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Reduction of Carbon Dioxide Emissions from Coal-Fired Generation of Electricity Regulations

Reference Method for Source Testing: Quantification of Carbon Dioxide Releases by Continuous Emission Monitoring Systems from Thermal Power Generation

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Abstract

The *Reference Method for Source Testing: Quantification of Carbon Dioxide Releases by Continuous Emission Monitoring Systems from Thermal Power Generation* document is incorporated by reference in the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations (the "Regulations"). This document provides requirements for regulatees using continuous emission monitoring systems (CEMS) to quantify annual carbon dioxide (CO_2) emissions for the purposes of the Regulations. All conditions, requirements, and restrictions set forth in the Regulations apply to this document. This document may be modified from time to time.

This method is based upon the *Protocols and Performance Specifications for Continuous Monitoring of Gaseous Emissions from Thermal Power Generation* Report EPS 1/PG/7 (revised December 2005). This method focuses on the quantification of annual CO_2 emissions and overrides 1/PG/7 for this purpose.

No specific monitoring system is designated in this reference method. Any system that meets the initial certification criteria and subsequent specified parameters contained in this document is acceptable. In situ or extractive CEM systems based on dynamic dilution technology or direct measurement of the target species may be used. Time-shared CEM systems using a single set of analyzers to determine emission rates for several adjacent sources are also acceptable.

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Units, Abbreviations, and Acronyms

avg	average
BAF	bias adjustment factor
BTU	British thermal unit
B_{wa}	moisture content of ambient air in % of volume
B_{ws}	moisture content of the stack gas in % of volume
°C	degree Celsius
CEM	continuous emission monitoring
CFR	U.S. Code of Federal Regulations
cm	centimetre
CO_2	carbon dioxide
|d|	absolute difference
DSm^3/GJ	dry standard cubic metre per gigajoule
DSm^3/MJ	dry standard cubic metre per megajoule
EGU	electricity generating unit
F-factor	F_c , F_d or F_w
F_c	ratio of the carbon dioxide volume generated by the combustion of a given fuel to the amount of heat produced in Sm^3/MJ
F_d	ratio of the stoichiometric volume of dry gas generated by the complete combustion of a given fuel with air to the amount of heat produced in DSm^3/MJ
F_w	ratio of the stoichiometric volume of wet gas generated by the complete combustion of a given fuel with dry air to the amount of heat produced in WSm^3/MJ
FS	full scale
g/GJ	grams per gigajoule
GCV	gross calorific value
GJ/h	gigajoules per hour
GJ/MWh	gigajoules per megawatt hour
ISO	International Organization for Standardization
K	Kelvin
kg/GJ	kilograms per gigajoule
kg/h	kilograms per hour
kg/MWh	kilograms per megawatt hour
kg/Sm^3	kilograms per standard cubic metre
kJ/kg	kilojoules per kilogram

kPa	kilopascal
m/s	metres per second
m^3/GJ	cubic metres per gigajoule
m^3/kg-mol	cubic metres per kilogram mole
m^3/s	cubic metres per second
MJ/h	megajoules per hour
MJ/MWh	megajoules per megawatt hour
MJ/s	megajoules per second
MW	megawatt
MWh	megawatt hour
ng/J	nanograms per joule
O_2	oxygen
OEM	original equipment manufacturer
OTP	operational test period
ppm	parts per million
QA	quality assurance
QA/QC	quality assurance / quality control
QC	quality control
RA	relative accuracy
RATA	relative accuracy test audit
RH	relative humidity
RM	reference method
Sm^3/GJ	standard cubic metres per gigajoule
Sm^3/h	standard cubic metres per hour
Sm^3/MJ	standard cubic metres per megajoule
Sm^3/MWh	standard cubic metres per megawatt hour
STDEV	standard deviation
U.S. EPA	United States Environmental Protection Agency
WSm^3/GJ	wet standard cubic metres per gigajoule
WSm^3/h	wet standard cubic metres per hour
WSm^3/h/MW	wet standard cubic metres per hour per megawatt
WSm^3/MJ	wet standard cubic metres per megajoule
%	percentage

Glossary

“**Accuracy**” means the extent to which the results of a calculation or the readings of an instrument approach the true values of the calculated or measured quantities, and are free from error.

“**Analyzer**” is the system that measures gas concentration in the discharge gas stream.

“**Availability**” means the number of valid hours divided by the number of hours that the generating unit burns fuel.

“**Backfilling**” means a technique to substitute data during an out-of-control period.

“**Bias**” means systematic error, resulting in measurements that are either consistently low or high relative to the reference value. Bias exists when the difference between the continuous emission monitoring data and the reference method data exceeds random error.

“**Calibration gas**” means a known concentration of (1) a gas that is traceable to either a standard reference material or the U.S. National Institute of Standards and Technology, (2) an authorized certified reference gas, or (3) a U.S. Environmental Protection Agency protocol gas.

“**Conditioning period**” means a recommended 168-hour period following the installation of a new continuous emission monitoring system, during which the system samples and analyzes the emissions from the source, prior to the operational test period.

“**Continuous emission monitoring system (CEM system)**” means the complete equipment for sampling, conditioning, and analyzing emissions or process parameters and for recording data.

“**Drift**” means an undesired change in output, over a period of time, that is unrelated to input or equipment adjustments.

“**Flow monitor**” is the system that monitors the actual linear velocity or flow rate of the discharge gas stream.

“**Full scale**” means the upper value of the monitor or analyzer range.

“**Gross unit load or load**” means the gross electrical and thermal output from an electricity generating unit.

“**Auditor**” means an individual who is independent of the owner/operator, certified as an auditor by a certification body accredited by the Standards Council of Canada and has good knowledge of continuous emissions monitoring systems

“**Interference rejection**” means the ability of a continuous emission monitoring system to measure a gaseous species without responding to other gases or substances, within specified limits.

“**Operational test period**” means a mandatory 168-hour period following the installation of a new continuous emission monitoring system, during which most of the performance specification tests are carried out.

“**Out-of-control period**” means a period when the output from the analyzer, flow monitor, or data acquisition system does not accurately represent the stack emissions.

"**Peaking unit**" means a generating unit ordinarily used to supply power during periods of high demand or during unforeseen outages. Such a unit will not operate more than 7500 hours in any 5-year period and, in those years, more than a total of 3000 hours during the months of May, June, July, August, and September.

"**Precision**" means the measure of the range of values of a set of repeated measurements; indicates reproducibility of the observations.

"**Range**" means the algebraic difference between the upper and lower limit of the group of values within which a quantity is measured, received, or transmitted.

"**Relative accuracy**" is the absolute mean difference between a series of concurrent measurements made by a continuous emission monitoring system and an appropriate reference method plus the 2.5% error confidence internal coefficient, divided by the mean of the reference method measurements.

"**Representative load**" is the typical unit operating level forecasted for the following 6 months.

"**Standard conditions**" means at 101.325 kPa pressure and 25°C temperature.

"**Traceable**" means the ability to relate individual measurement results, through a contiguous sequence of measurement accuracy verifications, to nationally or internationally accepted measurement systems (e.g., NIST, ISO).

"**U.S. Environmental Protection Agency (EPA) protocol grade gas**" means a calibration gas mixture prepared and analyzed according to Section 2 of the EPA *Traceability Protocol for Assay and Certification of Gaseous Calibration Standards*, September 1997, EPA-600/R-97/121.

"**Valid hour**" means an hour during which the generating unit burned fuel and the associated continuous emission monitoring system produced a minimum of 30 minutes of valid data. In the case of a time-shared continuous emission monitoring system, the minimum requirement is two data points per valid hour.

Section 1. Applicability

This reference method details the continuous emission monitoring (CEM) procedures for quantifying carbon dioxide (CO_2) releases from thermal electricity generating units (EGUs) and is based on the direct measurement of either wet or dry CO_2 or oxygen (O_2) concentration and stack gas flow rate, where applicable, as set out in Section 7.

The system for carbon dioxide monitoring may be part of a larger existing monitoring system for measuring other pollutants such as sulphur dioxide (SO_2) and nitrogen oxides (NOx).

Section 2. Summary of Specifications and Protocols

The specifications that must be met and the procedures that must be followed for the installation, certification, and continued operation of a CEM system are summarized in Figure 1. This summary is intended to help the operator to plan and carry out the numerous tasks involved in installing and operating the monitoring system and to continue to generate accurate long-term emissions data.

Figure 1 Summary of Specifications and Protocols for Continuous Emission Monitoring Systems

Section 3 **Design Specifications and Test Procedures**	**Section 4** **Installation Specifications**	**Section 5** **Certification of the System**	**Section 6** **Quality Assurance and Quality Control Procedures**
3.1 Interface/Conditioning • Location of Calibration Port 3.2 Gas Analyzer • Operating Range • Interference • Temperature-response Drifts 3.3 Flow Monitor • Operating Range 3.4 Stack Gas Moisture 3.5 Data Acquisition • Averaging Time • Backfilling of Missing Data • Data Quality Assessment 3.6 Cycle Time 3.7 Test Procedures • Interference Rejection • Temperature-response Drift • System Cycle Time • Manufacturer's Certificate of Conformance	4.1 Site Location 4.2 Representativeness • Stratification Test	5.1 Performance Specifications • Operational Test Period • Calibration Drift • Electronic Drift • System Response Time • Relative Accuracy • Bias 5.2 Calibration Gases 5.3 Test Procedures • Operational Test Period • Calibration Drift • System Response Time • Relative Accuracy • Bias	6.1 QA/QC Manual 6.2 Daily Performance Evaluations • Calibration Drift • Electronic Drift 6.3 Quarterly Performance Evaluations • Cylinder Gas Test • Stack Gas Flow Test 6.4 Semi-annual Performance Evaluations • Relative Accuracy and Bias • Exemptions 6.5 Annual Performance Evaluations • Availability • Independent Inspection 6.6 Recertification Requirements

Section 3 outlines the specifications for the overall CEM system and subsystems, along with associated procedures for measuring these parameters. This section will assist the operator during the initial design and/or purchase stages. Specific requirements are provided for the data acquisition system.

Specifications for installing the CEM system are provided in Section 4. Their use will ensure that a test location meets certain minimal requirements with respect to the representativeness of the gas flow and the accessibility of the equipment for maintenance purposes.

After installation, the monitoring system must be certified as per the protocols summarized in Section 5. Certification of the system takes place only once, following the initial installation of the CO_2 monitoring system, unless recertification is required (see Section 6.6). The emissions data gathered from the CEM system are compared against data gathered from reference methods to ensure that the specifications have been met. When an installed system has met or surpassed all these specifications, it is deemed to be certified and capable of generating quality-assured emissions data.

Section 6 describes the Quality Assurance and Quality Control (QA/QC) procedures that are required on an ongoing basis to satisfy the operating criteria. The QA/QC procedures for each installed CEM system must be described in a QA/QC manual to be developed, maintained, kept on file and made available upon request as per Section 8.

Section 3. Design Specifications and Test Procedures

A CO_2 CEM system consists of the following four subsystems:

- sample interface/conditioning
- gas analyzers
- stack gas flow monitor; and
- data acquisition.

Specifications for these subsystems are contained in sections 3.1 to 3.6, while Section 3.7 outlines the procedures for determining the value of the parameters, where applicable. The parameters and specifications for these subsystems are shown in Table 1.

Table 1 Design Specifications for CO_2 Continuous Emission Monitoring Systems

Subsystem	Parameter	Specification	Text reference	
			Specification	Test Procedures
Sample interface and conditioning	Location of calibration ports	See Table 2	3.1.1	-
Analyzer	Operating range	Average monthly concentration between 40% and 75% of full scale (FS)	3.2.1	-
	Interference	<4.0% FS for the sum of all interferences	3.2.2	3.7.1
	Temperature-response drifts	Zero drift <2.0% FS for 10°C change (5 - 35°C)	3.2.3	3.7.2
		Span drift <4.0% FS for 10°C change (5 - 35°C)	3.2.3	3.7.2
Flow monitor	Operating range	Maximum potential flow rate equal to 100% FS	3.3.1	-
Data acquisition	Averaging time	1 hour	3.5.1	-
	Missing data	≤168 hours - backfill >168 hours - alternative CEM system	3.5.2	-
Overall system	System cycle time*	≤15 minutes for complete cycle (15/n minutes for any one stream in an n-stream system)	3.6	3.7.3

* This design specification applies only to the time-shared systems.

This reference method does not specify measurement techniques. Components that meet the criteria specified in sections 3.1 to 3.6 and that allow the overall CEM system to achieve the certification specifications in Section 5 and the performance evaluations in Section 6 are acceptable.

3.1 Sample Interface/Conditioning Subsystem Specifications

3.1.1 Location of the Calibration Gas Injection Port

The location of the system calibration gas injection port is the sole criterion for the sample interface/conditioning subsystem, with the location of this port being specific to the type of CEM system. The location of the ports for the various types of CEM systems is shown in Table 2.

Table 2 Location of System Calibration Gas Injection Ports for Specific Continuous Emission Monitoring Systems

System type	Subsystem	Specification for location of system calibration gas injection port
Extractive	Direct measurement of gas concentrations	Calibration gas must be introduced no further than the probe exit.
	Dilution (in-stack and external)	Calibration gas must be introduced prior to dilution.
In situ	Point	Calibration gas must flood the measurement cavity of the analyzer.
	Path	Calibration gas must provide a check on the internal optics and all electronic circuitry. System may also include an internal calibration device for simulating a zero and an upscale calibration value.

3.2 Gas Analyzer Subsystem Specifications

3.2.1 Operating Range

The chosen range of the analyzer must encompass all anticipated concentrations for the gas stream being monitored. The average monthly concentration of each analyzed gas must fall between 40% and 75% of the chosen full-scale (FS) range. If the average monthly concentration of CO_2 or oxygen (O_2) falls outside these limits, the analyzer must be adjusted such that the average is brought back within these limits.

Note that numerous performance specifications are defined with reference to the full-scale (FS) setting of the CEM analyzers (see Table 1, Table 3 in Section 5 and Table 5 in Section 6). The gas analyzer of a CEM system may be capable of measuring levels higher than the defined FS level; however, this higher level cannot be applied to demonstrate conformance to the performance specifications, which are tailored to the characteristics of the emission source.

The highest range must include the maximum potential concentration anticipated for the process. Note that data that fall outside the range(s) of an analyzer are considered as missing and must be backfilled using the criteria shown in Section 3.5.2.

3.2.2 Interference

Each analyzer must exhibit a response of less than 4.0% of FS for the sum of all interferences due to other gas constituents, as measured by the procedures provided in Section 3.7.1.

3.2.3 Temperature-response Drifts

Each gas analyzer used in the system must exhibit a zero drift less than 2.0% of the FS setting for any 10°C change over the temperature range of 5 to 35°C. Additionally, each analyzer must exhibit a span drift of less than 4.0% of the FS setting for any 10°C change over the temperature range of 5 to 35°C. Both the zero and span drift tests are to be carried out within the acceptable temperature operating range of the analyzer, as specified by the manufacturer. The procedures outlined in Section 3.7.2 must be followed to determine the temperature-response drift.

Analyzers installed and operated in a temperature-controlled environment are exempt from this specification.

3.3 Flow Monitor Subsystem Specifications

The CEM system stack gas flow monitor must have the capability of carrying out checks at low and high flow rates as part of the system calibration procedures. Electronic simulation of low and high flow is acceptable provided that daily zero and span drift can be calculated. The sensor must cover the full range of gas velocities anticipated in the flue or duct. Flows exceeding the range of the sensor are deemed to be missing and must be backfilled, as described in Section 3.5.2 of this report.

The flow monitor must be designed and equipped in such a way to ensure that the moisture expected to occur at the monitoring location does not interfere with the proper functioning of the flow monitoring system.

If the flow monitor is based on the principle of differential pressure, the monitor must be designed and equipped in such a way to provide an automatic, periodic back purging (simultaneously on both sides of the probe) or equivalent method of sufficient force and frequency on a daily basis, at a minimum, to ensure that the probe and lines remain sufficiently free of obstructions to meet the calibration drift criteria set out in Section 5.1.2. The monitor must also be designed and equipped in such a way to provide a means for detecting leaks in the system on a quarterly basis, at a minimum.

If the flow monitor is based on the principle of thermal dissipation, the monitor must be designed and equipped in such a way to ensure on a daily basis, at a minimum, that the probe remains sufficiently clean to meet the calibration drift criteria set out in Section 5.1.2. This type of monitor shall not be used for stack gases containing water droplets.

If the flow monitor is based on the ultrasonic principle, the monitor must be designed and equipped in such a way to ensure on a daily basis, at a minimum, that the transceiver remains sufficiently free of dirt (e.g. through a back purging system) to meet the calibration drift criteria set out in Section 5.1.2.

3.3.1 Operating Range

The full-scale (FS) setting must be approximately 100% of the maximum potential flow rate.

Note that various performance specifications are defined with reference to the FS setting of the CEM flow monitor (see Table 1 above, Table 3 in Section 5 and Table 5 in Section 6). The flow monitor of a CEM system may be able to measure levels exceeding the defined FS level; however, this higher level cannot be applied to demonstrate conformance to the performance specifications, which are tailored to the characteristics of the emission source.

If flow varies widely, as in the case of stacks that serve several units, then the use of multi-range flow monitors is acceptable. The highest range must take account of the maximum potential flow anticipated for the process. Note that data that fall outside the range(s) of a flow monitor are considered as missing and must be backfilled using the criteria provided in Section 3.5.2.

3.4 Stack Gas Moisture Subsystem Specifications

If the CEM system includes a stack gas flow monitor and analyzers that measure on a dry basis, then the CEM system must include a moisture subsystem capable of estimating the hourly stack gas moisture levels all year round. The moisture estimate must be used to adjust the measured CO_2 or O_2 levels to a wet basis according to Section 7.

Tables 3 and 5 contain specifications for a moisture monitoring subsystem based on a single O_2 analyzer. Alternative stack gas moisture monitoring subsystems may be used if it is demonstrated that the system is able to calculate the hourly factor (100 – B_{ws}) with an error ≤ 2.0% all year-round.

3.5 Data Acquisition Subsystem Specifications

The CEM system must include a microprocessor-based data acquisition subsystem that accepts the outputs of the gas analyzers and other associated equipment and converts these into a CO_2 emission rate according to Section 7. The system must maintain a record of all parameters as indicated Section 8. The system must also record and compute daily zero and calibration drifts, provide for backfilling of missing data, and record any other relevant data that the operator may wish to include.

3.5.1 Averaging Time

Data must be reduced to 1-hour averages for all measured parameters. The 1-hour averages must be used to compute CO_2 mass emission rates, expressed as kg/hr as per Section 7.

For time-shared systems, 1-hour averages must be computed from four or more values, equally spaced over each 1-hour period, with the exception of periods during which calibrations, QA activities, maintenance, or repairs are being carried out. During these specific activities, a valid hour must consist of a minimum of two data points for a time-shared system or 30 minutes of data for a CEM system using dedicated analyzers. The calibrations must be conducted in a manner that avoids the loss of a valid hour of emissions data every time that a daily calibration is conducted. This may be achieved by using mixtures of several gases; by scheduling the calibration periods so that the emissions data loss is shared by two consecutive hours; or by scheduling the calibration of different analyzers at different hours of the day.

3.5.2 Backfilling of Missing Data

Any CO_2 emissions data that are missing due to a malfunction of the CEM system (e.g. CO_2 or O_2 analyzer, flow monitor, etc.) must be substituted for a period of up to 168 hours for any single episode using data derived from the most recent CO_2 emission versus load or heat input correlations determined by the certified, quality-assured CEM system, providing that the correlations are based on a minimum of 168 hours.

If the malfunction occurs before the certified CEM system could accumulate a minimum of 168 quality-assured hours of CO_2 emission data, then the missing data shall be backfilled on the basis of heat rate or load during the malfunction period. Calculation procedures for this potential backfilling period must be tailored to the specific conditions of the electricity generating unit (EGU). This must be described in the CEM system's Quality Assurance/Quality Control (QA/QC) manual.

When a CEM system (e.g. gas analyzer, flow monitor) malfunction extends beyond 168 hours for any single episode, data must be generated by means of another CO_2 measurement method. Other methods used for this purpose must meet all design and performance specifications presented in this report. When using another CEM system, the stack gas sample must be extracted from the sample port(s) used for the reference method during certification of the CEM system.

3.5.3 Data Quality Assessment

All emissions data must be quality-assessed by the operator to identify suspected data using procedures to be described in the QA/QC manual (Section 6.1). The procedures must include automatic flagging of a) out-of-range concentrations and flows, b) abnormal system calibration response times, c) abnormal flow-to-input or flow-to-output levels, and d) abnormal concentrations during periods when the generating unit burned no fuel.

The flagged data must be investigated and either accepted or backfilled using the criteria provided in Section 3.5.2. The quarterly report must identify such flagged data and provide a summary of reasons for their acceptance or backfilling.

3.6 Cycle Time Specifications for Time-shared Systems

The specification for cycle time applies to time-shared systems measuring emissions from a number of sources using a single set of gas analyzers. One complete measurement cycle of all streams must be completed in 15 minutes or less, generating a minimum of four sets of concentration and emissions data for each hour of operation. For a CEM system measuring the emissions from "n" stacks, the maximum time available for each source being monitored would be 15/n minutes, including switching, stabilization and analyzer output integration times.

3.7 Test Procedures for Verification of Design Specifications

3.7.1 Analyzer Interference

It is acceptable to carry out this test after the analyzers have been installed in the CEM system or in a laboratory or other suitable location before the analyzers are installed. The analyzer being tested must be allowed to warm up to manufacturer's specifications and then calibrated by introducing appropriate low- and high-level gases directly to the analyzer sample inlet. After the initial calibration, test gases must be introduced sequentially, each consisting of a single interfering gas at a concentration representative of that species in the gas flow to be monitored. The magnitude of the interference of each potential interfering species on the target gas must then be determined.

The analyzer is acceptable if the combined response of all interfering gases is less than 4.0% of the FS setting.

3.7.2 Analyzer Temperature-response Zero and Span Drifts

The analyzer must be placed in a climate-controlled chamber in which the temperature can be varied from 5 to 35°C. The analyzer must be allowed to warm up to manufacturer's specifications, and then the analyzer must be calibrated at 25°C using appropriate zero and span gases. The temperature of the chamber must be adjusted to 35, 15 and 5°C. It must be ensured that the analyzer temperature has stabilized and that the analyzer's power source remains on for the duration of this test.

When the analyzer has stabilized at each climate chamber temperature, each of the calibration gases must be introduced at the same flow or pressure conditions, and the response of the analyzer must be noted.

The temperature-response zero drift is calculated from the difference between the indicated zero reading and the reading at the next higher or lower temperature. The analyzer is acceptable if the difference between all adjacent (i.e., 5/15, 15/25, and 25/35°C) zero responses is less than 2.0% of the FS setting.

The temperature-response span drift is calculated from the differences between adjacent span responses. The analyzer is acceptable if the difference between all adjacent span responses is less than 4.0% of the FS setting.

3.7.3 System Cycle Time

The system cycle time is set by the manufacturer during design and must meet the specifications shown in Section 3.6.

3.7.4 Manufacturer's Certificate of Conformance

Specifications for both interference and temperature-response drifts have been met if the analyzer manufacturer certifies that an identical, randomly selected analyzer, manufactured in the same quarter as the delivered unit, was tested according to the procedures found in sections 3.7.1 and 3.7.2, and the parameters were found to respect the specifications.

Section 4. Installation Specifications

This section contains criteria for selecting a suitable sampling site on the flue or duct and determining the representativeness of the desired location with respect to the homogeneity of the gas flow.

4.1 Location of Sampling Site

The probe or in-situ analyzer must be installed in a location that is accessible at all times and under any weather conditions so that repairs, routine maintenance and accuracy testing can be performed on schedule as outlined in the QA/QC manual. The degree of exposure, seasonal weather conditions, servicing and maintenance, susceptibility to lightning strikes, and vibration of the duct and/or platform are some of the considerations when choosing a location for a probe or in situ analyzer.

The flow pattern at the sampling site must be determined prior to the installation of the flow sensor. The presence of a cyclonic flow pattern will add considerable complexity to both certification and operation of the installed sensor.

4.2 Representativeness

The probe or in situ analyzer must be installed in a location where the flue gases are well mixed. The degree of turbulence and mixing time are major factors that influence the extent of stratification of the flue gases.

The extent of CO_2 (or O_2) stratification of the flue gases at any location must be determined using the applicable test methods. The procedures outlined in Section 4.2.1 must be carried out at a proposed analyzer installation site to determine the extent of stratification before installing the CEM system. If significant gas stratification of any of the measured species is present at the proposed location, then an alternative sampling location must be selected where the flow is non-stratified.

Before the installation of the flow monitor, a number of velocity traverses must be carried out at the proposed sensor installation location over a range of loads using the equipment and procedures found in Method B of Reference Method EPS 1/RM/8 (*Reference Methods for Source Testing: Measurement of Releases of Particulate from Stationary Sources*, Environment Canada, December 1993, as amended). The degree of cyclonic flow is determined using the procedures found in Method A of Reference Method EPS 1/RM/8. These measurements will provide a basis for the location of the sensor and will also demonstrate the absence of cyclonic flow (average rotational angle ≤15 degrees). The location of sampling ports must be selected so as to avoid interference between the flow monitor, the concentration measurement point(s) or path, and the RM probes.

If a single-point stack gas velocity sensor is being installed, the sensing tip must be located at a point yielding velocity measurements within the specifications over the full range of loads. The velocity profile data must be used to select the optimum measurement point.

4.2.1 Stratification Test Procedure

A minimum of nine sampling points must be used in the stack or duct, applying the procedures for selecting sampling points found in Reference Method EPS 1/RM/8. Using two automated systems with similar response characteristics, the concentration of a target gas must be measured at each of the sampling points in the matrix with one system (traversing system), while simultaneously measuring the target gas concentration at a fixed or reference location, usually at the centre of the flue or duct.

Note that a stratification test must be carried out for each gaseous species measured by the installed CEM system (either CO_2 or O_2).

The concentration of the gas measured at the fixed location (stability reference measurement) in the flue or duct serves as an indicator of the stability of the gas flow. If this concentration varies by more than ±10% of the average concentration for longer than one minute during this test, the stratification test must be carried out when more stable conditions prevail.

Note that the installed analyzer in the CEM system, which withdraws a sample from a fixed point, is acceptable as the stability reference measurement for the stratification test. The response characteristics of the reference and the traversing analyzers must be similar.

The concentration of a target gas must be measured at each of the sampling points in the matrix. At the conclusion of the traverses, the measurement of the concentration must be repeated at the initial measurement point. If the concentrations differ by more than ±10% for the pre- and post-test values at this point, stratification must be retested when more stable conditions prevail.

The degree of stratification for each species is calculated at each traverse point within the gas flow using Equation 1.

$$ST_i = \left[\frac{C_i - C_{avg}}{C_{avg}}\right] \times 100$$ **Equation 1**

where:

ST_i = stratification in %
C_i = concentration of the measured species at point i
C_{avg} = average of all measured concentrations

The flow in the stack or duct is considered to be stratified if any calculated value using Equation 1 exceeds 10%.

Section 5. Certification Performance Specifications and Test Procedures

To achieve certification, an installed CEM system must meet all of the performance specifications outlined in Table 3. The specifications are relevant to the measurement of CO_2 or O_2, as well as stack gas moisture (if applicable) and stack gas flow measurement and the overall CEM system. It is acceptable for a system to be partially certified (e.g. for flow) and then fully certified at a later date when deficiencies in specific portions of the system have been corrected.

The specifications are described in Section 5.1. The gases used during certification testing are described in Section 5.2, while the applicable test procedures are outlined in Section 5.3.

5.1 Certification Performance Specifications

After the CEM system has been installed according to the manufacturer's written instructions, it must be operated for a conditioning period of not less than 168 hours, prior to the operational test period (OTP), during which the emission source must be operating. During the conditioning period, the entire CEM system must operate normally with the exception of periods during which calibration procedures are being carried out as well as other procedures indicated in the CEM system QA/QC manual.

5.1.1 Operational Test Period

The OTP is a 168-hour cumulative time period during which most of the performance specification tests are carried out. The 168-hour period may be contiguous or fragmented in periods of no less than 24 hours. No unscheduled maintenance, repairs, or adjustments to the CEM system are allowed during the OTP. The procedures in the CEM system QA/QC manual must be followed as if the CEM system were generating emissions data.

CEM systems installed at peaking units are exempted from the OTP and calibration drift tests.

5.1.2 Calibration Drift

The calibration drift specification is applicable at the levels indicated in Table 3 and for each gas analyzer. Table 3 also includes flow monitoring calibration drift specifications.

For the gas analyzers, this procedure tests both linearity and calibration drift.

At 24-hour intervals over the 168-hour OTP, the CEM system's response to calibration gases, as indicated by the data acquisition system, must not deviate from the certified value of the appropriate gas by an amount exceeding:

Gas Analyzer

Low level: 0.5% CO_2 (or O_2)
Mid level: 0.5% CO_2 (or O_2)
High level: 0.5% CO_2 (or O_2)

At 24-hour intervals over the 168-hour OTP, the CEM system response to the stack gas flow, as indicated by the data acquisition system, must not deviate from the internal reference value by an amount exceeding the greater of:

Flow monitor

Low level: 3.0% of the FS setting or 0.6 m/s, absolute difference
High level: 3.0% of the FS setting or 0.6 m/s, absolute difference

The electronic drift of stack gas flow monitors that do not perform daily flow system calibration checks must not deviate from the value of the electric input signal by more than 3.0% FS.

Calibration drift must be tested according to the procedures set out in Section 5.3.2.

Further details on the use of stack gas moisture monitoring systems are presented in Section 7.

5.1.3 System Response Time

For CEM systems using dedicated analyzers, the system response time is acceptable if the average of three increasing and three decreasing values is no greater than 200 seconds, for a 90% response to a step change in concentration of gas at the probe exit. Note that this includes the lag time.

For time-shared systems, the system response time is acceptable if the average of three increasing and three decreasing values is no greater than 15 minutes, for each analyzer on each stream, for a 90% response to a step change in concentration of gas at the probe exit. Note that this includes the lag time.

System response time must be tested according to the procedures set out in Section 5.3.3.

5.1.4 Relative Accuracy

The relative accuracy for a CO_2 (or O_2) gas analyzer must not exceed 10.0% or 0.5% CO_2 (or O_2) average absolute difference (|d|), whichever is greater.

The relative accuracy for a stack gas flow monitor must not exceed 10.0% or 0.6 m/s average absolute difference (|d|), whichever is greater, for the three levels tested.

The relative accuracy for a stack gas moisture monitor must not exceed 10.0% or 2.0% of (100 - B_{ws}), whichever is greater, for the three levels tested.

The relative accuracy for CO_2 mass emissions must not exceed 10.0%.

Relative accuracy must be tested according to the procedures set out in Section 5.3.4.

Further details on the use of stack gas moisture monitoring systems are presented in Section 7.

Table 3 Certification Performance Specifications

<table>
<tr><th rowspan="2">Parameter</th><th rowspan="2" colspan="2">Component</th><th rowspan="2">Level</th><th rowspan="2">Specification</th><th colspan="2">References</th></tr>
<tr><th>Specifi-cations</th><th>Test Procedures</th></tr>
<tr><td rowspan="4">24-hour calibration drift</td><td colspan="2">CO_2 (or O_2) analyzer</td><td>Low level (0 - 20% FS)
Mid level (40 - 60% FS)
High level (80 - 100% FS)</td><td>≤ 0.5% CO_2 (or O_2)
≤ 0.5% CO_2 (or O_2)
≤ 0.5% CO_2 (or O_2)</td><td rowspan="3">5.1.2</td><td rowspan="3">5.3.2</td></tr>
<tr><td colspan="2">Stack gas moisture monitor *
- wet O_2 /Temp./relative humidity (RH) type</td><td>Low level (0 - 20% FS)
High level (80 - 100% FS)</td><td>≤ 0.5% O_2
≤ 0.5% O_2</td></tr>
<tr><td rowspan="2">Flow monitor</td><td>with system calibration capability</td><td>Low level (0 - 20% FS)
High level (80 - 100% FS)</td><td>≤ the greater of
3.0% FS or 0.6 m/s absolute difference
3.0% FS or 0.6 m/s absolute difference</td></tr>
<tr><td>without system calibration capability</td><td>Electronic reference level</td><td>≤ 3.0% FS</td><td>6.2.2</td><td></td></tr>
<tr><td rowspan="2">System response time</td><td colspan="2">Dedicated analyzer</td><td>-</td><td>≤ 200 seconds for 90% change</td><td rowspan="2">5.1.3</td><td rowspan="2">5.3.3</td></tr>
<tr><td colspan="2">Time-shared system</td><td>-</td><td>≤ 15 minutes for 90% change</td></tr>
<tr><td rowspan="4">Relative accuracy (RA)</td><td colspan="2">CO_2 (or O_2) analyzer</td><td>Representative load level</td><td>≤ the greater of 10.0% RA or 0.5% CO_2 (or O_2) avg. absolute difference</td><td rowspan="4">5.1.4</td><td rowspan="4">5.3.4</td></tr>
<tr><td colspan="2">Stack gas moisture monitor*</td><td>Minimum safe and stable load level
Mid load (40 - 60%)
High load (90 -100%)</td><td>≤ the greater of
10.0% RA or 2.0% of (100 - B_{ws}) avg. absolute difference
10.0% RA or 2.0% of (100 - B_{ws}) avg. absolute difference
10.0% RA or 2.0% of (100 - B_{ws}) avg. absolute difference</td></tr>
<tr><td colspan="2">Flow monitor</td><td>Minimum safe and stable load level
Mid load level (40 - 60%)
High load level (90 -100%)</td><td>≤ the greater of
10.0% RA or 0.6 m/s avg. absolute difference
10.0% RA or 0.6 m/s avg. absolute difference
10.0% RA or 0.6 m/s avg. absolute difference</td></tr>
<tr><td colspan="2">CO_2 mass emission</td><td>Representative load level</td><td>≤ 10.0% RA</td></tr>
<tr><td rowspan="3">Bias</td><td colspan="2">CO_2 (or O_2) analyzer</td><td>Representative load level</td><td>≤ the greater of 5.0% of FS value or 0.5% CO_2 (or O_2) avg absolute difference</td><td rowspan="3">5.1.5</td><td rowspan="3">5.3.5</td></tr>
<tr><td colspan="2">Stack gas moisture monitor*</td><td>Representative load level</td><td>≤ the greater of 5.0% FS or 1.0% of (100-B_{ws}) avg absolute difference</td></tr>
<tr><td colspan="2">Flow monitor</td><td>Representative load level</td><td>≤ the greater of 5.0% of FS value or 0.6 m/s avg. absolute difference</td></tr>
</table>

Notes: * The performance specifications for stack gas moisture based on wet O_2 measurements (calibration drift, response time, relative accuracy, and availability) are summarized in tables 3 and 5. Other moisture monitoring systems may be used to correct dry measured concentrations, if it is demonstrated that the system is able to calculate the hourly factor (100 – B_{ws}) with an error ≤ 2.0% all year round. Note that B_{ws} is the moisture content of the stack gas (in % of volume).

5.1.5 Bias

The bias for a CO_2 (or O_2) gas analyzer must not exceed 5.0% of the full scale (FS) value or 0.5% CO_2 (or O_2) average absolute difference, whichever is greater.

The bias for a stack gas moisture monitor must not exceed 5.0% of the FS value or 1.0% (100 - B_{ws}) average absolute difference, whichever is greater.

The bias for a stack gas flow monitor must not exceed 5.0% of the FS value or 0.6 m/s average absolute difference, whichever is greater.

Bias must be tested according to the calculations in Section 5.3.5.

Further details on the use of stack gas moisture monitoring systems are presented in Section 7.

If there is any bias, as defined in Section 5.3.5, either positive or negative, in any measurements made by the CEM system, then the data that are subsequently generated must be corrected according to Section 5.3.5 for the bias before any subsequent use is made of the data.

5.2 Calibration Gases

The gases used by both the CEM system and the reference method during the relative accuracy test must be U.S. Environmental Protection Agency (EPA) protocol grade.

Gases used during the calibration drift and response time tests must be certified to an accuracy of 2.0% by the supplier, but protocol gases may be used if desired.

The CEM system's QA/QC manual must specify a method of cross-referencing successive gas cylinders to detect out-of-specification cylinders before the new cylinders are used to calibrate the CEM system.

5.3 Certification Test Procedures

5.3.1 Operational Test Period

During the OTP, the CEM system must continue to analyze flue gases without interruption and produce a record of the emissions data using the data acquisition system. This record must be kept for the time period indicated in Section 8. Sampling may be interrupted during this test period only to carry out system instrument calibration checks and specified procedures contained in the QA/QC manual.

During this period, no unscheduled maintenance, repairs, or adjustments to the CEM system may be carried out; otherwise, the OTP must be restarted. Calibration adjustments may be performed at 24-hour intervals or more frequently if specified by the manufacturer and stated in the QA/QC manual. Automatic zero and calibration adjustments made without operator intervention may be carried out at any time, but these adjustments must be documented by the data acquisition system.

If the test period is fragmented due to process shutdown, the times and dates of this period must be recorded and the test continued when the source resumes operation. If the test is interrupted due to CEM system failure, the entire test period must be restarted after the problem has been rectified.

The performance specification tests outlined in sections 5.3.2 to 5.3.5 must be carried out during the OTP, with the exception of the relative accuracy test (Section 5.3.4), which may either be conducted during the OTP or during the 168-hour period immediately following the OTP. It is acceptable for the calibration drift tests to be completed before attempting the relative accuracy tests, to minimize the risk associated with repeating the latter.

5.3.2 Calibration Drift Test Protocols

It is acceptable for the calibration drift test period to be fragmented into sub-periods of no less than 24 hours each.

The calibration drift must be determined for the gas analyzers, and stack gas flow monitor at approximately 24-hour intervals over the course of the 168-hour test period.

The procedures to be followed during this test are listed hereunder.

5.3.2.1 Calibration Adjustments Automatic or manual calibration adjustments must be carried out each day. The calibration drift test must be conducted immediately before any such adjustments or in such a manner that the magnitude of the drifts can be determined. Since the test is carried out before adjustments, the magnitude of any drift occurring in the system or analyzer over the 24-hour period is incorporated into the reported result.

5.3.2.2 Test Procedures The performance of preliminary runs is recommended (e.g. to determine the need to use Bias Adjustment Factors) but is not mandatory.

On the first day of the performance test period, the calibration of the system must be checked by injecting the three calibration gases (Section 5.2) at the primary CEM system calibration port, as indicated in Section 3.1.1.

The system must be challenged three times per day with each of the low-, mid- and high-level (as described in Table 3) calibration gases for CO_2 or O_2 for a total of nine tests. The series of tests must be carried out at approximately 24-hour intervals. The three ranges for each gas must not be introduced in succession or in the same sequence, but must be alternated with other gases. The response of the system, as indicated by the data acquisition system, must be recorded, and the average system response of the three calibration checks for that day must be calculated.

If the CEM system is fitted with a stack gas flow monitor, then low- and high- flow calibration check measurements must be performed once daily at approximately 24-hour intervals. The response of the system, as indicated by the data acquisition system, must be recorded, and the system response to the three calibration checks for that day must be calculated.

5.3.2.3 Gas Concentration Calculations The gas calibration drift for the responses to the low-, mid- and high-level test gases is calculated using Equation 2.

$$D_c = \left[\frac{|A - R|}{FS} \right] \times 100$$ **Equation 2**

where:

D_c	=	concentration calibration drift, in %
A	=	average of the three system responses to the low-, mid- or high-level calibration gas, in %
R	=	certified concentration of the low-, mid- or high-level test gas, in %
FS	=	full-scale setting of the analyzer, in %

5.3.2.4 Gas Flow Calculations The flow measurement calibration drift is calculated using Equation 3.

$$D_f = \left[\frac{\left| A_f - R \right|}{FS} \right] \times 100$$ **Equation 3**

where:

D_f	=	flow calibration drift, in %
A_f	=	average low or high gas velocity or flow rate, as measured by the CEM system, in m/s or m^3/s
R	=	average low or high nominal reference gas velocity or flow rate, in m/s or m^3/s
FS	=	full-scale setting of the flow monitor, in m/s or m^3/s

Note: the reference method and CEM system must have a common averaging period.

5.3.2.5 Acceptance Criteria for Certification The calibration drift test results must respect the performance specifications presented in Section 5.1.2.

5.3.3 System Response Time Test Protocols

This test is performed on the overall CEM system and on each gas analyzed, with the results expressed in concentration units. The test is carried out with the CEM system fully operational. Sample flow rates, pressures, and other parameters must be at the nominal values specified in the manufacturer's written instructions and must be outlined in the CEM system's QA/QC manual.

5.3.3.1 Test Procedures Low- and high-level calibration gases must be introduced alternatively at the system calibration gas injection port specified in Section 3.1.1. Sufficient time must be allowed for the system to stabilize, after which the responses of the data acquisition system to these gases must be recorded. This sequence must be carried out three times, thus generating a total of three increasing and three decreasing concentration changes. When a time-shared system is being tested, injection of the calibration gases must be timed to produce the longest possible response time for the system.

5.3.3.2 Calculations Using the output of the data acquisition system, the time required for the system to achieve a 90% response to the concentration difference between the low and high-level gases for both increasing and decreasing gas concentrations must be determined. The lag time of extractive systems (i.e. the time necessary to convey the gas sample through the sampling line) must be included when determining the time required by the system to reach a 90% response change.

5.3.3.3 Acceptance Criteria for Certification The system response time test results must meet the performance specifications presented in Section 5.1.3.

5.3.4 Relative Accuracy Test Protocols

This test is a comparative evaluation of CEM system performance using the reference methods found in Section 5.3.4.3.

The emission source must be operating at normal capacity or at greater than 50% maximum heat input while combusting the primary fuel normal for that unit. New generating units or units that did not operate in the previous two quarters must be operating at greater than 50% maximum heat input. The CEM system must be operated in a routine manner during this test, and no adjustments, repairs, or modifications to any portion of the system may be carried out other than those actions outlined in the

QA/QC manual. As the system includes the hardware and software associated with data acquisition, data manipulation and system control, parameters in this subsystem must not be modified during the test.

5.3.4.1 Reference Method Sampling Point for Non-stratified Flow Where it has been demonstrated, using the procedures outlined in Section 4.2.1, that the flue gases are not stratified, the reference method (RM) testing may be carried out at a single test point in the flue or duct, with the gas extraction point being no closer than 7.5 cm from any wall.

When certifying extractive or in situ point systems, the RM probe tip must be located no closer than 30 cm from the CEM probe. For in situ path systems, the RM probe must be no closer than 30 cm from the inner 50% of the measurement path. The RM probe must be positioned so that it will not interfere with the operation of the CEM system being tested.

5.3.4.2 Location of Reference Method Sampling Points in Presence of Stratified Flow If the gas flow has been found to be stratified using the procedures outlined in Section 4.2.1 or if the stratification test has not been performed, the RM sample must be collected at several points in the gas flow.

A “measurement line” that passes through the centroids of the flue or duct must be established.

This line must be located within 30 cm of the CEM sampling system cross-section. Three sampling points must be located at 16.7, 50, and 83.3% along the length of the measurement line. Other sampling points may be selected if it can be demonstrated that they will provide a representative sample of the bulk gas flow during the test period.

5.3.4.3 Test Methods U.S. EPA Method 3A must be used for measuring CO_2 or O_2 concentration. Environment Canada EPS 1/RM/8 must be used for stack gas flow and moisture measurement unless multi-dimensional stack gas velocity is present or when measuring velocities near the stack gas wall. When multi-dimensional stack gas velocity is confirmed in the stack, U.S. EPA Methods 2F and 2G must be used. When measuring velocities near the stack wall, U.S. EPA Conditional Test Method CTM-041 and U.S. EPA Method 2H must be used.

5.3.4.4 Sampling Strategy A minimum of nine comparisons of the RM and CEM results must be conducted to evaluate the performance of the CO_2 CEM system being tested. When manual sampling reference methods are being used, the sampling must be carried out at a fixed sampling rate; that is, the sampling rate must not be adjusted over the duration of the test, except to maintain the flow at the initial rate. Sampling must be carried out for 30 minutes during each test, divided equally over the three sampling points for stratified flow testing or at the single point for non-stratified flow.

The operator may choose to carry out more than nine sets of comparisons. If this option is exercised, then the results of a maximum of three tests may be rejected from the test data if an appropriate statistical test applied to the data demonstrates that these results are outliers. A minimum of nine RM tests must be available after the statistical rejection of data. All data must be reported, including the outliers, along with all calculations.

All appropriate gas and moisture measurements must be conducted simultaneously with the RM pollutant concentration measurements.

If the CEM is fitted with both a stack gas flow and a moisture monitor, then RM concentration measurements must be concurrent with RM flow measurements. Two additional sets of nine flow and moisture comparisons must be carried out either during the OTP or during the 168-hour period immediately following the OTP, so as to complete a set of flow and moisture measurements for the minimum safe and stable load, mid-load and high-load levels.

Flow monitors installed at peaking units and bypass stacks may perform flow and moisture comparisons at a single load level.

5.3.4.5 Correlating Reference Method and Continuous Emission Monitoring System Measurements In order to correlate the data from the CEM system and RM tests, the beginning and end of each test period must be clearly marked on the CEM data acquisition record and the CEM time must be synchronized with the RM test crew time. After each test is completed, the results from the CEM system must be compared with the data derived from the RM results over the exact time period during which the test was performed.

The CEM system and RM results must be correlated on the same basis. Thus, corrections must be applied for moisture, temperature, pressure, etc. The auxiliary measurements of the RM testing (such as stack gas moisture or barometric pressure) are used to make any adjustments to the RM results. The auxiliary measurements of the CEM system are used to make adjustments to the CEM results.

5.3.4.6 Calculations The relative accuracy of the system must be calculated for each gas measured by the system in terms of concentration in percent (by volume), as well as stack gas flow in terms of m/s or Sm^3/h.

(i) Calculation of relative accuracy

The relative accuracy is calculated using Equation 4.

$$RA = \left[\frac{|d| + |cc|}{RM}\right] \times 100$$ **Equation 4**

where:

RA	=	relative accuracy, in %
d	=	mean difference between the CEM system and RM results
cc	=	confidence coefficient
RM	=	average of the reference method results

(ii) Calculation of differences

The absolute value of the difference between the CEM system and RM results is calculated using Equation 5.

$$|d| = \left|\frac{1}{n_i}\sum_{i=1}^{n} d_i\right|$$ **Equation 5**

where:

d_i	=	difference between an RM value and a corresponding CEM system value ($d_i = CEM_i - RM_i$) for the i^{th} test run
n	=	number of data pairs

Note: The numeric signs for each data pair must be retained. The absolute value of the sum of differences is used, not the sum of absolute values of the differences.

(iii) Calculation of confidence coefficient and standard deviation

The values of the confidence coefficient and standard deviation are determined from equations 6 and 7, respectively.

$$\left| cc \right| = \frac{t_{0.025} \times stdev}{\sqrt{n}}$$ **Equation 6**

where:

cc	=	confidence coefficient
$t_{0.025}$	=	t value from Table 4 for a one-tailed t-test corresponding to the probability that a measured value will be biased low at a 95% level of confidence
stdev	=	sample standard deviation of the differences of the data pairs from the relative accuracy test, calculated using Equation 7
n	=	number of data pairs

$$stdev = \sqrt{\frac{\sum_{i=1}^{n}(d_i)^2 - \frac{1}{n}\left[\sum_{i=1}^{n}(d_i)\right]^2}{n-1}}$$ **Equation 7**

where parameters are as defined above.

Table 4 t Values

n-1	5	6	7	8	9	10	11	12	13	14
$t_{0.025}$	2.571	2.447	2.365	2.306	2.262	2.228	2.201	2.179	2.160	2.145

Note: These are t values for one-tailed t-test at a 95% confidence level.

(iv) Calculation of reference flow-to-output and heat-to-output ratios

If the CEM system includes a stack gas flow monitor, the flow-to-output or heat-to-output ratio is to be used as reference for the quarterly stack gas flow test in subsequent quarters.

Depending on the option chosen for the quarterly stack gas flow test, as described in Section 6.3.2, one or more of the following averages must be calculated, based on the process data and the RM measurements obtained during the relative accuracy test of the initial CEM certification or subsequent relative accuracy test audit (RATA):

- flow-to-output ratio; and
- heat-to-output ratio

The flow-to-output ratio is calculated from the results of the RM runs, using Equation 8.

$$R_{ref} = \frac{1}{n}\sum_{i=1}^{n}\frac{Q_{wi}}{MW_i}$$ **Equation 8**

where:

R_{ref}	=	reference value of flow-to-electric-output ratio on a wet basis, from the most recent RATA in WSm^3/MWh
Q_{wi}	=	flow measured during each test run on a wet basis in WSm^3/h
MW_i	=	mean gross electric output during each test run in MW
n	=	number of data pairs

The heat input is the average of the gross heat input during each RATA test run. It must be calculated on the basis of the measured stack gas flow and F-factors (as shown in Table A-1). The heat input corresponding to a RATA test run must be calculated with one of equations 9 to 12.

$$HI = Q_w\left[\frac{100 - B_{ws}}{100\,F_d}\right]\left[\frac{20.9 - O_{2,d}}{20.9}\right]$$ **Equation 9**

$$HI = Q_w\,\frac{1}{F_c}\left[\frac{O_{2,w}}{100}\right]$$ **Equation 10**

$$HI = Q_w\left[\frac{100 - B_{ws}}{100\,F_c}\right]\left[\frac{CO_{2,d}}{100}\right]$$ **Equation 11**

$$HI = Q_w\left[\frac{0.209(100 - B_{ws}) - O_{2,w}}{20.9\,F_d}\right]$$ **Equation 12**

where the following values represent test run averages:

HI	=	heat input in MJ/h
Q_w	=	stack gas flow on a wet basis in WSm^3/h
B_{ws}	=	moisture content of the stack gas in %
F_d	=	fuel-specific F-factor from Table A-1 or calculated as per Appendix A
F_c	=	fuel-specific F-factor from Table A-1 or calculated as per Appendix A
$O_{2,w}$	=	stack gas oxygen concentration in % on a wet basis
$CO_{2,d}$	=	stack gas carbon dioxide concentration in % on a dry basis
$O_{2,d}$	=	stack gas oxygen concentration in % on a dry basis

The reference heat-to-electric-output ratio (or gross heat rate) is calculated with Equation 13, from the results of the RM runs.

$$GHR_{ref} = \frac{1}{n}\sum_{i=1}^{n}\frac{HI_i}{MW_i}$$ **Equation 13**

where the following values are RM test run averages:

GHR_{ref}	=	reference value of gross heat rate, from the most recent RATA in MJ/MWh
HI_i	=	gross heat input during each test run in MJ/h
MW_i	=	mean gross electric output during each test run in MW
n	=	number of data pairs

5.3.4.7 Acceptance Criteria for Certification The performance specifications presented in Section 5.1.4 must be respected.

5.3.5 Bias Test Calculations

A bias or systematic error is considered to be present if, in the measurements of CO_2 (or O_2), moisture or stack gas flow the:

$$|d| \geq |cc|$$ **Equation 14**

As presented in Section 5.1.5, acceptable bias is

($|d| - |cc|) \leq 5.0\%$ FS
or $|d| \leq 0.5\%$ CO_2 (or O_2) for CO_2 or O_2 analyzers
or $|d| \leq 0.6$ m/s for stack gas flow monitor
or $|d| \leq 1\%$ of $(1 - B_{ws})$ for stack gas moisture analyzer

If bias is present, as determined by Equation 14, and it is within the above levels, then the subsequent measurements of the CEM system must be corrected by a bias adjustment factor (BAF), using equations 15 and 16.

$$CEM_{adjusted} = CEM_{monitor} \times BAF$$ **Equation 15**

where:

$CEM_{adjusted}$	=	data adjusted for bias
$CEM_{monitor}$	=	data provided by the monitor
BAF	=	bias adjustment factor, defined by Equation 16

$$BAF = \frac{RM}{CEM_{RATA\,avg}}$$ **Equation 16**

where:

BAF	=	bias adjustment factor
$CEM_{RATA\ avg}$	=	average CEM results during RATA
RM	=	average of the reference method results

The use of a BAF in any measurement must be stated in the QA/QC manual.

5.3.5.1 Acceptance Criteria for Certification The performance specifications presented in Section 5.1.5 must be respected.

Section 6. Quality Assurance/Quality Control Procedures

This section provides detailed descriptions of the step-by-step procedures required to operate and evaluate the system, including details about daily, quarterly, semi-annual and annual performance evaluations. Procedures and minimum criteria for a selection of these activities are provided in sections 6.2 to 6.5. A summary of these performance evaluations is outlined in Table 5.

6.1 Quality Assurance/Quality Control Manual

A QA/QC manual must be developed for each installed CEM system and updated, as needed, to reflect any changes in the system or the procedures. The QA/QC manual must describe the complete program of activities to be implemented to ensure that the data generated by the CEM system will be complete, accurate, and precise. The QA/QC manual must contain, as a minimum, the elements found in Table B-1 of Appendix B.

6.2 Daily Performance Evaluations

6.2.1 Calibration Drift

Calibration of the CEM system is one of the most important aspects of a QA/QC program. The following summarizes the requirements for calibration drift, all of which must appear in the CEM system's QA/QC manual.

6.2.1.1 Frequency The drift of each gas analyzer and flow monitor must be determined at least once daily, at 24-hour intervals. It is good practice to determine the drift of each analyzer even during periods when the generating unit is down. The operator may, however, skip the daily calibration during periods lasting more than a day in which the generating unit burns no fuel. However the CEM system must be successfully calibrated prior to or during start-up to avoid using the backfilling option (Section 3.5.2).

6.2.1.2 Test Gases Protocol gases or gases certified to an accuracy of 2.0% must be used for the daily calibration of gas analyzers.

6.2.1.3 Calibration Gas Injection Port The location of the applicable calibration gas injection port for each type of CEM system are shown in Table 2 of Section 3.1.1 Calibration checks must be carried out under the same system operating conditions as those used during monitoring (e.g., pressure, flow, temperature, etc.). For path-type analyzers that do not accept flowing gases, a sealed cell containing a known concentration of gas can be used for calibration checks.

6.2.1.4 Test Procedures Two concentration/flow calibration levels must be used: low level (0-20% FS) and high level (80-100% FS).

A calibration adjustment for the low-level gas must not be made before checking both the low- and high-level gases. If a multi-range instrument is used with a system that automatically selects the range, the drift of each range must be checked daily.

The gas analyzer must attain a steady output before use, as indicated by the data acquisition system.

Calibration drift must be tested according to the procedures set out in Section 5.3.2.

Further details on the use of stack gas moisture monitoring systems are presented in Section 7.

Table 5 Daily, Quarterly, Semi-annual, and Annual Performance Evaluations Summary

Parameter	Component		Level	Specification	References: Specifi-cations	References: Test Procedures
Daily performance evaluations						
24-hour calibration drift	CO_2 (or O_2) analyzer		Low level (0-20% FS) High level (80-100% FS) Out-of-control condition	≤ 0.5% CO_2 (or O_2) ≤ 0.5% CO_2 (or O_2) Exceedance of twice the above levels	6.2.1	5.3.2/6.2.1
	Stack gas moisture monitor * - wet O_2 /Temp./ RH System		Low level (0-20% FS) High level (80-100% FS) Out-of-control condition	≤ 0.5% O_2 ≤ 0.5% O_2 Exceedance of twice the above levels		
	Flow monitor	with system calibration capability	Low level (0-20% FS) High level (80-100% FS) Out-of-control condition	≤ the greater of 3.0% FS or 0.6 m/s absolute difference 3.0% FS or 0.6 m/s absolute difference Exceedance of twice the above levels		
		without system calibration capability	Electronic reference level Out-of-control condition	≤3.0% FS Exceedance of twice the above levels	6.2.2	
Quarterly performance evaluations						
Cylinder gas test	CO_2 (or O_2) analyzer (Note: alternative provisions for certain types of in situ analyzers in Section 6.3.1.7)		Low level (0-20% FS) Mid level (40-60% FS) High level (80-100% FS) Out-of-control condition	≤ 1.0% CO_2 (or O_2) ≤ 1.0% CO_2 (or O_2) ≤ 1.0% CO_2 (or O_2) Exceedance of the above levels	6.3.1	6.3.1
	Stack gas moisture monitor * - wet O_2 /temp./ RH system		Low level (0-20% FS) Mid level (40-60% FS High level (80-100% FS) Out-of-control condition	≤1.0% O_2 ≤1.0% O_2 ≤1.0% O_2 Exceedance of the above levels		
Stack gas flow test	Alternatives: -Flow-to-output evaluation		Representative load level	≤10% absolute difference, output ≥ 60 MJ/s ≤15% absolute difference, output < 60 MJ/s	6.3.2	6.3.2
	-Heat-to-output evaluation		Representative load level	≤10% absolute difference, output ≥ 171 MJ/s ≤15% absolute difference, output < 171 MJ/s		
	-Abbreviated flow-to-output test		Representative load level	≤10% absolute difference, output ≥ 60 MJ/s ≤15% absolute difference, output < 60 MJ/s		
	-Abbreviated heat-to-output test		Representative load level	≤10% absolute difference, output ≥ 171 MJ/s		

Parameter	Component	Level	Specification	References	
				Specifi-cations	Test Procedures
	-Flow RM test	 Representative load level Out-of-control condition	≤15% absolute difference, output < 171 MJ/s ≤ the greater of 6.0% FS or 1.2 m/s Exceedance of the above levels		
Semi-annual performance evaluations					
Relative accuracy (RA)	CO_2 (or O_2) analyzer	Representative load level Out-of-control condition	≤ the greater of 10.0% RA or 0.5% CO_2 (or O_2) avg. absolute difference Exceedance of the above levels	6.4.1	5.3.4/6.4.1
	Stack gas moisture monitor*	Representative load level Out-of-control condition	≤ the greater of 10.0% RA or 2.0% of (100-B_{ws}) avg. absolute difference Exceedance of the above levels		
	Flow monitor	Representative load level Out-of-control condition	≤ the greater of 10.0% RA or 0.6 m/s avg. absolute difference Exceedance of the above levels		
	CO_2 mass emission	Representative load level Out-of-control condition	≤ 10.0% RA Exceedance of the above levels		
Bias	CO_2 (or O_2) analyzer	Representative load level Out-of-control condition	≤ the greater of 5.0% of FS value or 0.5% CO_2 (or O_2) avg. absolute difference Exceedance of the above levels	6.4.1	5.3.5/6.4.1
	Stack gas moisture monitor*	Representative load level Out-of-control condition	≤5.0% of FS (100-%B_{ws}) value Exceedance of the above levels		
	Flow monitor	Representative load level Out-of-control condition	≤ the greater of 5.0% of FS value or 0.6 m/s avg. absolute difference Exceedance of the above levels		
Annual performance evaluations					
Relative accuracy (RA)	CO_2 (or O_2) analyzer	Representative load level Out-of-control condition	≤ the greater of 10.0% RA or 0.5% CO_2 (or O_2) avg. absolute difference Exceedance of the above levels	6.4.1	5.3.4/6.4.1
	Stack gas moisture monitor*	Representative load level Out-of-control condition	≤ the greater of 10.0% RA or 2.0% of (100-B_{ws}) avg. absolute difference Exceedance of the above levels		

Parameter	Component	Level	Specification	References	
				Specifications	Test Procedures
	Flow monitor	Representative load level Out-of-control condition	≤ the greater of 10.0% RA or 0.6 m/s avg. absolute difference Exceedance of the above levels		
	CO_2 mass emission	Representative load level Out-of-control condition	≤ 10.0% RA Exceedance of the above levels		
Bias	CO_2 (or O_2) analyzer	-Representative load level Out-of-control condition	≤ the greater of 5.0% of FS value or 0.5% CO_2 (or O_2) avg absolute difference Exceedance of the above levels	6.4.1	5.3.5/6.4.1
	Stack gas moisture monitor*	Representative load level Out-of-control condition	≤5.0% of FS (100 - B_{ws}) value Exceedance of the above levels		
	Flow monitor	Representative load level Out-of-control condition	≤ the greater of 5.0% of FS value or 0.6 m/s avg absolute difference Exceedance of the above levels		
Availability	Non-peaking units Peaking units	-	≤90% annually in first year ≤95% annually thereafter ≤80% annually	6.5.1	6.5.1
Independent Auditing	-	-	Evaluation by an independent auditor	6.5.2	

***** The performance specifications for stack gas moisture based on wet O_2 measurements (calibration drift, response time, relative accuracy, and availability) are summarized in tables 3 and 5. Other moisture monitoring systems may be used to correct dry measured concentrations, if it is demonstrated that the system is able to calculate the hourly factor (100 – B_{ws}) with an error ≤ 2.0% all year round. The specific QA activities related to the moisture monitoring system must then be described in the QA/QC manual. Further details on the use of stack gas moisture monitoring systems are presented in Section 7. Note that B_{ws} is the moisture content of the stack gas (in % of volume)

6.2.1.5 Adjustment of Analyzers/Monitors Gas analyzers and flow monitors must be adjusted whenever the daily low- or high-level calibration drift exceeds the following specifications:

Gas analyzer

Low level: 0.5% CO_2 (or O_2)
High level: 0.5% CO_2 (or O_2)

Flow monitor

Low level: 3.0% of the FS setting or 0.6 m/s absolute difference, whichever is greater
High level: 3.0% of the FS setting or 0.6 m/s absolute difference, whichever is greater

Stack gas moisture monitor (wet O_2 system)

Low level: 0.5% O_2 (24 hours)
High level: 0.5% O_2 (24 hours)

6.2.1.6 Out-of-Control Period An out-of-control period occurs when either the low- or high-level calibration drift of a gas analyzer, flow monitor or stack gas moisture monitor exceeds twice the applicable drift specification, as indicated in Section 6.2.1.5. This period begins the minute of the calibration drift check and ends the minute after corrective action has been taken and the system has demonstrated that it is operating satisfactorily. When a gas analyzer, flow monitor, or stack gas moisture monitor is out-of-control, the data generated by the specific component are considered missing and do not qualify for meeting the requirement for system availability. Missing data must be backfilled using the criteria provided in Section 3.5.2.

6.2.1.7 Tabulation of Data All calibration drift data must be recorded and tabulated by day, month, and hour, with the magnitude of the drifts in percent for gas analyzers, and flow-related levels for flow monitors. These data must be summarized on a quality control chart.

6.2.1.8 Quantification of Drifts When the data acquisition subsystem automatically compensates data for drifts, the system must be capable of also storing unadjusted concentrations of the calibration gases, unadjusted flow levels, and the magnitude of all adjustments. If strip chart recorder data are reported, any automatic calibration adjustment must be noted on the strip chart record.

For a CEM system that physically resets the analyzer automatically, the data acquisition system must store the unadjusted concentrations in addition to the magnitude of the adjustment.

6.2.2 Electronic Drift

The electronic drift of flow monitors that do not perform daily system calibration checks must not deviate from the reference electric input value by more than 3.0% FS equivalent.

6.3 Quarterly Performance Evaluations

During each quarter, a cylinder gas test and one of the options for a stack gas flow test must be performed on the CEM system. Special provisions apply to peaking units and to path-type analyzers that do not have the capability of accepting a flowing calibration gas. Summarized hereunder are the requirements for these tests, all of which must appear in the CEM system’s QA/QC manual.

6.3.1 Cylinder Gas Test

This test, which investigates the average linearity error of the analyzers, is to be performed on all gas analyzer ranges used during the previous quarter.

Where the type of analyzer used does not allow for the use of a test gas (e.g., certain in situ path-type analyzers), an independent check of the performance of the CEM system must be carried out. A check of the response for each gas being measured against a reference method or an approved portable analyzer will be satisfactory. The comparison must be carried out over a period of not less than 15 minutes for each test run. Three such comparisons will be deemed to be equivalent to the cylinder gas test.

6.3.1.1 Frequency A three-level cylinder gas test must be performed in each quarter of the calendar year, with tests being no closer than 30 days apart for two adjacent quarters, using the following test gases and procedures. In peaking units, this test must be performed annually, immediately before the relative accuracy test period (RATA).

6.3.1.2 Test Gases Protocol gases at low (0-20% FS), mid (40-60% FS) and high levels (80-100% FS) for each gas analyzer must be used.

6.3.1.3 Calibration Gas Injection Port The test gases must be introduced at the CEM system calibration gas port specified in Table 2 (Section 3.1.1).

6.3.1.4 Test Procedures During the test, all pressures, temperatures, and flows must be within the operating parameters of the CEM system. Each test gas must be introduced and the system response allowed to stabilize, then the concentration of the gas indicated by the data acquisition system output must be recorded. The three ranges for each gas must not be introduced in succession or in the same sequence, but must be alternated with other reference gases.

Further details on the use of stack gas moisture monitoring systems are presented in Section 7.

6.3.1.5 Calculations The average linearity error for the responses to each of the low-, mid-, and high-level test gases must be calculated using Equation 17.

$$L_j = \frac{100}{3 \times FS} \sum_{i=1}^{3} \left| d_{ji} \right|$$ **Equation 17**

where:

L_j	=	linearity error of the low-, mid-, or high-level calibration in %
FS	=	full-scale value of the tested CEM range in %
d_{ji}	=	difference between the low-, mid-, or high-level reference gas and the corresponding CEM system measurement for the i^{th} test run in ppm or %
j	=	low-, mid-, or high-level reference gas
i	=	1 of 3 injections of each low-, mid-, or high-level reference gas

6.3.1.6 Acceptance Criteria The average linearity error must not exceed:

Gas analyzer

Low level: 1.0% CO_2 (or O_2)
Mid level: 1.0% % CO_2 (or O_2)
High level: 1.0% % CO_2 (or O_2)

Stack gas moisture monitor (wet O_2 system)

Low level: 1.0% O_2
Mid level: 1.0% O_2
High level: 1.0% O_2

6.3.1.7 Alternative quarterly test Where the type of CEM does not allow a test gas to be used (e.g., certain in-situ path-type analyzers), an alternative validation test on the CEM system performance must be carried out by the operator every quarter, when the generation unit is operational. The procedures of this alternative quarterly test are described below.

A portable analyzer that meets the specifications of Environment Canada's Reference Method EPS 1/RM15 must be used to compare the response for each gas being monitored.

The portable analyzer must be calibrated in the field, as per the manufacturer's recommended procedure, with low-level and high-level U.S. EPA protocol (as described in table 5) grade gases. The analyzer must then be fed a stack gas sample extracted from a point within 0.3 m from the CEM sensing point or path. After a stabilization period, the measurements from the portable analyzer must be logged every 30 seconds, for a minimum period of five minutes. Then the analyzer must be fed low-level calibration gas or filtered ambient air until stable readings are obtained.

The low-level drift must be recorded. The stack gas extraction and logging must be repeated for a second sampling period of the same duration, and so on, for a minimum total of six test periods. Finally the analyzer must be fed high-level calibration gas until stable readings are obtained. The high-level drift must be recorded. The relative accuracy of the concurrent CEM measurements must be calculated using equations 4 to 7 (Section 5.3.4.6).

The relative accuracy for a CO_2 or (O_2) gas analyzer must not exceed 15% or 0.5% absolute difference (|d|), whichever is greater.

6.3.1.8 Out-of-Control Period An out-of-control period occurs when a cylinder gas test exceeds the specification as presented in Section 6.3.1.6 or Section 6.3.1.7, as applicable. This period begins the minute after the completion of the test and ends the minute after corrective action has been taken and when the system has demonstrated that it meets the specification as presented in Section 6.3.1.6 or Section 6.3.1.7. When an analyzer or system is out-of-control, the data generated by the specific analyzer or system are considered missing and do not qualify as meeting the requirement for system availability. Missing data must be backfilled using the criteria provided in Section 3.5.2.

6.3.2 Stack Gas Flow Test

The stack gas flow monitor must be tested quarterly by the operator, using one of the four following options:

Option A evaluation of flow-to-output quarterly data
Option B evaluation of heat-to-output quarterly data
Option C performance of abbreviated flow-to-output or heat-to-output tests; or
Option D performance of flow RM tests

One of options A to D must be selected, taking into consideration the operating conditions of the generating unit during the quarter, including type and variety of fuel(s) combusted, the output types (steam versus electricity), the operating mode (base load versus peaking), and the estimated measurement accuracy of flow-related parameters.

Options A and B are only applicable if the quarter includes a minimum of 168 hours of valid CEM data at electric output levels within 10% of the average output of the last RATA. Where these conditions cannot be met, options C or D must be used.

Procedures for options A to D are outlined in sections 6.3.2.4 to 6.3.2.7 respectively.

6.3.2.1 Frequency A stack gas flow test must be performed in each quarter of the calendar year, with tests being no closer than 30 days apart for two adjacent quarters. In peaking units and bypass stacks this test may be performed only once per year.

6.3.2.2 Acceptance Criteria Acceptance criteria for options A to D are presented at the end of each of sections 6.3.2.4 to 6.3.2.7.

6.3.2.3 Out-of-Control Period An out-of-control period occurs when a stack gas flow test exceeds the specifications presented in sections 6.3.2.4 to 6.3.2.7, as applicable. This period begins the minute after the completion of the test and ends the minute after corrective action has been taken and the system has demonstrated that it meets the applicable specifications presented in sections 6.3.2.4 to 6.3.2.7. When a flow monitor is out-of-control, the data generated by the flow monitor are considered missing and do not qualify for meeting the requirement for system availability. Missing data must be backfilled using the criteria provided in Section 3.5.2.

6.3.2.4 Analysis of Flow-to-Output The average flow-to-output ratio is calculated using Equation 18.

$$R_h = \frac{1}{n}\sum_{h=1}^{n}\frac{Q_{wh}}{MW_h}$$ **Equation 18**

where:

R_h	=	average value of flow-to-electric-output ratio, from the quarterly hours in which the electric output was within 10% of the average electric output during the last RATA in WSm^3/h/MW
Q_{wh}	=	flow from the quarterly hours in which the electric output was within 10% of the average electric output during the last RATA in WSm^3/h
MW_h	=	electric output from the quarterly hours in which the electric output was within 10% of the average electric output during the last RATA in MW
n	=	number of quarterly hours in which the electric output was within 10% of the average electric output during the last RATA, $n \geq 168$

Periods of diverse fuel blends, output ramping, scrubber bypass, or other non-representative hourly data must be excluded from the calculation of average R_h. In peaking units, the potential data base must include all the preceding 12 months of unit operation.

$E_{Q\ to\ MW}$, the absolute percent difference between R_h and R_{ref} (the latter based on previous RATA data and calculated with Equation 8), is calculated using Equation 19.

$$E_{Q\ to\ MW} = \frac{\left|R_{ref} - R_h\right|}{R_{ref}} \times 100$$ **Equation 19**

Acceptable flow-to-output results are as follows:

$E_{Q\ to\ MW}$ ≤ 10% for output levels ≥ 60 MJ/s
$E_{Q\ to\ MW}$ ≤ 15%, for output levels < 60 MJ/s

6.3.2.5 Analysis of Heat Input to Electric Output Data The hourly heat inputs must be calculated with one of equations 9 to 12 (as applicable) and the average heat-input-to-electric-output ratio (or gross heat rate in GHR_h) must be calculated using Equation 20.

$$GHR_h = \frac{1}{n}\sum_{h=1}^{n}\frac{HI_h}{MW_h}$$ **Equation 20**

where:

GHR_h	=	average value of gross heat rate from the quarterly hours in which the electric output was within 10% of the average electric output of the last RATA in GJ/MWh
HI_h	=	gross heat input from the quarterly hours in which the electric output was within 10% of the average electric output during the last RATA in GJ/h
MW_h	=	gross electric output from the quarterly hours in which the electric output was within 10% of the average electric output during the last RATA in MW
n	=	number of quarterly hours in which the electric output was within 10% of the average electric output during the last RATA, $n \geq 168$

Periods of diverse fuel blends, output ramping, scrubber bypass or other non-representative hourly data may be excluded from the calculation of average GHR_h. In peaking units, the potential data base must include all the preceding 12 months of unit operation.

$E_{GHR\ to\ MW}$, the absolute percentage difference between GHR_h and GHR_{ref} (the latter based on RATA data and calculated with Equation 13), is calculated using Equation 21.

$$E_{GHR\ to\ MW} = \frac{\left| GHR_{ref} - GHR_h \right|}{GHR_{ref}} \times 100$$ **Equation 21**

Acceptable heat-to-output results are as follows:

$E_{GHR\ to\ MW}$ ≤ 10%, for input levels ≥171 MJ/s
$E_{GHR\ to\ MW}$ ≤ 15%, for input levels <171 MJ/s

6.3.2.6 Performance of Abbreviated Flow-to-Output or Heat-to-Output Tests An abbreviated flow-to-output test consists of a period of 6 to12 consecutive hours during which the process conditions reproduce as closely as practicable the conditions of the most recent flow RATA. The output must be held constant to within 10% of the average output during the last flow RATA and the CO_2 or O_2 to within 0.5% of the corresponding level.

For a flow-to-output test, for this period, R_h is calculated using Equation 18 and $E_{Q\ to\ MW}$ using Equation 19. Acceptable $E_{Q\ to\ MW}$ levels are the same as in Section 6.3.2.4.

For a heat-to-output test, for this period, GHR_h is calculated using Equation 20 and $E_{GHR\ to\ MW}$ using Equation 21. Acceptable $E_{GHR\ to\ MW}$ levels are the same as in Section 6.3.2.5.

6.3.2.7 Performance of Flow Reference Method Measurements This test must be carried out using Method B from *Reference Methods for Source Testing: Measurement of Releases of Particulate from Stationary Sources* (Environment Canada, December 1993, as amended). Wall effects and complex velocity patterns must be determined with U.S. EPA Methods 2H, CTM-041 and 2F/2G. The audit comprises three consecutive reference method (RM) measurements. CO_2, O_2, and moisture values from a certified CEM system may be used for calculating molecular weights during this testing.

E_f is calculated using Equation 22.

$$E_f = \frac{1}{3 \times RM} \sum_{i=1}^{3} |d_i|$$ **Equation 22**

where:

E_f	=	average of the absolute difference between the RM value and the corresponding CEM system flow measurement
d_i	=	difference between an RM value and the corresponding CEM system measurement for the i^{th} test run in m/s or m^3/s
RM	=	average gas velocity or flow rate, as measured by the reference method in m/s or m^3/s

Acceptable results are as follows: $E_f \leq 6\%$ of FS, or average $|d_i| \leq 1.2$ m/s.

6.4 Semi-annual Performance Evaluations

Two test procedures are involved in the semi-annual performance evaluation: a relative accuracy test and a bias test. They are carried out for each gas measured, as well as for stack gas flow and stack gas moisture (if the CEM system is fitted with stack gas flow and moisture monitors).

6.4.1 Relative Accuracy and Bias Tests

6.4.1.1 Frequency and Timing of Evaluations A performance evaluation must be carried out twice a year, no less than four (4) months apart.

6.4.1.2 Test Gases The gases used by both the CEM system and the reference method during the RA test must be U.S. EPA protocol grade.

6.4.1.3 Test Procedures Relative accuracy and bias must be tested according to procedures and calculations in Section 5.3.4 and Section 5.3.5. Only one capacity level needs to be tested.

Further details on the use of stack gas moisture monitoring systems are presented in Section 7.

6.4.1.4 Acceptance Criteria The following performance specifications must be met, providing that the CEM system includes the monitored parameter.

Relative accuracy

The relative accuracy for a CO_2 (or O_2) monitor must not exceed 10% or 0.5% CO_2 (or O_2) average absolute difference (|d|), whichever is greater.

The relative accuracy for a stack gas flow monitor must not exceed 10% or 0.6 m/s average absolute difference (|d|), whichever is greater.

The relative accuracy for the stack gas moisture monitor must not exceed 10% or 2% of $(100-B_{ws})$, whichever is greater.

The relative accuracy for CO_2 mass emissions must not exceed 10%.

Meeting the relative accuracy for CO_2 (or O_2), moisture and stack gas flow does not guarantee meeting the relative accuracy for CO_2 mass emissions.

Bias

The bias for a CO_2 (or O_2) monitor must not exceed 5.0% of the FS value or 0.5% CO_2 (or O_2) average absolute difference when no bias adjustment factor (BAF) is used, whichever is greater.

The bias for a stack gas flow monitor must not exceed 5.0% of the FS value or 0.6 m/s average absolute difference when no BAF is used, whichever is greater.

The bias for a stack gas moisture monitor must not exceed 5.0% of the FS value, or 2% of (100 - B_{ws}) average absolute difference when no BAF is used, whichever is greater.

If there is any bias, as defined in Section 5.3.5, either positive or negative, in any measurements made by the CEM system, then the data that are subsequently generated must be corrected for the bias before any subsequent use is made of the data.

6.4.1.5 Out-of-Control Period An out-of-control period occurs when the relative accuracy or bias tests exceed the specifications as presented in Section 6.4.1.4. This period begins with the minute after the completion of the test and ends with the minute after corrective action has been taken and the system has demonstrated that it meets the specifications presented in Section 6.4.1.4. When an analyzer, monitor, or system is out of control, the data generated by the specific analyzer, monitor, or system are considered missing and do not qualify as meeting the requirement for system availability. Missing data must be backfilled using the criteria provided in Section 3.5.2.

6.4.2 Exemptions from Semi-annual Evaluations

The semi-annual test may be waived and conducted annually after the first year of operation if all of the following criteria have been met:

- the system availability is greater than 95% annually
- the previous relative accuracy for the gas analyzers is less than either 7.5% or 0.5% CO_2 (or O_2) mean absolute difference
- the previous relative accuracy for the flow monitor is less than either 7.5% or 0.6 m/s mean absolute difference
- the previous relative accuracy for the stack gas moisture monitor is less than 7.5% or 2% of (100 - B_{ws}) mean absolute difference; and
- the previous relative accuracy of the CO_2 mass emission system is less than 7.5%

6.5 Annual Performance Evaluations

6.5.1 Availability

The percentage availability for the system, for each gas or moisture analyzer, and for the flow monitor is calculated annually using Equation 23.

$$AVA = \frac{T_a}{T} \times 100 \qquad \textbf{Equation 23}$$

where:

AVA = availability of the system, gas analyzer, or flow monitor in %

T_a = number of hours during which a) the generating unit burned fuel and b) the system, gas analyzer or flow monitor generated data that met the valid hourly requirements of Section 3.5.1

T = total number of hours during which the generating unit burned fuel during the year

The availability of the system, gas analyzers, and flow monitor must be at least 90% annually for the first full year of operation and 95% annually thereafter. The availability for peaking units must be at least 80% annually. Data that are backfilled using a procedure other than a certified alternative CEM system cannot be credited towards meeting the CEM system availability criteria.

When a CEM system is unable to meet the above annual availability criteria, then the cause of the out-of-control periods must be investigated and an action plan to prevent and/or repair recurrent failures must be prepared and recorded in the QA/QC manual.

A CEM system that fails to meet the annual availability criteria on two successive years must be repaired or replaced and in either case recertified.

6.5.2 Independent Auditing

The CEM system and the QA/QC program must be evaluated by an auditor every 12 months (+/-) 1 month.

The auditor must review the QA/QC manual, the CEM system operation, reports, and other associated records to determine if the procedures in the QA/QC manual are being followed. The auditor must also note any changes in the system or the procedures since the last yearly evaluation and ensure that they have been included in the QA/QC manual.

6.6 Recertification Requirements

When components of the CEM system are replaced or modified in a manner that affects the ability to fulfill the CEM objectives (e.g. replacement of the analyzer, change in the location or orientation of the sampling probe or the complete replacement of the CEM system), or when the electricity generating unit (EGU) is modified in a manner that affects the fulfillment of the CEM objectives, the certification of the affected components must be repeated according to the procedures of Section 5. The recertification must be completed within 30 days.

Section 7. Calculations

7.1 Introduction

The annual CO_2 mass emissions, in tonnes, using a CEM system must be calculated from hourly average CO_2 mass emission rates using Equation 24.

$$E_u = \frac{\sum_{h=1}^{H_R} ER_h t_h}{1000}$$ **Equation 24**

where:

E_u = quantity of CO_2 emissions from the unit, "u", during the calendar year from combustion of fuel, in tonnes

ER_h = hourly CO_2 mass emission rate during unit operation, in kg/hour

T_h = unit operating time, in hours or fraction of an hour

H_R = number of hourly CO_2 mass emission rates available during the calendar year.

Hourly average CO_2 mass emission rates, in kg/hour, must be determined according to one of the following options:

Option A: wet carbon dioxide-based measurement systems where both the stack gas flow rate and CO_2 concentration are measured on a wet basis (Section 7.2)
Option B: dry carbon dioxide-based measurement systems where the stack gas flow rate is measured on a wet basis and the CO_2 concentration is measured on a dry basis (Section 7.3)
Option C: wet oxygen-based measurement systems where both the stack gas flow rate and O_2 concentration are measured on a wet basis (Section 7.4)
Option D: dry oxygen-based measurement system where the stack gas flow rate is measured on a wet basis and the O_2 concentration is measured on a dry basis (Section 7.5)

7.2 Wet Carbone Dioxide-Based Measurement Systems – Option A

This option is applicable in all situations.

When both the CO_2 concentration and stack gas flow rate are measured on a wet basis, the hourly average CO_2 mass emission rate must be calculated using Equation 25.

$$ER_h = 1.8\, Q_w\, CO_{2,w}$$ **Equation 25**

where:

ER_h = hourly average mass emission rate of CO_2 during unit operation in kg/h

1.8 = CO_2 gas density in kg/Sm^3

Q_w = hourly average stack gas volumetric flow rate during unit operation in WSm^3/h on a wet basis

$CO_{2,w}$	=	hourly average stack gas concentration of CO_2 during unit operation, in % of volume and on a wet basis

7.3 Dry Carbon Dioxide-Based Measurement System – Option B

This option is applicable when either:

- using a wet O_2 analyzer for determining stack gas moisture and no water other than that generated during the combustion process is introduced into the gas flow; or
- the CEM system is installed after a pollution control device that reduces the flue gas temperature so that the exit gas is saturated or contains liquid water; or
- using an alternative stack gas moisture monitoring system that has been demonstrated to calculate the factor (100-Bws) with an error ≤ 2.0%, hourly all year round.

When the CO_2 concentration is measured on a dry basis whereas the stack gas flow rate is measured on a wet basis, the hourly CO_2 mass emission rate must be calculated using Equation 26.

$$ER_h = 1.8\, Q_w\, CO_{2,d}\, \frac{(100 - B_{ws})}{100}$$ **Equation 26**

where:

ER_h	=	hourly average mass emission rate of CO_2 during unit operation in kg/h
1.8	=	CO_2 gas density in kg/Sm^3
Q_w	=	hourly average stack gas volumetric flow rate during unit operation in WSm^3/h, on wet basis
$CO_{2,d}$	=	hourly average stack gas concentration of CO_2 during unit operation, in % of volume and on a dry basis
B_{ws}	=	hourly average stack gas moisture content determined in accordance with Section 7.6 during unit operation, in % of volume

7.4 Wet Oxygen-Based Measurement System – Option C

This option is only applicable when either:

- no water other than that generated during the combustion process is introduced into the gas flow; or
- the CEM system is installed after a pollution control device that reduces the flue gas temperature so that the exit gas is saturated or contains liquid water.

The stack gas CO_2 wet concentration can be derived from measuring the stack gas O_2 wet concentration using the following methods:

- the method described in section 7.4.1 when no water other than that generated during the combustion process is introduced into the gas flow; or
- the method described in section 7.4.2 when the CEM system is installed after a pollution control device that reduces the flue gas temperature so that the exit gas is saturated or contains liquid water.

If neither of theses conditions can be met, a carbon dioxide-based measurement system must be used.

7.4.1 No Water Injection

When measuring both the stack gas flow rate and O_2 concentration on a wet basis and no water other than that generated during the combustion process is introduced into the gas flow, then the hourly average stack gas CO_2 wet concentration must be calculated using Equation 27.

$$CO_{2,w} = \frac{F_c}{F_w}\left[\frac{(100 - B_{wa})}{100} - \frac{O_{2,w}}{20.9}\right] \qquad \textbf{Equation 27}$$

where:

$CO_{2,w}$	=	hourly average stack gas concentration of CO_2 during unit operation, in % and on wet basis
F_c	=	ratio of the volume of CO_2 resulting from the combustion of fuel with air, to the amount of heat produced in DSm^3/GJ
F_w	=	ratio of the volume of wet gas resulting from stoichiometric combustion of the fired fuel with air to the amount of heat produced in Sm^3/GJ
B_{wa}	=	hourly ambient air moisture content determined in accordance with Section 7.7 during unit operation, in % of volume
$O_{2,w}$	=	hourly average stack gas concentration of O_2 during unit operation, in % of volume and on a wet basis

The CO_2 wet concentration calculated by Equation 27 is then introduced in Equation 25 to determine the mass emissions of CO_2. For any hour where Equation 27 results in a negative hourly average $CO_{2,w}$ value, a value 0.0% shall be recorded.

7.4.2 Saturated Exit Gas

When measuring both the stack gas flow rate and O_2 concentration on a wet basis and the CEM system is installed after a pollution control device that reduces the flue gas temperature so that the exit gas is saturated or contains liquid water then the hourly average CO_2 wet concentration must be calculated using Equation 28.

$$CO_{2,w} = \frac{100\ F_c}{20.9\ F_d}\left[\frac{20.9\,(100 - B_{ws})}{100} - O_{2,w}\right] \qquad \textbf{Equation 28}$$

where:

$CO_{2,w}$	=	hourly average stack gas concentration of CO_2 during unit operation, in % and on a wet basis
F_c	=	ratio of the volume of CO_2 resulting from the combustion of fuel with air, to the amount of heat produced in DSm^3/GJ
F_d	=	ratio of the volume of dry gas resulting from stoichiometric combustion of fuel with air to the amount of heat produced in WSm^3/GJ
B_{ws}	=	hourly average stack gas moisture content determined in accordance with Section 7.6.2 during unit operation, in % of volume
$O_{2,w}$	=	hourly average stack gas concentration of O_2 during unit operation, in % of volume and

on a wet basis

The hourly average CO_2 wet concentration calculated by Equation 28 is then introduced in Equation 25 to determine the mass emission of CO_2. For any hour where Equation 28 results in a negative hourly average $CO_{2,w}$ value, a value 0.0% shall be recorded.

7.5 Dry Oxygen-Based Measurement System – Option D

This option is only applicable when no water other than that generated during the combustion process is introduced into the gas flow.

When measuring the stack gas flow rate on a wet basis and the O_2 concentration on a dry basis and no water other than that generated during the combustion process is introduced into the gas flow, the hourly average stack gas O_2 wet concentration must be derived from the hourly average stack gas O_2 dry concentration using Equation 29.

$$O_{2,w} = \frac{O_{2,d}(100 - B_{ws})}{100}$$ ***Equation 29***

where:

$O_{2,w}$ = hourly average stack gas concentration of O_2 during unit operation, in % of volume and on a wet basis

$O_{2,d}$ = hourly average stack gas concentration of O_2 during unit operation, in % of volume and on a dry basis

B_{ws} = hourly average stack gas moisture content determined in accordance with Section 7.6 during unit operation, in % of volume

The hourly average stack gas O_2 wet concentration must then be inserted into Equation 27 to determine the hourly average stack gas CO_2 wet concentration which must then inserted into Equation 25 to determine the hourly average CO_2 mass emission rate.

7.6 Stack Gas Moisture Determination

When applying equations 26, 28 and 29, the hourly average stack gas moisture content must be determined using one of the methods described in sections 7.6.1 to 7.6.3.

Section 7.6.1 applies to stack gas moisture monitoring systems that use a wet O_2 monitor that meets the specifications set out in tables 3 and 5 of this document where no water other than that generated during the combustion process is introduced into the gas flow.

Section 7.6.2 applies where the CEM system is installed after a pollution control device that reduces the flue gas temperature so that the exit gas is saturated or contains liquid water.

Section 7.6.3 applies where an alternative moisture monitoring system is used.

7.6.1 Using a Wet O2 Monitor with no Water Injection

Where a wet O_2 monitor that meets the specifications set out in tables 3 and 5 of this document is used for determining the stack gas moisture content and no water other than that generated during the combustion process is introduced into the gas flow, then the stack gas moisture must be determined using Equation 30.

$$B_{ws} = 100 - \frac{F_d}{F_W}(100 - B_{wa})\frac{O_{2,w}}{20.9} - \left(100 - \frac{F_d}{F_W}\right)$$ **Equation 30**

where:

B_{ws}	=	hourly average stack gas moisture content during unit operation, in % of volume.
F_d	=	ratio of the volume of dry gas resulting from stoichiometric combustion of the fuel with air to the amount of heat produced in DSm^3/GJ
F_w	=	ratio of the volume of wet gas resulting from stoichiometric combustion of the fuel with air to the amount of heat produced in WSm^3/GJ
B_{wa}	=	hourly ambient air moisture content during unit operation, in % of volume
$O_{2,w}$	=	hourly average stack gas concentration of O_2 during unit operation, in % of volume and on a wet basis

7.6.2 Saturated Exit Gas

When the CEM system is installed after a pollution control device that reduces the flue gas temperature so that the exit gas is saturated or contains liquid water then the stack gas moisture content must be determined from the stack gas temperature by applying equations 31 and 32.

$$B_{ws} = \frac{p_{H_2O}}{P_{stack}}$$ **Equation 31**

where:

B_{ws}	=	hourly average stack gas moisture during unit operation in % of volume
p_{H_2O}	=	hourly partial water vapour pressure of the stack gases in mm Hg, as calculated with Equation 32
P_{stack}	=	hourly stack gas absolute pressure during unit operation in mm Hg

$$\log_{10} p_{H_2O} = A - \frac{B}{(C + T)}$$ **Equation 32**

where:

p_{H_2O}	=	hourly partial water vapour pressure of the stack gases in mm Hg
A	=	constant = 8.0886767
B	=	constant = 1739.351
C	=	constant = 234.1
T	=	hourly stack gas temperature during unit operation in °C

Note: the constants A to C apply to a 55 to 80°C temperature range.

7.6.3 Alternative Stack Gas Moisture Monitoring Systems

Alternative stack gas moisture monitoring systems may be used for determining the hourly average stack gas moisture content, if the system is able to calculate the factor (100 - B_{ws}) with an error ≤ 2.0%, hourly all year round.

7.7 Ambient Air Moisture Determination

When applying equations 27 and 29, the hourly ambient air moisture must be determined using equations 33 and 34:

$$B_{wa} = RH \frac{p_{H_2O}}{P_{atm}}$$ **Equation 33**

where:

B_{wa}	=	hourly ambient air moisture during unit operation in % of volume
RH	=	hourly relative humidity , in %, during unit operation, as measured with traceable thin film capacitance sensor, or equivalent
p_{H_2O}	=	hourly partial water vapour pressure at ambient air temperature in mm Hg, as calculated with Equation 34
P_{atm}	=	hourly atmospheric pressure during unit operation in mm Hg, calculated as 760 mm Hg minus 8.33 mm Hg per 100 m elevation above sea level

$$log_{10}\, p_{H_2O} = A - \frac{B}{(C + T)}$$ **Equation 34**

where:

p_{H_2O}	=	hourly partial water vapour pressure at ambient air temperature in mm Hg
A	=	constant = 8.184254
B	=	constant = 1791.3
C	=	constant = 238.1
T	=	hourly ambient air temperature in °C

Note: the constants A to C apply to a 0 to 30°C temperature range.

Section 8. Record Keeping Requirements

8.1 General Record Keeping

All records related to the design, installation, certification, operation and performance evaluation of the CEM system as well as to the determination of the CO_2 mass emissions and to the quality assurance/quality control manual must be kept for a period of no less than seven years from the year of respect of which the data has been collected in both paper and electronic format and made available upon request. This must include the records described in sections 8.1.1 to 8.1.7.

8.1.1 Quality Assurance/Quality Control Manual Record Provisions

The current quality assurance/quality control (QA/QC) manual for each installed CEM system and all previous and updated versions relevant to the seven year record keeping period must be kept.

8.1.2 Design, Installation and Certification Record Provisions

The operator shall record and keep the following design, installation and certification information for each installed CEM system:

a) Design record provisions
   i. Analyzer interference test results, if applicable;
   ii. Analyzer temperature-response zero and span drift test results, if applicable;
   iii. Manufacturer's certificate of conformance for analyzer interference and temperature-response drifts, if applicable
b) Installation record provisions
   i. Flow pattern and stratification test procedure results
c) Certification record provisions
   i. CO_2 emissions data during the operational test period
   ii. Results from performance specification tests:
   iii. Calibration drift test results, if applicable;
   iv. System response time test results;
   v. Relative accuracy test results;
   vi. Bias test results;
   vii. Calibration gas test results
   viii. Certificate attesting that the operator has met the certification requirements

8.1.3 Daily, Quarterly, Semi-annual and Annual Performance Evaluations Recordkeeping Provisions

The operator shall record and keep the following information on daily, quarterly, semi-annual and annual performance evaluations for each installed CEM system:

a) Daily performance evaluation record provisions
   i. Date and results of 24-hour calibration drift tests.
b) Quarterly performance evaluation record provisions
   i. Date and results of cylinder gas tests;
   ii. Date and results of stack gas flow tests;
c) Semi-annual performance evaluation record provisions
   i. Date and results of relative accuracy tests;
   ii. Date and results of bias tests.
d) Annual performance evaluation record provisions

i. Date and results of relative accuracy tests ;
ii. Date and results of bias tests;
iii. Date and results of independent audit; and
iv. Availability.

8.1.4 Operating Parameter Record Provisions

The operator shall record and keep for each hour the following information on unit operating time, heat input rates, and loads for each EGU and also for each group of EGUs utilizing a common stack and a common monitoring system:

a) Unit operating time;
b) Hourly gross unit load (electrical and/or thermal);
c) Hourly heat input rate.

8.1.5 CO_2 Emissions Record Provisions

The operator shall record and keep for each hour of unit operation the following information for CO_2 mass emissions, as measured and reported by the certified primary monitor, certified back-up monitor or other backfilling procedure method of determining emissions :

a) Date and hour;
b) Hourly average wet and/or dry CO_2 concentration;
c) Hourly average wet and/or dry O_2 concentration, if an oxygen analyzer is used to determine CO_2 mass emissions);
d) Hourly average stack gas moisture content, if applicable;
e) Hourly wet- oxygen readings, if applicable;
f) Hourly partial water vapour pressure of the stack gases, if applicable;
g) Hourly stack gas absolute pressure, if applicable;
h) Hourly stack gas temperature, if applicable;
i) Hourly ambient air moisture, if applicable;
j) Hourly relative humidity, if applicable;
k) Hourly atmospheric pressure, if applicable;
l) Hourly partial water vapour pressure at ambient air temperature, if applicable;
m) Hourly ambient air temperature, if applicable;
n) Hourly average volumetric flow rate;

In addition to the above hourly records, the operator shall keep the following information:

a) F-factors used for determining CO_2 mass emissions;
b) Method of determining hourly average CO_2 mass emission rate.

8.1.6 Missing Data Records

For missing data periods, the operator shall record and keep:

a) the reason for which data was not obtained;
b) the element for which, and the given period during which, data was not obtained, including the hour or day as the case may be, on which that given period begins and ends;
c) the value determined for that element using replacement data, along with details of that determination, including
    i. the data used to make that determination for each period;
    ii. the method used to obtain that data; and
    iii. a justification of the period or periods used as the basis of that determination.

8.1.7 F-factor Data Records

If customized F-factors are used, all data relating to the determination of the customized F-factors must be kept.

8.1.8 Alternative Moisture Monitoring System Records

If an alternate moisture monitoring system is used, the following information must be kept:

a) A description of the alternative moisture monitoring system
b) Method and data used to demonstrate that the system is able to calculate the factor (100 - Bws) with an error ≤ 2.0%, hourly all year round.

Appendix A. F-factors

A.1 Introduction

Fuel F-factors are used to characterize the products of complete atmospheric combustion for a given amount of heat released. These factors are quite consistent, despite the variability of fuel density, ash and moisture.

The F_c-factor is the ratio of the carbon dioxide volume generated by the combustion of a given fuel to the amount of heat produced. The F_d factor is the ratio of the stoichiometric volume of dry gas generated for complete combustion of a given fuel with air to the amount of heat produced. The F_w factor is the ratio of the stoichiometric volume of wet gas generated for complete combustion of the fuel with dry air, to the amount of heat produced.

In the context of CO_2 CEM systems, F factors are used to a) to determine CO_2 emissions by monitoring O_2 levels and stack gas flow rates, and b) to determine indirectly moisture levels in systems where stack gas CO_2 levels are measured on a dry basis.

Note that the reference conditions for the F-factors are 25°C and 101.325 kPa. Where the results are compared with data generated at other reference conditions, the data must be compensated.

The F-factors for specific fuels provided in Table A-1 shall be used. For fuels not listed in Table A-1, F-factors shall be calculated according to Section A.3.

Table A- 1 F-Factors for Selected Canadian Fuels

Fuel	Type	Oxygen-based F-factor		Carbon dioxide-based F-factor (F_c) (Sm^3/GJ)*
		Fd, dry basis (DSm^3/GJ)*	Fw, wet basis (WSm^3/GJ)*	
Coal	Anthracite Bituminous Sub-bituminous Lignite	277 267 263 273	288 286 301 310	54.2 49.2 49.2 53.0
Oil	Crude, residual, or distillate	255	289	39.3
Gas	Natural Propane	240 238	295 281	28.4 32.5

* Sm^3 denotes one standard cubic metre (i.e., 1 m^3 at 101.325 kPa and 25°C);
GJ = 1 000 000 000 Joules.

A.2 Combined Combustion of Fuels

For sources simultaneously burning a combination of fossil fuels, a combined F-factor shall be calculated using Equation A-1.

$$F_m = \sum_{i=1}^{n} \left(X_i F_i \right) \qquad \textbf{Equation A-1}$$

where:

F_m	=	combined F-factor
X_i	=	fraction of the total heat input from fuel i
F_i	=	appropriate F-factor for fuel i
n	=	number of fuels burned

A.3 Calculation of Customized F-Factors

For fuels not listed in Table A-1, F-factors shall be calculated using the ultimate analysis and gross calorific value (GCV) of the fuel. Equations A-2 to A-4 shall be used to calculate the various F-factors.

$$F_d = 10^4\ [(K_{hd}\ \%H) + (K_c\ \%C) + (K_s\ \%S) + (K_n\ \%N) + (K_o\ \%O)] \,/\, GCV_d$$ **Equation A-2**

$$F_w = 10^4\ [(K_{hw}\ \%H) + (K_c\ \%C) + (K_s\ \%S) + (K_n\ \%N) + (K_o\ \%O) + (K_w\ \%H_2O)] \,/\, GCV_w$$ **Equation A-3**

Note: The $\%H_2O$ term must be omitted in the equation for F_w if %H and %O include unavailable hydrogen and oxygen in the form of H_2O.

$$F_c = 10^4\ (K_{cc}\ \%C) \,/\, GCV_d$$ **Equation A-4**

where:

F_d, F_w, F_c	=	volumes of combustion components per unit of heat content in m^3/GJ, at 25°C and 101.325 kPa
%H, %C, %S, %N, %O, $\%H_2O$	=	concentrations of hydrogen, carbon, sulphur, nitrogen, oxygen, and water, respectively, from the ultimate analysis of fuel, weight percent
GCV_d	=	gross calorific value of dry fuel in kJ/kg
GCV_w	=	gross calorific value of wet fuel in kJ/kg
10^4	=	conversion factor in kJ/GJ/100
K_{hd}	=	22.97 Sm^3/kg, volume of dry exhaust gases resulting from the stoichiometric combustion of hydrogen in the fuel
K_c	=	9.75 Sm^3/kg, volume of dry exhaust gases resulting from the stoichiometric combustion of carbon in the fuel
K_s	=	3.65 Sm^3/kg, volume of dry exhaust gases resulting from the stoichiometric combustion of sulphur in the fuel
K_n	=	0.87 Sm^3/kg, volume of dry exhaust gases resulting from nitrogen in the fuel
K_o	=	-2.89 Sm^3/kg, volume of dry combustion gases avoided due to oxygen in the fuel

K_{hw}	=	35.10 Sm^3/kg, volume of wet exhaust gases resulting from the stoichiometric combustion of hydrogen in the fuel
K_w	=	1.36 Sm^3/kg, volume of water vapour resulting from the water contained in the fuel
K_{cc}	=	2.04 Sm^3/kg, volume of carbon dioxide produced during the complete combustion of the fuel

Appendix B. Quality Assurance/Quality Control Manual

A QA/QC manual must be developed for each installed CEM system. The QA/QC manual must describe a complete program of activities to be implemented to ensure that the data generated by the CEM system will be complete, accurate, and precise. The manual must include the QA/QC procedures specified in Table B-1.

Table B- 1 Table of Contents for the Quality Assurance/Quality Control Manual

Subsection	Contents
Quality assurance policies and system descriptions	
1 Quality Assurance Goals and Objectives	Specific system goals relating to precision, accuracy, and completeness. Emission standards and emission reporting requirements.
2 CEM System Description and Design Considerations	Detailed system description, including principles of operation, sample location layout, flow and temperature measurement, sample conditioning system, analyzer layout, CEM shelter, and data handling system. Design considerations and engineering evaluation of CEM system options, including sample location, extractive vs. in situ, flow monitoring, and supplier. Includes a detailed list of CEM system component serial and model numbers.
3 Exceptions/Clarifications/ Alternative Methods	Any exceptions/clarifications or alternative methods relating to this document or reference test methods.
4 Organization and Responsibilities	Description of the organization of personnel involved with the CEM system and its quality system. Defines the roles and responsibilities of the personnel involved as related to CEM system operation and maintenance, control of documents/records, and control of data.
5 Calibration and Quality Control Checks	Description of the calibrations and QC checks that are performed on a routine basis, generally daily, to determine whether the system is functioning properly. Includes daily zero and calibration checks and visual checks of system operating indicators, such as vacuum and pressure gauges, rotameters, analyzer displays, LEDs, and so on.
6 Data Acquisition and Analysis	Description of the data acquisition system and analysis program. Includes references to data completeness, validation, reporting, storage, and revision management. Includes roles and responsibilities of the personnel involved in the data handling.
7 Preventative Maintenance Policy	Description of the CEM system preventative maintenance program, including how preventative maintenance scheduling is determined and maintained along with roles and responsibilities of the personnel involved.
8 Corrective Action Program	Description of the policies for correcting any CEM system non-conformance. Parameters such as CEM system downtime/reliability should be addressed. Roles and responsibilities of the personnel involved in the corrective action program.
9 Performance Evaluations/Audits	Description of the policies and specifications for performance evaluations/audits (i.e., stack quarterly audits and RATAs). Describe the action necessary to ensure that the appropriate evaluations are carried out on the appropriate schedule.
10 Document Control System	Description of the policies and systems used to control all the documents that form part of the CEM system's quality system. Lists how and where the related documents are located, how they are reviewed and revised, and how they are approved for use by authorized personnel prior to issue.
11 Reports and Records	Description of all reports and records collected including method of collection, person responsible, data storage location, data security, data distribution, and length of data storage.
12 Modifications and Upgrades	Description of the policies regarding modifications and upgrades to the CEM system.
13 Training and Qualification Policy	Training and qualification policy for CEM system maintainers, CEM system coordinators, computer and programming technicians, data validators, quarterly audit and RATA testers. Includes educational and experience requirements, on-the-job training, job shadowing, and classroom training requirements.

Subsection	Contents
14 References	References for QA/QC plan.
Quality control (standard operating) procedures	
1 Startup and Operation	Lists in detail complete, step-by-step procedures for the startup and operation of the CEM system.
2 Daily CEM System Operation and Inspection	Detailed description of daily routine operation and inspection of the CEM system. Includes descriptions of equipment and data validation procedures and examples of daily equipment checks and/or logbook entries.
3 Daily and Manual Calibration Procedures	Lists in detail complete, step-by-step procedures for daily and manual calibrations. References to specific OEM documentation/manuals are acceptable. Includes schedule for manual (mid-point) calibration, if done.
4 Gas Bottle Check Procedures	Description of procedure to cross-reference cylinder gases. Gases can be cross-referenced to previous gas bottles and quarterly bottles. Specifications for rejection of gas bottle to be stated.
5 Preventative Maintenance Procedures	Detailed description of the CEM system preventative maintenance procedures along with the preventative maintenance schedule.
6 Spare Parts List and Inventory Procedures	Detailed descriptions of the spare parts inventory available for the CEM system, along with a description of the procedures for obtaining spare parts from inventory and ensuring that the spare parts inventory is maintained.
7 Corrective Maintenance Procedures	Detailed descriptions of the non-routine maintenance that is performed when the system or part of the system fails. References to specific OEM documentation/manuals are acceptable.
8 Data Backfilling Procedures	Procedures for data backfilling when a CEM system is not available. Data backfilling algorithms to be based on process variables.
9 Data Backup Procedures	Procedures for regular backup of data in hard or soft copy.
10 Data Quality Assessment Procedures	Procedures to identify suspected data. Includes automatic flagging of a) out-of-range concentrations and flows, b) abnormal system calibration response times, c) abnormal flow-to-input or flow-to-output levels, and d) abnormal concentrations during periods when the generating unit burned no fuel.
11 CEM System Security	Includes security actions for CEM equipment software and data.
12 Data Approval and Reporting Procedures	Procedure for approval and reporting of CEM data. Includes any systems for review, modifications, approval, summary, and release of data.
13 Quarterly Audit Procedures	Detailed procedures on conducting quarterly audit procedures. Includes roles and responsibilities, gas bottle requirements, scheduling, and test methods.
14 Semiannual Relative Accuracy Test Audit Procedures	Detailed pretest sampling plan for executing RATAs. Pretest plan to include organization plan, sampling points, scheduling, test methods, calibration requirements, reporting schedule, reporting format, and site safety plan.
15 Bias Procedures	Describes process of assessing and correcting for bias. Includes roles and responsibilities for assessing and approving bias factors.
16 Annual System Audit Procedures	Describes procedure for annual system audit. Includes selection of auditor, scheduling, audit plan, and reporting.
17 Managing Change	Procedure for managing change when upgrades are required due to failure of equipment, changes in regulation, changes in system management. Includes approval process for accepting changes with roles and responsibilities. Addresses replacement of CEM systems.
Appendices 1 CEM System Specifications 2 Reference Method Procedures 3 Blank Forms	

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