifications
- Maps showing the plant location, monitoring locations, and potential receptor locations
- Hourly and cumulative emissions data, including an emissions inventory with total pollutants reported in tonnes
- Hourly unit operating information (e.g., load, heat input rate, operating time, flow rate), if being monitored by the CEMS
- Results of required certification, recertification, and QA tests (e.g., daily calibrations, RATAs)
- Certification statements from a designated representative (or an alternate representative), attesting to the completeness and accuracy of the data
- Excess Emission Report (EER), including a summary of the EER.

1.3 Excess Emission Reports

There are uses for CEMS data beyond permit provisions. EERs track the events when monitored emissions exceed the emissions standards. EERs can be used for several purposes. First, EERs can indicate if the source is using good operating and maintenance practices on its process and control equipment to minimise emissions. Second, EERs can provide EAD with data on upset conditions or trend data, indicating a degradation of control equipment performance. Lastly, EERs can provide a continuous record on the source's ability to comply with standards. This information can be used as a screening tool in inspections to target problems. EERs should include the following information:

- Total operating time of each source during the reporting period
- Documentation of excess emissions, including the following:
 - Date of each exceedance of the applicable standard
 - Start and end times of each exceedance of the applicable standard
- Magnitude of each exceedance of the applicable limit (exceedances in the units of the standard and averaging period shall be reported)
- Nature or cause of each exceedance of the applicable standard and averaging period, including occurrence due to startups, shutdowns, and malfunctions
- Corrective actions or preventive measures of each exceedance of the applicable standard
- Any mathematical factors used to convert emissions to units of the applicable standard
- Documentation of the CEMS's performance, including the following:
 - Date when monitoring system was inoperative (daily zero and span checks are exempt)
 - Start and end times when the CEMS was inoperative
 - Nature of system repairs or adjustments

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- Documentation of any time the monitor exceeded the instrument range (include the date, duration, nature or cause, and corrective action)
- A summary of the EER, conveying information on excess emissions and CEMS availability. The important numbers are the excess emissions (percentage of excess emissions) and monitor availability (percentage of process operating time that the monitor is operating and available to provide valid data). **Annex 5** provides an example on how to present data for the EER and CEMS performance summary.

2. How to Evaluate Monitoring Reports

When reviewing monitoring reports, certain criteria should be evaluated to ensure compliance with applicable regulations and EAD requirements. In particular, the Owner or Operator should thoroughly evaluate the following:

- Excess emissions (i.e., the number and percentage of measurements that exceed standards)
- Values close to emission limits
- Total air pollutant emissions (i.e., emissions inventory)
- CEMS availability
- QA/QC results.

Focusing the analysis on these criteria will help EAD evaluate facility compliance and overall CEMS performance.

3. Standards Used to Compare Results

It is important for the source Owner or Operator to know which regulation(s) cover the installation, certification, operation, QA, and data reporting for each CEMS. Although some activities such as sampling location, installation, and certification are usually consistent from one permit to another, activities such as QA (i.e., frequency of audits and audit pass or fail limits) or reporting requirements may be very different depending on the regulation, permit condition, or other requirements. Accordingly, the Owner or Operator should identify standards applicable to its facility, source, or process and compare the emissions data generated by the CEMS against appropriate standards.

Allowable emissions limits for criteria pollutants and other hazardous pollutants from stationary sources in Abu Dhabi Emirate were established by Ministerial Cabinet Decree No. 12 in 2006. Hydrocarbon fuel combustion sources (e.g., electrical generating units) are significant sources of pollution monitored by CEMS in Abu Dhabi; EAD has established air pollution emissions standards for hydrocarbon fuel combustion sources. These standards are the same as those outlined in the United Arab Emirates federal regulations and are listed in **Table 4**.

Table 4. Maximum Allowable Emissions Limits of Air Pollutants Emitted from Hydrocarbon Fuel Combustion Sources

Substance	Symbol	Sources	Maximum Allowable Emissions Limits (mg/Nm ³)
Nitrogen oxides (expressed as nitrogen dioxide [NO ₂])	NO _x	Fuel combustion units: <ul style="list-style-type: none"> ▪ Gas fuel ▪ Liquid fuel 	350 500
		Turbine units: <ul style="list-style-type: none"> ▪ Gas fuel ▪ Liquid fuel 	70 150
Sulphur dioxide	SO ₂	All sources	500
Carbon monoxide	CO	All sources	500
Total suspended particles	TSP	All sources	250

Note: mg/Nm³ = milligrammes per normal cubic metre.

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Annex 1: Application of the Continuous Emissions Monitoring System (CEMS) at Thermal Power Plants

1. Emissions Monitoring

Continuous Emissions Monitoring Systems (CEMS) are automated instrument systems that measure the amount of a pollutant in a gas stream. At thermal power plants, instrumentation to monitor the flue gas O₂ and carbon monoxide (CO) concentrations or the carbon dioxide (CO₂) concentration is routinely used as part of the control system to optimise the combustion efficiency. Additional monitoring systems can be installed and operated to measure concentrations of pollutants in the flue gases vented through the stack into the atmosphere. This annex presents background information about the use of CEMS for measuring sulphur dioxide (SO₂), nitrogen oxides (NO_x), and PM emissions in combustion flue gases and discusses the application of these monitoring systems at thermal power plants in the United States. This overview of emissions monitoring technologies and analyser manufacturers used by the electric utility industry for complying with the CEMS regulations is intended to provide relevant information to assist with the application of CEMS to thermal power plants in Abu Dhabi and other locations in United Arab Emirates (UAE).

1.1 SO₂ and NO_x Emissions Monitoring

This section of Annex 1 presents background information about the use of CEMS to measure SO₂ and NO_x emissions in combustion flue gases and discusses the potential application of these monitoring systems to thermal power plants in the size range currently in use or to be built at facilities in Abu Dhabi. The information in Annex 1 was presented in a report prepared by J.R. Jernigan and presented at the 7th International Conference on Emissions Monitoring, which was held in Paris, France, in February 2006. The report presents an overview of the SO₂ and NO_x CEMS installed at U.S. electric utility power plants as part of the requirements under the U.S. Environmental Protection Agency's (U.S. EPA's) program to control acid rain in the eastern United States.

More than 3,000 CEMS have been installed and certified at U.S. electric utility power plants to meet the requirements of national emissions standards and emissions trading programs. The use of these CEMS has resulted in extensive experience being gained by the U.S. electric utility industry regarding the most reliable air pollution emissions monitoring technologies and analyser manufacturers. Over the years, the availability of more reliable pollutant analysers, including flue gas flow rate and moisture monitors, has increased significantly. As a result of the continuous monitoring regulatory requirements, the demand for extremely accurate and reliable equipment for CEMS has also increased to meet the tighter precision and reliability requirements specified. The monitoring instrumentation available today is based on improved analytical techniques and is equipped with enhanced electronics, programmable software capabilities, and troubleshooting diagnostics.

1.1.1 Sample Acquisition Techniques

A CEMS used to measure SO₂ and NO_x emissions incorporates one of three sample acquisition systems: dilution-extractive, non-dilution extractive (i.e., sampling without dilution of the sample gas), and in situ. Inherent differences exist among the three sampling techniques, and thus each technique has distinct strengths and weaknesses, which should be carefully evaluated when selecting an appropriate technique for a specific application. The sample acquisition techniques chosen by electric utility companies in the United States are presented in **Table A-1**. The following sections of Annex 1 address the principles of operation for the most widely used and currently available equipment and the technological advancements for each sample acquisition technique.

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Table A-1. SO₂ and NO_x CEMS Installations by Sample Acquisition Method at Electric Utility Power Plants Participating in U.S. EPA's Acid Rain Program^a

Sample Acquisition Method	SO ₂ CEMS (1,045 Analysers)	NO _x CEMS (3,193 Analysers)
Dilution-extractive systems (In-stack and out-of-stack)	87.9%	47.2%
Non-dilution extractive systems (Cool/dry and hot/wet)	10.0%	51.5%
In situ systems ("Point" method and "across-stack" method)	2.1%	1.3%

^a Distribution is based on monitoring practices reported by U.S. electric utilities in 2003.

1.1.1.1 Dilution-Extractive Systems

Most of the SO₂ CEMS and approximately one half of the NO_x CEMS installed at U.S. electric utility power plants to meet U.S. EPA monitoring requirements were dilution-extractive systems. These types of systems are extractive systems that dilute the sample gas with dry contamination-free dilution air to a level below the dew point of the diluted flue gas to eliminate condensation problems in the CEMS (in lieu of using a moisture condenser). The main reason for selecting a dilution-extractive system is its ability to measure flue gas pollutant concentrations on a wet basis. Many SO₂ emissions standards applicable to thermal power plant in the United States require emissions to be reported as a mass emissions rate (i.e., kilogrammes [kg] of sulphur dioxide per hour [SO₂/hr]). All flue-gas flow-rate measuring techniques are on a wet basis; consequently, wet basis SO₂ emissions data can be used more conveniently to calculate SO₂ mass emissions rates. Additionally, the requirement to measure CO₂ added to the convenience of using a dilution-extractive system because CO₂ is measured as the diluent gas (instead of O₂) in dilution-extractive systems. The diluted sample is analysed by pollutant and CO₂ monitors operating at or near ambient concentration ranges. The most unique component of a dilution-extractive system (relative to other extractive systems) is the dilution-sampling probe. There are two basic types of dilution-extractive probes: in-stack, in which the dilution of the flue gas is performed in the probe, and out-of-stack (ex situ).

- **In-stack dilution-extractive probe.** The in-stack probe design is equipped with coarse and fine filters for removing PM from the stack gas prior to sample dilution, a quartz or glass critical orifice for flow regulation, and an air-driven aspirator and venturi for dilution of the sample gas. Approximately 86.4% and 81.0% of the SO₂ and NO_x, respectively, of the dilution-extractive systems used are the in-stack type.
- **Out-of-stack dilution-extractive probe.** The out-of-stack device uses the same basic dilution-extractive sampling technology as the in-stack dilution-extractive probe; however, the out-of-stack device is designed to constantly heat the sampling assembly and all critical parts are mounted out of the stack for quick access and easy maintenance.

The principle difference is that undiluted stack gas is continuously drawn through the sampling probe tube into the sampling chamber by a bypass pump at a rate of 1.5 litres per minute (Lpm) to 15 Lpm. A vent in the sampling chamber ensures a constant flow of "fresh" stack gas through the sampling chamber. The dilution probe draws a small sample of the gas out of the sampling chamber through a sampling tube at a flow rate determined by the critical orifice of the probe. The operation of the dilution-extractive probe at this point is the same as previously described.

Dilution air-cleanup system. Dilution-extractive probe systems require a constant source of contamination-free dilution air. The compressed air supply should be dry and delivered at constant pressure (e.g., approximately 6.3 kilogrammes per square centimetre [kg/cm²]). Additionally, the dilution air should be free of oils, particulates, CO₂, NO_x, and SO₂. A plant's compressed air system does not generally provide dilution air to the needed specification; therefore, an additional air-cleanup system is required. In U.S. dilution-extractive CEMS, the air-cleanup system is the critical component of the dilution-extractive system. Compressed air either from the plant's compressed air supply or from a dedicated air compressor is first filtered for particulates, and then liquid and oils condensate by a coalescing filter. Oil removal is necessary to prevent the contamination of silica gel or other drying agents in the heatless air dryer. Additional drying of the dilution air is performed by a heatless dryer that can dry the air to approximately -73°C. The CO₂ extractor uses two columns with different adsorbent materials to adsorb any CO₂ in the dilution air. Some air cleaning systems may add a CO to CO₂ converter before the CO₂ extractor if the analysers respond to interferences from CO. A charcoal filter trap may also be added to remove any hydrocarbons that may be in the dilution air. An

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additional desiccant dryer may be added to provide additional moisture removal. A submicron filter removes any particulates that may be released from the upstream desiccant traps.

Gas sample dilution ratios. Dilution ratios typically range from 50:1 to 300:1. The dilution ratio most widely used by U.S. sources is 100:1. The sample gas flow rates from the various dilution probes range from 50 millilitres per minute (mL/min) to 300 mL/min. Two criteria are used to determine the desired dilution ratio: (1) the analyser span range should correspond to the diluted sample gas concentration, and (2) the ratio should be selected to ensure that no condensation occurs in the sample line at the lowest possible ambient temperature.

Sample umbilical bundles. The sample umbilical bundles of dilution-extractive systems usually consist of four to six separate lines; one Teflon line for sampling, a second Teflon line to deliver calibration and purge gases to the probe, a third line to deliver dilution air to the probe, sometimes a fourth line to monitor the vacuum in the probe, and sometimes one or two “spare” Teflon lines. The spare lines are often used for diagnostic purposes (e.g., resolving or isolating leak problems) or for back-up monitoring equipment. The diluted gas sample line should be at least 0.95 centimetres (cm) in diameter and, if the overall sample line length exceeds approximately 107 metres (m), a 1.27-cm sample line may be needed to reduce the pressure drop between the probe and the monitors. High pressure drops may prevent adequate sample flow to the monitors or cause condensation problems. Using a 1.27-cm sample line over long distances, however, can significantly impact response times (response times for a 0.95-cm line are typically 15 seconds for every 30.5 m) such that time-sharing a CEMS between two locations may be precluded. Heat-traced umbilical bundles are required only in very cold ambient conditions or when dilution ratios less than 25:1 are used in climates subject to below freezing ambient conditions in the winter.

1.1.1.2 Non-Dilution Extractive Systems

Non-dilution extractive systems are classified as “cold/dry” or “hot/wet” systems. For cold/dry systems, the moisture is removed from the flue gas sample prior to entering the analysers. Electric utilities in the United States predominately use cold/dry systems. For hot/wet systems, the moisture is not removed from the flue gas sample prior to entering the analysers. Use of the hot/wet system is very limited, with less than 0.6% of the total U.S. SO₂ CEMS using them and less than 0.7% of the total NO_x CEMS using them.

Typical cold/dry non-dilution extractive systems have four common subsystems:

- Effluent/CEMS interface
- Sample transport system
- Sample moisture removal system
- Pollutant and diluent analysers.

Effluent/CEMS interface. The effluent/CEMS interface typically consists of a corrosion-resistant rigid probe, positioned at a representative location in the effluent. A coarse filter made of sintered stainless-steel or porous ceramic material is used to filter out PM ranging from 10 microns (µm) to 50 µm. Historically, the coarse filter was located at the probe inlet; however, some current designs have the filter positioned out of the stack for ease of maintenance.

Sample transport system. The sample transport system begins at the junction between the probe and the sample transport line, usually positioned just outside the stack or duct. Sample transport systems consist of heated sample transport lines and a mechanism such as a pump to move the gas sample. The sample tubing is usually a non-reactive material such as Teflon and the parts of the sample pump exposed to the flue gas are coated or fabricated from non-reactive materials. The sample pump should be designed so no lubricating oil can contact and contaminate the sample gas and no air in-leakage occurs. The most common types of pumps to meet these specifications are diaphragm and ejector pumps.

Sample moisture removal system. The sample moisture removal system provides a clean, dry, interference-free sample to the analysers. Two moisture-removal methods (i.e., condensation and condensation/permeation) were primarily used by U.S. sources in sample moisture removal systems.

Condensation systems rapidly cool the sample, thereby condensing sample moisture. The condensed moisture is trapped and periodically removed from the condenser assembly. To avoid absorption of the target gases by the condensed liquid, precautions are usually taken in designing condensers and traps that minimise contact between the condensate and the cooled

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sample. Two basic techniques are generally used to prevent the trapped condensate from contacting the target gases. The first and most common technique uses a standard compressor-type refrigeration unit; the other technique uses a thermoelectric plate chiller, which is a solid-state unit with no moving parts.

Permeation dryers are used in conjunction with refrigerated condensers at several U.S. sources to provide additional moisture removal in the event of moisture carryover from the upstream condensers. This technique is based on the selective permeability of water through a membrane. Permeation occurs continuously as moist stack gas flows in one direction through the dryer, while dry purge air flows counter currently on the other side of the membrane.

Pollutant and Diluent Analysers. Pollutant analysers (e.g., analysers for NO_x, CO, SO₂) continuously monitor pollutants of concern. Diluent analysers, such as O₂ and CO₂, allow for measurements made by the pollutant analysers to be corrected to the O₂ level specified in the emissions standard, if the emissions standard is in the form of a specified flue gas concentration. Correcting to a specific O₂ level prevents excess air or duct in-leakage from creating artificially low stack concentration values.

1.1.1.3 In Situ Systems

As the name implies, in situ gas monitoring systems are designed to measure gas concentrations directly in the stack or duct, without extracting samples for external analysis. Two types of in situ monitoring systems are currently in use. The first type of an in situ monitoring system is an across-stack (or path in situ) system that analyses the effluent passing by a specific "line of sight" of the monitor, typically ranging from a few feet to the full distance across the interior stack or duct diameter. Approximately 0.3% of the SO₂ CEMS and 0.1% of the NO_x CEMS used in U.S. EPA's Acid Rain Program are the path in situ type. The entire path in situ CEMS measure flue gases by differential optical absorption spectroscopy. The U.S. EPA distinguishes between path and point analysers by the percentage of the stack or duct diameter (or equivalent diameter for non-circular ducts) represented by the measurement path. Instruments that measure gas concentrations along a path less than or equal to 10% of the diameter are point analysers. If the measurement path is greater than 10% of the equivalent diameter, then the instrument is considered a path analyser.

The second type of in situ monitoring system is a point in situ instrument, which analyses the effluent at one specific point or along a short path in the stack or duct. Approximately 1.8% of the SO₂ CEMS and 1.2% of the NO_x CEMS in the U.S. EPA Acid Rain Program are point in situ types. All point in situ systems measure flue gas by ultraviolet (UV) second-derivative spectroscopy.

1.1.2 Gaseous Continuous Emission Monitors

The following subsections provide a brief overview of the SO₂, NO_x, CO₂, and O₂ monitors that were most widely used at U.S. electric utility power plants.

1.1.2.1 SO₂ Monitors

SO₂ monitoring technologies are well established, and several of these monitors (e.g., fluorescence and UV spectrophotometric monitors) now incorporate a microprocessor, enabling the Operator to check certain monitor operating parameters, perform calibrations automatically, and perform numerous diagnostic functions. A brief overview of these technologies is provided below.

Fluorescence monitors. Fluorescence SO₂ analysers, both pulsed and continuous UV light source types, were originally manufactured for ambient air monitoring. Ambient air SO₂ concentrations are in the parts per billion (ppb) range, and these units operate well at that low concentration. Because the fluorescence technology was a proven technology in low concentration ranges and was well-matched for dilution probe applications, it was chosen by approximately 90% of the U.S. sources with dilution-extractive systems for monitoring SO₂.

UV spectrophotometric monitors. Several manufacturers offer UV and two (i.e., Teledyne/Monitor Labs and Sick Maihak) offer second-derivative spectroscopic UV SO₂ monitors for in situ and extractive applications. UV-type SO₂ monitors have proven to be reliable instruments, and as with many other monitoring systems, electronic components (e.g., for optical contamination and lamp current compensation) have been improved over the past 5 years. Because the UV spectroscopic-type SO₂ monitors were either used in extractive or in situ CEMS, less than 15% of the U.S. SO₂ analysers are the UV spectroscopic types.

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1.1.2.2 NO_x Monitors

Typically, only chemiluminescence, UV spectrophotometric, or infrared (IR) monitors are used for monitoring NO_x . The following paragraphs present a brief overview of recent advances in chemiluminescence and UV spectrophotometric monitors.

Chemiluminescence monitors. Approximately seven different chemiluminescence monitor vendors are used by U.S. sources for NO_x monitoring. These monitors have been installed and operated at utility sites for years and have a proven performance record. Approximately 96.6% of the NO_x monitors were chemiluminescence monitors. Similar to SO_2 monitors, several of these monitors now incorporate a microprocessor, enabling the Operator to check certain monitor operating parameters, perform calibrations automatically, and perform numerous diagnostic functions. If ammonia interference is a potential problem, catalytic converters are available that will convert nitrogen dioxide (NO_2) to nitric oxide (NO) without converting ammonia to NO. Essentially all chemiluminescence monitors incorporate a high-vacuum sample chamber to minimise quenching (absorption of the fluorescent light by other molecules).

UV spectrophotometric monitors. Several vendors offer UV spectrophotometric and second-derivative spectroscopic analysers for monitoring NO_x . Similar to the chemiluminescence monitors, UV spectrophotometric monitors have been used to monitor NO_x emissions at numerous electric utility power plants prior to the origination of U.S. EPA's Acid Rain Program; however, less than 3% of UV spectrophotometric monitors were used for NO_x monitoring. UV spectrophotometric analysers require sample filtering to remove PM and sample conditioning or heated sample cells to maintain the sample gas temperature above the dew point. Various design modifications and improvements to the electronic components (e.g., isolating the electronic and optic components from the sample cell) have been implemented.

1.1.2.3 CO_2 Monitors

Essentially, all CO_2 monitors used IR-based technologies to detect CO_2 ; either non-dispersive IR or gas filter correlation technology is used. Before U.S. EPA's Acid Rain Program was started, CO_2 monitors were generally considered to be less reliable and less accurate (for the concentration ranges typically observed in flue gas) than O_2 monitors. When using a dilution-extractive CEMS, however, the relative differences, advantages, and limitations between CO_2 and O_2 monitors are not an issue. A CO_2 monitor should be used to determine diluent concentrations for a dilution-extractive CEMS, and CO_2 mass emissions should also be reported.

1.1.2.4 O_2 Monitors

Approximately 75% of the U.S. O_2 monitors are paramagnetic monitors, and the remaining O_2 monitors are primarily electrocatalytic O_2 analysers. These monitoring technologies have been used for many years and provide reliable O_2 emissions data.

1.1.3 Flue Gas Flow Monitoring Techniques

Most commercially available flue gas flow monitors operate using one of the five principles for measuring velocity and volumetric flow: ultrasonic pulse detection, differential pressure, thermal detection (convective cooling), audible acoustic detection, and optical scintillation. The five varieties of flow monitors are stack or duct mounted and operate as a component (including a microcomputer, pressure transmitters, and temperature transmitters) of a system. Two other types of flow monitoring systems are available (i.e., fan efficiency and IR detection); however, these two types have yet to be used by U.S. sources.

1.1.3.1 Ultrasonic Flow Monitors

Approximately 62% of all flow monitors used in the U.S. EPA Acid Rain Program are ultrasonic-type monitors. The volumetric flow rate of stack gas is measured by transmitting ultrasonic pulses across the stack in both directions. The tone pulses are accelerated or retarded due to the gas velocity in the stack. The time required to traverse the distance of the stack travelling with and against the flow is a function of the sound velocity and the effluent velocity. Stack flow can be calculated based on the difference in the times required to traverse the stack in both directions. The ultrasonic pulses should traverse the stack or duct at a minimum angle of 10 degrees; however, traverses between angles of 40 degrees and 70 degrees tend to provide the best results, as long as the traverse path length is not so long that the ultrasonic pulses become difficult to detect.

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1.1.3.2 Differential Pressure Flow Monitors

Approximately 30% of all flow monitors used in the U.S. EPA Acid Rain Program are differential pressure-type flow monitors. Three different types of commercially available flow monitoring devices are based on measuring differential pressure: S-type pitot tubes, the Fechheimer dual-manifold pitot probe, and annubars. The principles of operation, which differ somewhat among these three types of flow monitoring devices, are discussed in Section 1.2.1 of this annex.

The S-type pitot tube is designed after the Stausscheibe, or reverse type pitot tube, as described in U.S. EPA's Method 2 in 40 *Code of Federal Regulations* (CFR) Part 60, Appendix A. The probe is constructed of two inline tubes. The sampling point of the probe consists of two opposing open faces perpendicular to the traverse axis. A side view of the probe resembles two stacked tubes with the ends tapered away from one another and the openings planed parallel to the horizontal axis.

The Fechheimer dual-manifold pitot probe consists of flow sensors mounted on two multipoint averaging manifolds. The probe design consists of two manifolds (tubes) welded together with a truss plate. The truss maintains a distance between the manifolds in a plane perpendicular to the flow and the stack wall. One manifold averages multiple points of impact pressure, and the other manifold averages multiple points of wake pressure. The impact and wake pressure averages are registered by the flow transmitter. This technology is used in numerous gas flow monitoring applications other than flue gas.

The annubar flow monitoring technology is a multipoint, dual-chambered probe. The probe averages multiple inline (impact and wake pressures) sample points across the stack diameter. The interior of the probe consists of tubes within a tube. The exterior tube shrouds two averaging chamber tubes. The inner tubes consist of the impact differential pressure chamber and the wake differential pressure chamber. Precision pressure points are tapped through the exterior tube into the inner tubes. The pressure registered at the flow transmitter is the average across the stack. Although this technology has been used for many airflow monitoring applications over the years, only 9.4% of all differential pressure type flow monitors in the U.S. EPA Acid Rain Program are annubar-type probes.

1.1.3.3 Thermal Flow Monitors

Approximately 5% of the flow rate monitors installed in the U.S. EPA Acid Rain Program are thermal flow monitors. Thermal flow monitors measure the electric power required to maintain a constant temperature of approximately 24 degrees Celsius (°C) to 38°C above the exhaust gas temperature in a flow sensor. The monitors are available for both single-point and multipoint analyses, and non-sensing components of the systems can be constructed from various corrosion-resistant metals.

1.2 PM Monitoring Technologies

Although CEMS have extensively been used for many years to measure SO₂ and NO_x emissions from power plants, only relatively recently have CEMS begun to be used to measure PM emissions from thermal power plants in the United States. This section present background information about the use of CEMS to measure PM emissions in combustion flue gases and discusses the potential application of these monitoring systems to PM emissions sources currently in use or to be built in Abu Dhabi Emirate. The information presented in this section is an adaptation of a recent status report prepared by RTI International for U.S. EPA that describes the application of PM CEMS to coal-fired electric utility power plants.

1.2.1 Principles of Operation

A variety of solid particle measurement principles are applied to the development of PM CEMS. With the exception of one technology, the current PM monitoring technologies provide only an indirect measure of the PM concentration or mass in a gas stream. Consequently, for application as a PM CEMS at a given site, each instrument should be capable of being calibrated against some direct measurement of actual PM emissions from the individual source such as that obtained by conducting a source test using U.S. EPA Method 5. For PM monitors currently commercially available, the monitoring technologies most commonly used for PM CEMS applications are either light-scattering or beta-ray attenuation. Additional measurement technologies presently receiving considerable attention for application to PM CEMS include probe electrification, light extinction, optical scintillation, harmonic oscillation, and other technologies. A summary of each of these technologies follows.

Light scattering. A light-scattering PM monitor operates on the principle that light falling upon particles in a gas stream is scattered in various directions. The amount of light scattered is a function of several parameters, including the concentration, size, shape, and colour of the particles in the path of the light. A light-scattering instrument includes a light source and a sensor

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that detects the amount of light scattered in a specific direction. The sensor generates a signal that is proportional to the amount of light scattered, and that signal is then correlated to the concentration of PM. Light-scattering instruments generally use pulsed light to reduce interference from other light sources. These instruments also are equipped with a second light source used as a reference light to determine if any degradation of the primary light source has occurred.

Beta-ray attenuation. The operation of a beta ray–attenuation type of PM monitor is based on the principle that for most materials, the attenuation of beta rays is proportional to the mass of material present. The PM monitors that use this technology typically are referred to as beta gauges. Beta-gauge PM monitors include a beta-ray source (typically carbon-14) and a filter media in the form of a tape that is fed through the instrument at predetermined intervals. The instrument operates in batch mode by taking a beta count of clean filter media, collecting the PM on the media, taking a second beta count on the media after sample collection, and comparing the baseline (before) and post-sampling (after) beta counts. The difference between the baseline count and the post-sampling beta count is proportional to the mass of PM collected on the filter media. A typical batch cycle for a beta-gauge PM monitor is approximately 15 minutes, consisting of a 2- to 3-minute baseline measurement, an 8- to 9-minute sample collection period, and another 2- to 3-minute post-sampling measurement period. Most beta-gauge PM monitors also measure the volume of the sample gas extracted for each sample.

Probe electrification. The probe electrification PM monitor operates using two principles. First, the friction of particles impacting a sensor generates a small electrical current in the sensor. Second, a small electrical current is also generated when charged particles pass near, but do not impact, a sensor. The electrical current produced by the friction of impacting particles is proportional to the momentum of the particles. This principle is also known as the triboelectric effect, and it has been used primarily for fabric filter (baghouse) bag leak detectors. Factors that affect the signal generated in a triboelectric device include the velocity, size, composition, and charge of the particles in the gas stream. Although sometimes marketed as continuous PM monitors, probe electrification instruments generally cannot meet the correlation criteria in the standardised performance specifications developed by the U.S. EPA for PM CEMS (discussed in more detail later in this section).

Light extinction. The light-extinction PM monitor operates on the principle that light passing through a gas stream is attenuated by the particles in the stream. Comparing the intensity of the light source to the intensity of light at a receptor provides an indication of the concentration of particles in the gas stream. The receptor can either be located at the opposite side of the stack (a single-pass instrument) or on the same side of the stack as the light source (a double-pass instrument). Light-extinction instruments, also known as transmissometers, are commonly used as the measurement components of Continuous Opacity Monitoring Systems (COMSs). Similar to probe electrification instruments, light-extinction monitors generally cannot meet the correlation criteria specified in standardised performance specifications.

Optical scintillation. An optical scintillation PM monitor operates on the principle that particles in a gas stream cause variations in the amplitude of light received by a sensor. The greater the concentration of particles in the gas stream, the greater the variation in light amplitude (scintillation) at the sensor. This type of instrument generates a signal, based on the variations in light amplitude, which can then be correlated to PM concentration.

Harmonic oscillation. A harmonic oscillation PM monitor operates on the principle that the vibration, or oscillation, of a tube (or rod) fixed at one end is proportional to the mass of the tube. The most widely used harmonic oscillation monitor on the market includes a filter attached to the end of a small tube. An electronic sensor measures the vibration of the tube. As the gas stream sample is drawn through the tube and particles are collected on the filter, the mass of the tube and the filter increases and alters the frequency of the oscillation. The mass collected on the filter can be determined by comparing the baseline frequency to the frequency at any time. Although marketed as a continuous monitor, the current models are not designed for long-term use. Once the filter becomes saturated, which can take anywhere from a few hours to a few days depending on the PM concentration, the monitor should be taken offline for filter replacement.

Other technologies. Adaptation of other PM measurement technologies has been tried for application to PM CEMS. One technology called “acoustic energy” operates by detecting shock waves caused by particles impacting a probe inserted into the flue gas. The number of impacts and the energy of each impact measured are used with the flue gas velocity to calculate particulate mass. An acoustic energy PM monitor was initially included for testing in a U.S. EPA–sponsored PM CEMS field demonstration program conducted on a hazardous waste incinerator in the mid 1990s. Although this technology is presently being marketed by the developer, no recent information was found about the suitability and performance of this technology for PM CEMS applications.

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1.2.2 Comparison of Technologies

A summary comparison of the PM monitoring technologies described in the preceding section is presented in **Table A-2** based on key criteria affecting the potential application of the monitors to electric utility steam-generating units. The comparison criteria are as follows: mass measurement parameter measured by the instrument, installation configuration, operating mode, the extent of current use, the history of use, the effects of changes in particle characteristics, and potential interferences. The following paragraphs explain the basis for these criteria.

Mass measurement parameter (direct versus indirect). Harmonic oscillation is the only type of PM monitoring technology that can directly measure PM concentration or mass. All of the other technologies measure mass indirectly based on the optical or other physical properties of the particles in the gas stream. The applicable properties should then be correlated to PM concentration or mass by conducting concurrent source testing with monitor operation.

Installation configuration (in situ versus extractive). A PM CEMS is designed either as an in situ system, which is mounted in the stack, or as an extractive system, which uses in-stack probe and sample lines for transporting the sample to the analyser installed outside the stack. In situ systems eliminate the need for sample transport and conditioning. With extractive systems, it is necessary to transport the sample from the stack to the sensor and maintain isokinetic conditions. A sample transport system incorporates additional mechanical components, which require maintenance. In addition, there can be loss of sample within the transport system. Finally, because of the additional components, the installation of extractive systems is generally more difficult and more expensive.

Operating mode (continuous versus batch). A PM CEMS operates either in true continuous mode or in a continuous series of short-term batch cycles. Continuous operation is more straightforward. A batch mode system includes a sample volume measuring system, which should be calibrated periodically, and it also has additional mechanical components, which require maintenance. Batch mode systems complicate correlation testing because the sampling at each traverse point should be timed to coincide with batch cycles.

Extent of current use (extensive versus limited). Certain PM CEMS technologies are currently in much wider use than others. Widespread use is an indication of the acceptability of a technology for PM monitoring applications.

History of use (long versus short). Some technologies are emerging, whereas others have an established history of use for PM monitoring applications.

Effects of changes in particle characteristics (more susceptible versus less susceptible). With the exception of harmonic oscillation systems, PM CEMS technologies rely on particle characteristics other than mass. Because some of these particle characteristics are more likely to change than others, certain types of instruments are more susceptible to drift or calibration shifts than are others. Specifically, optical instruments (i.e., those based on light scattering, light extinction, or optical scintillation) generally are sensitive to the particle characteristics that are more likely to change (particle size, density, composition) than are non-optical instruments (beta gauge, probe electrification, harmonic oscillation). Also, because probe electrification instruments utilise particle charge, the devices cannot be used downstream of an electrostatic precipitator (ESP).

Potential interferences (more susceptible versus less susceptible). Some PM CEMS technologies are more susceptible to interferences. Specifically, other light sources can interfere with the operation of optical instruments, although optical instruments generally are designed to minimise the effects of external light sources. The presence of water droplets in a gas stream (e.g., immediately downstream of a wet scrubber) can also interfere with PM CEMS responses, particularly with optical instruments. This problem generally limits the applicability of optical systems to dry stacks (i.e., sources controlled with fabric filters, ESPs, or other dry control devices), unless the systems extract and heat the sample to eliminate excess moisture.

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Table A-2. Comparison of PM Monitoring Technologies

Criterion	PM Monitor Principle of Operation					
	Light Scattering	Beta-Ray Attenuation	Probe Electrification	Light Extinction	Optical Scintillation	Harmonic Oscillation
Mass measurement parameter	Amount of light scattered by particles	Amount of beta rays attenuated by particles	Electrical current generated by particle friction and charge	Amount of light attenuated by particles	Variations in amplitude of light due to particles	Change in oscillation due to mass collected on filter
Installation configuration	In situ	Extractive	In situ	In situ	In situ	Extractive
Operating mode	Continuous	Batch	Continuous	Continuous	Continuous	Batch
Extent of current use	Widespread use	Widespread use	Widespread use as fabric filter bag leak detectors	Widespread use as COMS	Limited use	Limited use
History of use	Long history	Long history	Long history as bag leak detectors	Long history of use as COMS	Short history	Short history
Effects of changes in particle characteristics	Highly dependent	Less dependent	Highly dependent	Highly dependent	Highly dependent	Not dependent
Potential interferences	Water droplets	None	Electrical fields	Water droplets	Water droplets	None
Other comments	May not be appropriate for wet scrubber-controlled sources	None	<ul style="list-style-type: none"> ▪ May not be appropriate for sources controlled with ESPs ▪ Difficult to correlate to mass 	<ul style="list-style-type: none"> ▪ May not be appropriate for wet scrubber-controlled sources ▪ Difficult to correlate to mass 	May not be appropriate for wet scrubber-controlled sources	Current designs suitable for short-term use only (up to approximately 3 days)

1.2.3 Commercial Availability

Optical-based monitors, particularly those based on light scattering, have been used for more than two decades to monitor PM emissions from municipal waste incinerators and other combustion sources in Europe. Manufacturers have continued to make improvements to the light-scattering PM CEMS, based on the field experience obtained from operating the monitors on these combustion sources.

After light-scattering instruments, beta gauges represent the most commonly used PM CEMS technology. On one hand, because beta-gauge PM CEMS are extractive batch sampling instruments, they generally include more mechanical components than do most light-scattering instruments. As a result, maintenance may be more of a concern with beta-gauge instruments. On the other hand, beta-gauge instruments may be more appropriate than light-scattering instruments for monitoring sources controlled with wet scrubbers because of the potential for light-scattering instruments to treat water droplets as PM. In addition, beta-gauge instruments may be more reliable than light-scattering instruments in gas streams that are subject to more variations in the size and other characteristics of the particles that comprise the PM.

Among the other PM monitoring technologies, monitors based on light extinction or probe electrification have been successfully marketed and sold for applications other than for use as PM CEMS. Light extinction monitors are installed in combustion unit stacks at electric utility power plants and other facilities to monitor opacity. Many standards established by U.S. EPA to regulate

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PM emissions from large sources using fabric filter control devices require the use of probe electrification (triboelectric) monitors to detect bag leaks. However, to date, neither of these technologies has been able to demonstrate much success in correlating instrument response to PM concentrations or mass emissions. Light scintillation monitors are relatively new on the market and have yet to be used to any great extent. Currently available harmonic oscillation monitors provide direct PM concentration or mass measurements with accurate results, but they have not been adapted for long-term continuous measurement operation needed for PM CEMS applications.

1.2.4 Standardised PM CEMS Performance Specifications

The U.S. EPA has developed standardised specifications for the application of PM CEMS to thermal power plants and other PM emissions sources. *Performance Specification 11 (PS-11)—Specifications and Test Procedures for Particulate Matter Continuous Emission Monitoring Systems at Stationary Sources* in 40 CFR Part 60, Appendix B establishes procedures for selecting, installing, and operating the PM CEMS. In addition to specifying requirements for the PM CEMS, PS-11 also includes several recommended procedures to help ensure their proper installation and operation. *Procedure 2—Quality Assurance Requirements for Particulate Matter Continuous Emission Monitoring Systems at Stationary Sources* in 40 CFR Part 60, Appendix F specifies the minimum requirements for evaluating the quality of the data generated by the PM CEMS and for evaluating the effectiveness of quality assurance (QA) and quality control (QC) procedures for a PM CEMS.

1.2.4.1 Performance Specification 11

The following paragraphs summarise the instrument design, testing, and correlation requirements specified in PS-11.

Design requirements. Section 6 of PS-11 specifies several design requirements for PM CEMS, including the following:

- Sample interface that is capable of delivering a representative sample of the exhaust gas to the instrument
- System capability of performing zero and upscale drift checks
- For extractive systems, the capability of checking the sample volume
- Capability to sample isokinetically if the system is extractive and the exhaust gas flow rate varies by more than 10%.

Testing requirements. Section 8 of PS-11 specifies the initial testing requirements for PM CEMS, which consist of a 7-day drift test and a correlation test. The 7-day drift test requires daily measurements of zero (low-level) and upscale drift measurements, which should be completed successfully before the correlation test is performed.

Unlike CEMS used to measure gaseous air pollutants, there are no calibration gases for checking the accuracy of PM CEMS. Instead, PM CEMS responses should be correlated to reference method measurements of PM concentrations. Consequently, the correlation test is the primary means for evaluating the initial performance of a PM CEMS in monitoring PM emissions on a continuous basis. The test requires a minimum of 15 test runs. Each test run should include sampling PM using a manual reference test method with the simultaneous recording of PM CEMS responses. The reference test method should be the same method that is specified in the applicable regulation (e.g., U.S. EPA Methods 5, 5i, or 17). Section 8 of PS-11 also specifies the conditions under which additional correlation testing is required.

Correlation requirements. Following completion of the correlation test, the PM CEMS response data should be correlated to the reference test method data using a regression analysis. Section 12 of PS-11 specifies the procedures for performing the analysis. The outcome of the regression analysis is a correlation equation, which subsequently is used to determine the PM concentration that corresponds to a specific PM CEMS response. The correlation equation should satisfy criteria specified in Section 13.2 of PS-11 for correlation coefficient, confidence interval half range, and tolerance interval half range. If the correlation equation does not satisfy all of these criteria, then additional correlation testing is required. In some cases, it may be necessary to relocate the PM CEMS or make other changes to the exhaust system to achieve an acceptable correlation.

1.2.4.2 Procedure 2

Procedure 2 requires a QC Plan that specifies procedures for routine operational checks and periodic audits of PM CEMS performance. This procedure specifies the minimum requirements for these checks and audits, which include the following:

- Daily zero (or low-level) and upscale drift checks on all PM CEMS
- For light-scattering or extinction-type instruments, daily checks of system optics

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- For extractive instruments that measure sample volume, daily sample volume checks.

In addition to routine system checks, Procedure 2 requires several periodic audits, including the following:

- For all PM CEMS, quarterly absolute correlation audits, which require comparison of PM CEMS responses to three audit points
- For extractive instruments that measure sample volume, quarterly sample volume audits, which require comparison of sample volume measurements over three cycles to the volume measured using a calibrated device
- For all PM CEMS, periodic relative response audits, which require comparison of PM CEMS responses to the results of three reference method test runs
- For all PM CEMS, periodic response correlation audits (RCAs), which require comparison of PM CEMS responses to the results of 12 reference test method test runs.

In the event that a PM CEMS fails any of these audits, PS-11 specifies the corrective actions that should be taken. If a system fails an RCA, a new correlation equation should be developed that satisfies all of the correlation criteria specified in PS-11.

1.2.5 PM CEMS Installation and Operation

1.2.5.1 Instrument Selection

The types of control devices used and exhaust gas characteristics for a combustion unit can affect which type of PM CEMS is selected and installed for a given application. Because of potential interference from water droplets, optical instruments should be avoided for use on combustion units controlled with wet scrubbers unless the PM CEMS is designed to extract and heat the sample sufficiently to vaporise the water droplets. Because probe electrification (triboelectric) instruments respond to particle charge, this type of measurement technology is not appropriate for use on combustion units controlled with ESPs. Finally, optical instruments may not be appropriate for gas streams that experience significant variations in particle size, colour, or shape under normal operations.

Space availability for installing the PM CEMS components is another consideration that can also affect the selection of the PM monitor type to be used. In general, extractive-type PM monitors require significantly more space than do in situ-type PM monitors. The additional space is needed for the peripheral equipment associated with transporting, heating, and measuring the volume of the sample. In some locations, space limitations may dictate the use of an in situ instrument.

1.2.5.2 Installation Location

The installation location can be critical for PM CEMS because, as is the case for other types of CEMS, it is important to monitor a representative PM concentration. The typical location for installing a PM CEMS is in the stack downstream of the emissions control device. However, a number of factors related to location can affect the performance of a PM CEMS, the two most important of which are the potential for stratification and moisture interference.

Whenever possible, a location should be selected that meets the criteria specified in U.S. EPA Reference Method 1 in 40 CFR Part 60, Appendix A. That is, the probe of the PM CEMS should be located at least a two-duct (or stack) diameter upstream of any flow disturbance and at least an eight-duct diameter downstream of any flow disturbance. Flow disturbances include any bends or changes in direction of the duct; any junction, such as locations where dilution air is introduced into the duct or where other gas streams merge with the duct; induced or forced draft fans; and any changes in the diameter of the duct (e.g., tapering or flaring out). If the “two-duct diameter upstream, eight-duct diameter downstream” criteria cannot be satisfied, then the PM CEMS should be located so as to maximum the distance to or from any flow disturbance.

In addition to the location along the duct, for any PM CEMS that uses a probe, the location of the PM CEMS probe within the cross-section of the duct is also critical. In many stacks and ducts, the PM concentration can be stratified. That is, the concentration of PM can vary significantly over the cross-section of a duct at any given time. For example, the PM concentration near the wall of the duct may be only half of the concentration at the centroid of the duct. Stratification has been recognised as a potential problem with gaseous CEMS, and U.S. EPA has included a stratification test in several of its performance specifications for gaseous pollutant CEMS. Examples include PS-2 for SO₂ and NO_x CEMS, PS-14 for chlorine (Cl₂) CEMS, and 40 CFR, Part 75, Appendix A, *Specifications and Test Procedures*. However, stratification of PM generally is more severe

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than for gases due to the inertial forces acting on the PM. Furthermore, testing for PM stratification can be expensive and time consuming.

Although the PM CEMS calibration correlation will account for stratification in many cases, stratified locations should be avoided when possible, particularly in locations where the stratification varies temporally. Another reason to select a location that satisfies the “two-duct diameter upstream, eight-duct diameter downstream” criteria is that stratification often occurs near flow disturbances. Ideally, the probe should be placed at a location where the PM concentration is comparable to the average PM concentration over the cross-section of the duct. In most stacks, the closer the probe is to the duct centroid, the more likely the PM concentration at that point will be representative of the average PM concentration.

Another factor to consider when placing a PM CEMS probe is the location of reference test method sampling ports. As required by PS-11, PM CEMS are calibrated by developing a correlation between PM CEMS responses and reference test method measurements (typically, U.S. EPA Method 5). To develop a good correlation between PM CEMS responses and reference test method measurements, the PM CEMS location should be as close as possible to the cross-section where sampling ports are or can be located. In general, locating a PM CEMS near other types of CEMS (e.g., SO₂ or NO_x CEMS) should not present a problem.

1.2.5.3 General Installation Requirements

Installing a PM CEMS on a combustion unit has the same general requirements as installing a CEMS used to measure a gaseous pollutant (e.g., SO₂ or NO_x). These requirements include installing a sampling port in the stack for the PM CEMS, and, if there are no existing test ports, additional ports for emissions source testing. Depending on the location of the CEMS, it may also be necessary to install a platform to allow personnel to easily access the analyser and other system components.

Once a PM CEMS is installed, a series of diagnostic tests is performed to check that all components are functioning properly. The data acquisition system should also be programmed for converting input signals to the proper units and recording data with the appropriate averaging time and other requirements specified in the applicable regulation.

1.2.5.4 Shakedown and Preliminary Testing

The proposed version of PS-11 included the requirement for operating the PM CEMS for both a shakedown and correlation test planning period prior to conducting the correlation test to certify the instrument. Although the final rule does not require these preliminary testing periods, they are still recommended. The purpose of the shakedown period is to allow Operators to work out initial problems and familiarise themselves with the operation of the instrument and monitoring system. Based on demonstration studies conducted by U.S. EPA and industry comparing the performance of various types of PM CEMS, extractive-type PM CEMS generally are more likely to have problems during installation and initial start up than are in situ PM CEMS due to the additional mechanical components needed for transporting the sample to the analyser, heating the sample, and measuring sample volume.

The correlation test planning period allows time for the operator to conduct a “dry run” of the correlation test to help ensure that the correlation test is conducted without problems. Ultimately, conducting the correlation test over a wide range of PM concentrations is critical to developing a correlation that will remain representative over the entire range of normal operating conditions; the correlation test planning period allows time to determine what ranges of PM concentrations are feasible during the correlation test.

1.2.5.5 Correlation Test

Before a PM CEMS can be used to monitor emissions, it is necessary to establish the relationship between PM concentrations in the gas stream and how the instrument responds to those PM concentrations. A correlation test is used to establish this relationship. The minimum requirements specified in PS-11 for correlation tests include a minimum of 15 test runs, during which the response of the PM CEMS is recorded with simultaneous reference method measurements of PM concentrations. The reference method used should be the same method that is specified in the applicable regulation, typically, U.S. EPA Method 5, 5i, or 17 in 40 CFR Part 60, Appendix A. Paired reference test method sampling trains (i.e., two independent sampling trains measuring PM concentrations simultaneously) are recommended to ensure the accuracy of PM concentration measurements. To ensure that the correlation is valid over the entire range of normal operating conditions and control device performance, the correlation test should also be conducted over as wide of a range of PM concentrations as is practical. This can be

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accomplished by varying the source operating rate or adjusting the operation of the control device to simulate episodes of lower and higher emissions.

Once the correlation test is completed, a correlation equation is developed using regression analysis. Procedures for developing correlation equations are specified in PS-11. In some cases, it may be necessary to develop multiple correlations to characterise the full range of source operating conditions. If a correlation equation cannot be developed that satisfies the criteria of PS-11, additional test runs may be needed.

1.2.5.6 Operating Requirements

For the most part, PM CEMS are marketed as fully automated systems that sample emissions, record monitor responses, conduct routine system diagnostic checks, and alert the Operator of problems. However, some instruments do not have automatic drift-check capabilities; for those systems, manual drift checks should be performed daily. Bringing a new PM CEMS online generally requires several days and can take weeks to ensure that all components are working properly.

Unlike CEMS used to measure gaseous pollutants, PM CEMS cannot be calibrated against standard gases. The initial correlation test establishes the relationship between instrument response and PM concentrations. Procedure 2 specifies both daily and periodic audits to ensure that the system continues to produce good quality data. These data include daily drift checks for all types of instruments and daily sample volume checks for extractive instruments that measure sample volume. In addition, quarterly and periodic audits of instrument operation are required. Some of these audits require reference test method sampling as a means of checking that the correlation equation remains valid.

1.2.5.7 Maintenance Requirements

Maintenance requirements are a function of the type of system. Extractive systems generally require more maintenance due to the additional mechanical components required for their operation. For beta-gauge systems, the filter tape should be replaced periodically. For optical instruments, the lenses should be checked and cleaned on a routine basis. Other routine maintenance requirements include replacing purge air filters periodically. Adjustments should also be made periodically to correct for calibration drifts.

1.2.6 PM CEMS Costs

The costs for purchasing, installing, and operating a PM CEMS depend on a variety of factors, including the type of instrument used, site-specific conditions, and the frequency of audits and other QA and QC activities specified in the applicable rule requiring use of the CEMS. In general, the initial capital investment and annual costs for extractive-type PM CEMS are higher than for in situ-type PM CEMS because of the additional equipment needed for the extractive systems to transport and condition the sample.

Initial costs (in U.S. dollars) for a new PM CEMS include money for equipment purchase, installation, and initial correlation of the instrument. Initial costs for a light-scattering PM CEMS range from approximately \$100,000 to \$140,000. Initial costs for a beta-gauge PM CEMS range from approximately \$140,000 to \$170,000.

Annual costs for PM CEMS include costs for operation and maintenance, system QA and QC, and capital recovery. These costs can vary widely depending on the frequency of the QA and OC required under the applicable rules. For example, Procedure 2 for PM CEMS does not specify a minimum frequency for RCAs; instead, those frequencies are to be specified in the applicable rule that requires the use of PM CEMS. The estimated cost to perform a typical RCA ranges from \$15,000 to \$26,300. Assuming one RCA per year, the annualised costs for a light-scattering PM CEMS would range from \$52,000 to \$84,000, and the annualised costs for a beta-gauge PM CEMS would range from approximately \$59,000 to \$90,000. Requirements for a less-frequent RCA (e.g., once every 18 months, once every 3 years) will lower the annual costs for the PM CEMS.

1.3 Application to Thermal Power Plants in Abu Dhabi Emirate

The installation and operation of CEMS at major air pollutant sources at industrial plants in Abu Dhabi Emirate will provide useful emissions data that can be used to: (1) demonstrate compliance with existing EAD and UAE federal environmental regulations, (2) develop new emissions standards, and (3) provide the capability to use CEMS for a future emissions trading or

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pollution control programs. The selection and use of CEMS at specific facilities or plants in Abu Dhabi will depend on a combination of factors including site-specific conditions, regulatory requirements, and facility owner preferences.

Gaseous pollutants, such as SO₂ and NO_x, can be measured using either an in situ or extractive-type system. An in situ system utilises an analyser that measures the gas concentration in the stack (or duct); and an extractive system extracts a sample of the gas and transports it to the analyser. Available, SO₂ and NO_x analysers designed to operate in extractive systems include analysers using spectroscopic and electrochemical technologies. The spectroscopic technologies include IR, UV, and luminescence (chemiluminescence and fluorescence). In situ monitors include UV spectroscopic analysers.

Presently, the most commonly used PM monitoring is based on the principle of light extinction (transmissometers); these instruments measure opacity (an indicator of PM) and are referred to as COMS. COMS are in situ instruments. Other newer PM monitoring technologies have been widely used in Europe and are now beginning to be installed and used in the United States. These technologies provide a quantitative PM concentration measurement. These technologies are discussed in Section 1.2.1 and include light scattering, beta-ray attenuation, optical scintillation, and harmonic oscillation; with the exception of beta-ray attenuation, these instruments are in situ. Another technique, probe electrification, is used to provide qualitative/semi-quantitative PM measurements.

The foremost design and installation consideration with respect to using a CEMS to measure air pollutant emissions is the selection and availability of a representative monitoring location. The location of the analyser measurement point should meet the specifications in the applicable pollutant reference test method for certifying/auditing performance of the analyser. For new construction, this task is as straightforward as locating the CEMS to meet the applicable specifications that can be incorporated into the design. However, finding a suitable monitoring location can be difficult for installing a CEMS on an existing plant. In this case, installing and operating a CEMS that complies with the required specifications may not be possible for the existing flue gas duct and stack configuration without modifications. Criteria to be considered when determining the optimal CEMS design for a given plant include the following:

- Emissions concentration. The type of CEMS analyser used should be capable to accurately measure the full range of pollutant emissions concentrations expected to occur in the flue gases. If needed, the CEMS design may require addition of a dilution system to lower the sample concentration to within the analyser's measurement range.
- Potential interferences and gas stream properties. The location of the CEMS should allow for measurement of a representative sample. The condition of the sample (e.g., wet or dry, particulate concentration) should be considered. For extractive gaseous analysers, this will be a factor in how the sample gas should be conditioned prior to analysis. Stratification of the gas concentration (due to factors such as air in-leakage) and PM concentration (due to bends and turns in the ductwork) should be considered. There may be severe limitations due to the existing duct and stack configurations.
- Measurement location and environment. The analyser should be located in an environment that meets the manufacturer's requirements relative to temperature, vibration, and exposure to the elements. Some locations may be more suited for an in situ system than an extractive system. On one hand, if a selected measurement location is a harsh environment that cannot be moderated, then an in situ system may be a poor choice. On the other hand, if space or other conditions limit the ability to locate an extractive system within an acceptable distance of the measurement location, then an in situ system may be a better choice.
- Analyser accessibility. Each analyser and associated equipment should be readily accessible to facility personnel for routine maintenance.
- Analyser complexity. In situ systems typically require less routine maintenance because they do not have the parts associated with sample transport and conditioning; however, the analysers themselves may be more complicated and difficult to maintain and repair. Selection of an analyser type may depend on whether a facility will have technical staff with necessary expertise to maintain the CEMS.
- CEMS vendor technical support availability. The ability to readily obtain spare parts for the CEMS and receive technical support from the vendor in Abu Dhabi Emirate should be considered in the CEMS design.

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Annex 2: Outline of a Continuous Emissions Monitoring System (CEMS) Quality Assurance Manual

Section 1—The Quality Assurance Plan

1. Quality policy and objectives
2. Document Control System
3. Continuous Emissions Monitoring System (CEMS) regulatory mandates and CEMS description
4. Organisation and responsibilities
5. Facilities, equipment, and spare parts inventory
6. Methods and procedures (analysis and data acquisition)
7. Calibration and quality control (QC) checks
8. Maintenance (preventive)
9. Performance audits
10. Systems audits
11. Corrective action program
12. Data review, verification, and validation
13. Reporting
14. Recordkeeping
15. References.

Section 2—Standard Operating Procedures

1. Start up and operation
2. Daily CEMS inspection and preventive maintenance
3. Calibration procedures
4. Preventive maintenance procedures
5. Corrective maintenance procedures
6. Performance audit Procedure 1 (cylinder gas audit [CGA])
7. Performance audit Procedure 2 (relative accuracy test audit [RATA])
8. Performance audit Procedures 3 (relative accuracy audit [RAA])
8. Systems audit procedures
9. Data back-up procedures
10. Training procedures
11. CEMS security
12. Data reporting procedures.

Annexes:

- A. Facility operating permit
- B. CEM specifications and rules
- C. Reference test methods
- D. Blank forms

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Annex 3: Emissions Monitoring Reports

Annex 3a—Example of a CEMS Hourly Emissions Report

Facility Information									
Owner/Operator									
Unit Description					Fuel Type, Fuel Factor				
					EAD Emissions Limits (mg/Nm ³)				
		Flue Gas Temperature	Volume Flow Rate	Active Power	Flue Gas Stack O ₂	Flue Gas Stack NO _x	Flue Gas Stack CO	Flue Gas Stack SO ₂	Remarks
Date	Time	(°C)	(Nm ³ /h)	(MW)	(% VOL)	(mg/Nm ³)	(mg/Nm ³)	(mg/Nm ³)	
1-Jan	0:00								
1	01:00								
1	02:00								
1	03:00								
1	04:00								
1	05:00								
1	06:00								
1	07:00								
1	08:00								
1	09:00								
1	10:00								
1	11:00								
1	12:00								
1	13:00								
1	14:00								
1	15:00								
1	16:00								
1	17:00								
1	18:00								
1	19:00								
1	20:00								
1	21:00								
1	22:00								
1	23:00								
2	0:00								
2	01:00								
2	02:00								

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Facility Information									
Owner/Operator									
Unit Description						Fuel Type, Fuel Factor			
						EAD Emissions Limits (mg/Nm ³)			
		Flue Gas Temperature	Volume Flow Rate	Active Power	Flue Gas Stack O ₂	Flue Gas Stack NO _x	Flue Gas Stack CO	Flue Gas Stack SO ₂	Remarks
Date	Time	(°C)	(Nm ³ /h)	(MW)	(% VOL)	(mg/Nm ³)	(mg/Nm ³)	(mg/Nm ³)	
2	03:00								
2	04:00								
2	05:00								
2	06:00								
2	07:00								
2	08:00								
2	09:00								
2	10:00								
2	11:00								
2	12:00								
2	13:00								
2	14:00								
2	15:00								
2	16:00								
2	17:00								
2	18:00								
2	19:00								
2	20:00								
2	21:00								
2	22:00								
2	23:00								
3	0:00								
3	01:00								
3	02:00								
3	03:00								
3	04:00								
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3	07:00								
3	08:00								
3	09:00								
3	10:00								

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Facility Information									
Owner/Operator									
Unit Description						Fuel Type, Fuel Factor			
						EAD Emissions Limits (mg/Nm ³)			
		Flue Gas Temperature	Volume Flow Rate	Active Power	Flue Gas Stack O ₂	Flue Gas Stack NO _x	Flue Gas Stack CO	Flue Gas Stack SO ₂	Remarks
Date	Time	(°C)	(Nm ³ /h)	(MW)	(% VOL)	(mg/Nm ³)	(mg/Nm ³)	(mg/Nm ³)	
3	11:00								
3	12:00								
3	13:00								
3	14:00								
3	15:00								
3	16:00								
3	17:00								
3	18:00								
3	19:00								
3	20:00								
3	21:00								
3	22:00								
3	23:00								

Note: % VOL = percent volume; °C = degrees Celsius; mg/Nm³; milligrammes per normal cubic metre; MW = megawatt; Nm³/h = normal cubic metres per hour.

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Annex 3b—Example of a CEMS Daily Emissions Report

Unit #																					
Day of Month	Average Load Power (MW)		Running Hours			Fuel Data		Operating Data for Exhaust Gas at Stack			Emissions Data										
	Average Load Power (MW)	Total Load Power (MWH)	Below 60% Baseload	Total Running Hours of Equip.	Equip Shutdown Due to Maintenance and Other Purposes	Gas	Fuel Oil	Temperature (°C)			NO _x (mg/Nm ³)			CO (mg/Nm ³)			CO ₂ (mg/Nm ³)	SO ₂ (mg/Nm ³)			O ₂ (%)
						Consumption or Quantity (Sm ³)	Consumption or Quantity (m ³)	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Avg	Max	Min	Avg	Avg
1																					
2																					
3																					
4																					
5																					
6																					
7																					
8																					
9																					
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19																					
20																					
21																					

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Unit #																						
Day of Month			Running Hours			Fuel Data		Operating Data for Exhaust Gas at Stack			Emissions Data											
	Average Load Power (MW)	Total Load Power (MWH)	Below 60% Baseload	Total Running Hours of Equip.	Equip Shutdown Due to Maintenance and Other Purposes	Gas	Fuel Oil	Temperature (°C)			NO _x (mg/Nm ³)			CO (mg/Nm ³)			CO ₂ (mg/Nm ³)	SO ₂ (mg/Nm ³)			O ₂ (%)	
						Consumption or Quantity (Sm ³)	Consumption or Quantity (m ³)	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Avg	Max	Min	Avg	Avg	
22																						
23																						
24																						
25																						
26																						
27																						
28																						
29																						
30																						
31																						
Average																						

Note: m³ = cubic metre; mg/Nm³ = milligrams per cubic nanometres; MW = megawatt; MWH = megawatt-hour; Sm³ = standard cubic metre.

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Annex 3c—Example of a CEMS Annual Emissions Report

Reporting Period	Time/Date	Facility Total Fuel Usage	Facility Total Load Power	Air Pollutant Emissions Loads into the Atmosphere			
				NO _x	SO _x	CO	CO ₂
	(Months/Year)	(Sm ³)	(MWH)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)
1	January						
2	February						
3	March						
Quarter 1 Totals							
4	April						
5	May						
6	June						
Quarter 2 Totals							
Quarter 1+2 Totals							
7	July						
8	August						
9	September						
Quarter 3 Totals							
Quarter 1+2+3 Totals							
10	October						
11	November						
12	December						
Quarter 4 Totals							
Quarter 1+2+3+4 Totals							

Note: CO = carbon monoxide; CO₂ = carbon dioxide; NO_x= nitrogen oxides; SO_x = sulphur dioxide.

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Annex 3d—Examples of How to Calculate Values During Periods of CEM Malfunction or Calibration

Day	Hour	NO _x Reading (ppm)	Power ^a (MW)	Comment
01/01/2009	01:00	50	100	
01/01/2009	02:00	50	100	
01/01/2009	03:00	40	91	
01/01/2009	04:00	50	100	
01/01/2009	05:00	47.5	100	NO _x CEM malfunction. Values presented are averages for hours 01, 02, 03, and 04, and 06, 08, 09, and 10.
01/01/2009	06:00	50	100	
01/01/2009	07:00	30	83	
01/01/2009	08:00	50	92	
01/01/2009	09:00	50	100	
01/01/2009	10:00	40	100	
01/01/2009	11:00	30	62	
01/01/2009	12:00	30	64	
01/01/2009	13:00	30	61	
01/01/2009	14:00	40	70	
01/01/2009	15:00	33.8	70	NO _x CEM malfunction. Values presented are averages for hours 11, 12, 13, and 14, and 18, 19, 20, and 21.
01/01/2009	16:00	45.0	100	NO _x CEM malfunction. Values presented are averages for hours 07, 08, 09, and 10, and 17, 22, 23, and 24.
01/01/2009	17:00	50	100	
01/01/2009	18:00	40	80	
01/01/2009	19:00	30	70	
01/01/2009	20:00	40	70	
01/01/2009	21:00	30	62	
01/01/2009	22:00	40	90	
01/01/2009	23:00	50	100	
01/01/2009	24:00	50	100	

ppm = parts per million.

^a Plant has a rated power of 100 MW; therefore, $\pm 10\%$ of the rated power is ± 10 MW.

NOTE: Values in bold italic are computed based on the average of the values in the nearest 4 hours before and 4 hours after instrument malfunction that were at a plant power level of ± 10 MW of the power during instrument malfunction.

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Annex 4: Correcting CEM Readings to Oxygen Contents Specified by Emissions Standards

1. Background

It is common for concentration emissions standards to be corrected to a specific oxygen (O₂) concentration. When concentration emissions standards are corrected to a specified O₂ concentration, sources that otherwise would not meet the standard cannot simply comply by allowing more ambient air into the turbine exhaust stack. Instead, concentration readings must be adjusted to whatever specific O₂ level is specified in the standard.

1.1 Calculation Procedure

Pollution concentrations are adjusted to the O₂ concentration specified in a standard according to Equation 1:

$$\text{Conc. } i_{(\text{Std. O}_2)} = \text{Conc. } i_{(\text{Measured O}_2)} \left(\frac{20.9\% - \text{Std. O}_2\%}{20.9\% - \text{Measured O}_2\%} \right) \quad (\text{Eq. 1})$$

Where

- Conc. i (Std. O₂) = the pollutant concentration at the O₂ level specified in the standard
- Conc. i (Measured O₂) = the pollutant concentration measured in the exhaust stack
- 20.9% = O₂ concentration in the atmosphere
- Std. O₂% = O₂ concentration specified in the standard

1.2 Example Calculation

Suppose the NO_x standard for a gas-fired turbine is 70 mg/Nm³ at 15% O₂, and the measured value is 68 ppm at 17% O₂. Does the turbine meet the emissions standard?

$$\text{Conc. } i_{(\text{Std. O}_2)} = \text{Conc. } i_{(\text{Measured O}_2)} \left(\frac{20.9\% - \text{Std. O}_2\%}{20.9\% - \text{Measured O}_2\%} \right)$$

Where

- Conc. i (Std. O₂) = 68 ppm (20.9–15) ÷ (20.9–17)
- Conc. i (Std. O₂) = 68 ppm (1.51)
- Conc. i (Std. O₂) = 103 ppm at 15% O₂.

Therefore, the measured value does not meet the emissions standard.

Compliance Monitoring Using Continuous Emissions Monitoring Systems (CEMS)

Annex 5: Summary of Excess Emission Report (EER) for Gaseous Monitoring System Performance

Pollutant: SO₂/NO_x/CO Reporting Period: _____
 Diluent: O₂/CO₂ _____
 Volumetric Flow: Yes/No _____
 Owner/Operator: _____
 Unit Description: _____
 Emissions Limit: _____
 Total Source Operation Time: _____ hours
 Monitor Manufacturer, Model No., and Serial No.: _____

Emissions Data Summary

1. Duration (fraction of hours) of excess emissions (EEs) in reporting period due to
 - a. Startup/shutdown _____
 - b. Control equipment problems _____
 - c. Process problems _____
 - d. Other known causes _____
 - e. Unknown causes _____
2. Total duration of EEs, hours _____
3. Total duration of EEs ÷ total source operation time × 100 _____ %

CEMS Performance Summary

1. Duration (fraction of hours) of monitor downtime (MDT) in reporting period due to
 - a. Monitoring equipment malfunction _____
 - b. Non-monitor equipment malfunction _____
 - c. Quality assurance calibrations _____
 - d. Other known causes _____
 - e. Unknown causes _____
2. Total duration of MDTs _____
3. Percentage of availability of the CEMS; ([total source operation time – duration of MDT] ÷ total source operation time) × 100 _____ %

Comments:

I certify that the information contained in this report is true, accurate, and complete.

Signature: _____

Date: _____

Compliance Monitoring Using Continuous Emissions Monitoring Systems (CEMS)

Document Change History

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