JUNE 2023

BEST PRACTICES IN CEM (CONTINUOUS EMISSION MONITORING)

SANJEEV K KANCHAN
COUNCIL ON ENERGY, ENVIRONMENT AND WATER (CEEW), INDIA

INTERNATIONAL CENTRE FOR SUSTAINABLE CARBON

CEEW

BEST PRACTICES IN CEM
(CONTINUOUS EMISSION MONITORING)

INTERNATIONAL CENTRE FOR SUSTAINABLE CARBON
EPSILON HOUSE
THE SQUARE
GLOUCESTER BUSINESS PARK
GLOUCESTER
GL3 4AD
UNITED KINGDOM

+44[0]20 3905 3870

WWW.SUSTAINABLE-CARBON.ORG

AUTHOR

SANJEEV K KANCHAN
COUNCIL ON ENERGY, ENVIRONMENT AND WATER (CEEW), INDIA

CONTRIBUTIONS FROM:

DR LESLEY SLOSS, ICSC, UK
SEAN R WARDEN, US SOURCE EVALUATION SOCIETY
ROLAND ZEPECK, IBD LTD, GERMANY
STEVEN NORFLEET, AGORA ENVIRONMENTAL, USA

PUBLICATION DATE JUNE 2023

CEM-INDIA

CEEW
THE COUNCIL

This is the first document in a series of best practice documents approved and produced by the new CEM-India stakeholder initiative, hosted by the Council on Energy, Environment and Water (CEEW), India.

PREFACE

This report has been produced by the International Centre for Sustainable Carbon (ICSC) and is based on a survey and analysis of published literature and information gathered in discussions with interested organisations and individuals. Their assistance is gratefully acknowledged. It should be understood that the views expressed in this report are our own and are not necessarily shared by those who supplied the information, nor by our member organisations.

The International Centre for Sustainable Carbon was established in 1975 and has contracting parties and sponsors from Australia, China, Italy, Japan, South Africa.

The overall objective of the International Centre for Sustainable Carbon is to continue to provide our members, the International Energy Agency (IEA) Working Party on Fossil Energy and other interested parties with definitive and policy-relevant independent information on how various carbon-based energy sources can continue to be part of a sustainable energy mix worldwide. The energy sources include but are not limited to coal, biomass, and organic waste materials. Our work is aligned with the UN Sustainable Development Goals (SDGs), which include the need to address the climate targets as set out by the United Nations Framework Convention on Climate Change. We consider all aspects of solid carbon production, transport, processing, and utilisation, within the rationale for balancing security of supply, affordability, and environmental issues. These include efficiency improvements, lowering greenhouse and non-greenhouse gas emissions, reducing water stress, financial resourcing, market issues, technology development and deployment, ensuring poverty alleviation through universal access to electricity, sustainability, and social licence to operate. Our operating framework is designed to identify and publicise the best practice in every aspect of the carbon production and utilisation chain, so helping to significantly reduce any unwanted impacts on health, the environment and climate, to ensure the well-being of societies worldwide.

The International Centre for Sustainable Carbon is a Technology Collaboration Programme organised under the auspices of the International Energy Agency (IEA) but is functionally and legally autonomous. Views, findings, and publications of the International Centre for Sustainable Carbon do not necessarily represent the views or policies of the IEA Secretariat or its member countries.

BACKGROUND

This technical report is part of a significant project undertaken by the ICSC on behalf of the US Department of State, Agreement Number: SLMAQM19CA238: '*Capacity building in Southeast Asia to reduce mercury and other pollutant emissions from the coal combustion sector*'.

The project comprises two major areas of effort to reduce emissions from the coal-fired power sector: one in Indonesia which focuses on mercury emissions; and the second in India which addresses additional pollutants (SO_2, NOx and particulates) as well as mercury.

The project in India is focused on knowledge sharing and capacity building in three pillars of work:

- Pillar 1 – emissions monitoring;
- Pillar 2 – emissions reduction, and ash management;
- Pillar 3 – flexibility of plant operation.

This report expands on the work from Pillar 1: evaluation of the status of continuous emission monitoring (CEM) systems in India. The conclusions and lessons learned from ICSC workshops held in India in 2023 have proved informative to this document.

More detail on the US Department of State project can be found on the ICSC website (www.sustainable-carbon.org).

ABSTRACT

India has set challenging new emission limits for sources such as coal-fired power plants. For this legislation to be effective, the sector must be able to monitor emissions accurately to ensure that any preventative measures or reduction strategies will be effective and can be verified. Continuous emission monitoring systems (CEMS) have been developed to automate the accurate quantification of various pollutants from emission sources. CEMS must be operated and maintained to minimum performance standards to produce consistently valid emission measurements.

Europe and the USA have established best practices in CEMS monitoring over decades. India plans to evolve their national guidelines and to develop their own CEMS equipment certification system. Under the current CEMS guidelines, the Indian government allows operators to certify and to quality assure CEMS using either the European or US approach. Although the approaches are similar, there are inherent differences. Similar or even identical equipment is used, but the methodologies are not identical, and the European and US systems are not designed to be merged. Therefore, it is not possible to switch readily between the two approaches unless the applicable requirements are met – a single operational approach must be used over the lifetime of a CEMS.

This document is intended to act as a single guidance document on best practices for the implementation of CEMS in India, regardless of which international approach is used. This should be a living document, to be updated by Indian stakeholders as the country moves towards establishing its own unified guidance documents.

ACRONYMS AND ABBREVIATIONS

API	application programming interface
ARP	Acid Rain Program, India
CAAQMs	continuous ambient air quality monitoring stations
CAMD	Clean Air Markets Division
CSIR-NPL	Council for Scientific and Industrial Research – National Physical Laboratory, India
CEM	continuous emission monitor
CEMS	continuous emission monitoring systems
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CEQM	continuous effluent quality monitoring system
CFR	Code of Federal Regulations, USA
CPCB	Central Pollution Control Board, India
CSA	Canadian Standards Association
CTO	consent to operate
CTE	consent to establish
CAIR	Clean Air Interstate Regulation
CAMD	Clean Air Markets Division
CAMR	Clean Air Mercury Regulation
DOAS	differential optical absorption spectroscopy
DAHS	data acquisition and handling system
ELVs	emission limit values
FTIR	Fourier transform infrared spectroscopy
ICSC	International Centre for Sustainable Carbon
IEA	International Energy Agency
IPPCD	Integrated Pollution Prevention and Control Directive
IR	infrared
ISO	International Organization for Standardization
MCERTS	Monitoring Certification Scheme, UK
MOEFCC	Ministry of Environment, Forest, and Climate Change, India
NABL	National Accreditation Board for Testing and Calibration Laboratories, India?
NCR	National Capital Region, India
NCAP	National Clean Air Programme, India
NDIR	non-dispersive infrared
NDUV	non-dispersive ultraviolet
NGT	National Green Tribunal, India
NPL	National Physical Laboratory, India
OCEMs	online continuous emission/effluent monitoring system
SPCB	State Pollution Control Board, India
PCC	Pollution Control Committee, India
PM	particulate matter
ppm	parts per million

PTZ	pan-tilt-zoom camera
QA/QC	quality assurance and quality control
QSTI	qualified source testing individual, USA
QSTO	qualified source testing observer, USA
RATA	relative accuracy test audit
RA	relative accuracy
RM	reference method
SES	Source Evaluation Society, USA
SRM	standard reference method
USEPA	United States Environmental Protection Agency
TDLS	tuneable diode laser spectrometry
TÜV	Technischer Überwachungsverein (German Technical Inspection Association)
UKEA	UK Environment Agency
UV	ultraviolet

UNITS

Btu	British thermal units
lb/h	pounds per hour (1lb/h = 0.45 kg/h)
lb/MBtu	pounds per million Btu
lb/scf	pounds per standard cubic foot (1lb/scf = 0.028 m^3)
m^3	cubic metre (assumed to be Nm^3, unless otherwise stated)
mA	milliamps
MMBtu	million British thermal units
MMBtu/h	million Btu per hour
mg	milligramme
mg/Nm^3	milligramme per normal cubic meter
mg/m^3	milligramme per cubic meter
scfh	standard cubic feet per hour (0.028 m^3)
t	metric tonne
ton	0.907 tonne
tons/h	tons per hour

Note: all monetary values are in United States dollars ($) unless otherwise stated.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Since February 2014, the Indian Central Pollution Control Board (CPCB) has required real-time monitoring and reporting of pollutant emissions using continuous emission monitoring systems (CEMS). Under this directive, CEMS are mandatory for 17 categories of highly polluting industries within the 'red' category, which includes power plants, pulp and paper, iron and steel production, cement plants and others. As well as CEMS for stack emission monitoring, real-time water pollution monitoring using continuous effluent quality monitoring systems (CEQMS) have been mandated for relevant industries.

Emission monitoring techniques have evolved in the European Union (EU), the UK and the USA over the last four to five decades. India has been able to learn from this experience and accelerate the application of CEMS. However, the Indian approach requires all CEMS to report directly to the regulator, online and in real-time. This level of regulatory supervision is unique to India; emission sources in Europe and the USA report their data regularly to the relevant authorities but are not required to do so continuously and in real-time.

The introduction of advanced, automated, and real-time emission monitoring and reporting systems has been a technological leap for India's environmental governance system. The automated approach is seen as largely resolving persistent data credibility problems. The previous methods were based on periodic (monthly and quarterly) emission monitoring and reporting using third-party laboratory services. CEM-based systems located at the source, are assumed to be tamper-proof if installed properly, and to provide the necessary information to identify emission sources which are not in compliance with the relevant emission limits. They are also seen as a driver for promoting self-regulation across industrial sources.

Most red-category industries have installed the CEMS since 2014, and data are supplied to the regulators, both the Central Pollution Control Board (CPCB) and the relevant State Pollution Control Board. However, the installation of equipment and online data transfer to the regulatory agency does not guarantee that the system is operating correctly or that the data are accurate. Most of the installations have reported technical issues, often related to appropriate CEMS selection, installation, operation and maintenance (O&M), and data transfer.

For the first years following the 2014 requirement for CEMS, there were no official guidelines on CEMS installation and operation. This absence of technical support along with a lack of skills and training within the sector led to errors. The CPCB published 'Guidelines for continuous emission monitoring systems' in August 2017. However, there have been minimal attempts to confirm if corrective measures have been taken or to ensure that all systems are now installed properly and operational.

Europe and the USA have created certification and accreditation systems for both CEMS equipment and the personnel using it. The relevant sectors in India must learn from these regions while producing a system which is appropriate to India. Certification and benchmarking could be the foundation to ensure that CEMS in India are operated correctly and that decisions made based on emission data are valid and appropriate.

The initial selection of CEM equipment depends on specific requirements. In the EU, sources can only install CEM systems which have passed a 'type approval' test and have received certified status. In the USA, any CEM system can be used if it can be proven fit for purpose through testing once it is installed. Indian regulators allow both approaches and will accept any CEM system that has been demonstrated as appropriate. The first step in a CEM selection and installation process is to ensure that the chosen CEMS is legally approved for use, so this is the focus of Chapter 2. Chapter 3 looks at best practice for CEM selection, installation, and operation. The quality assurance and quality control (QA/QC) requirements of the European (Chapter 4) and US (Chapter 5) approaches follow. Data acquisition and reporting is covered in Chapter 6 and then Chapter 7 gives a brief account of the status of training on CEMS use in India.

This report is based on guidance documents and standard methodologies published in the EU, the USA and India. The collation of these approaches serves to provide the basis for best practice in India. Stakeholders should use this document as a guide based on best practices for the application of CEMS. However, stakeholders should always refer to the appropriate documents when working with CEMS at a specific source – this could be the US or EU standards, reference documents from the CPCB or relevant SPCB, or even from a site-specific or vendor-recommended CEMS protocol. This document does not include details on individual CEM systems. The general principles of CEM monitoring techniques are summarised in Chapter 3, noting their applicability, advantages, and disadvantages. Whilst this can help an operator narrow down the choice of CEMS for a source, the information in this document is insufficient to prescribe a CEMS for a specific source. Source operators should follow expert advice and purchase a CEM system from a vendor following appropriate investigations to confirm that it is the correct instrument to work on the intended source.

2 CEMS CERTIFICATION/APPROVAL

The first stage in a CEMS selection process is to identify legally acceptable equipment for compliance monitoring under national guidelines. There are two international approaches to CEMS selection:

- Type-approval/certification – an independent laboratory field tests equipment and certifies that it is fit for purpose on defined sources. This is the approach used in Europe.
- Certification process/performance test – any installed CEMS can be used once it has been proven to meet the accuracy requirements of the relevant regulation on site and it is approved by the administrator. This is the approach used in the USA.

Post-installation tests are carried out periodically for quality control, both in the EU and the USA, as required by the specific regulatory provisions.

There are advantages and disadvantages to both the EU and US approaches, as discussed in this chapter. The Indian approach, which permits the use of either method, allows flexibility and opens the market to all international vendors and the evolution of new indigenous Indian technologies. This blended approach means that this best practice guidance for India covers both EU and US approaches.

2.1 EU CERTIFICATION

CEMS are also known as automated monitoring systems (AMS) in Europe but are referred to as CEMS in this report as this is the terminology used in India and the USA. CEMS have been used in industry in the EU for many years, but it was the Integrated Pollution Prevention and Control Directive (IPPCD) that mandated the installation of CEMS in large industrial processes, including coal-fired utilities, and in steel and cement plants. The key requirements for quality, suitability, and calibration, led the EU to develop the EN-15267 and EN-14181 standards in the 1990s. The EN-15267 standard became the basis for the CEMS 'type approval' scheme (Quality Assurance Level 1; QAL1 approval, *see* below) and the EN-14181 standard became the baseline for the selection, quality assurance and calibration of CEMS in Europe. Various procedures and test requirements under QALs are explained in the Chapter 4.

'Type approval' or device certification ensures that the CEMS equipment is reliable and complies with the requirements for compliance monitoring. Certification is carried out by a competent authority, or an approved agency which has been authorised to evaluate and approve the quality and functionality of the product. Once a device passes the tests specified in such standards, it becomes certified. Certification provides recognition and assurance of the quality of the product across different national and sectoral markets. It can be seen as approval of the technology in an almost 'plug-and-play' manner. It eliminates any requirements to retest the device for new international markets and so allows smooth international trade. However, the credible and accurate performance of a CEMS is determined by how well it operates after installation and over its operational lifetime. Therefore, the selection and installation of a certified system do not guarantee valid results; an ongoing quality assurance and quality control (QA/QC) system is an integral part of compliance monitoring.

The European certification scheme includes both type-approval of the product, as described above, and regular manufacturing factory audits to ensure that each product that is made and sold is identical to that which was tested for certification. Certification has evolved due to regulatory drivers. Table 1 shows the certification schemes developed in various European countries.

TABLE 1 CEM QUALITY ASSURANCE SYSTEMS IN EUROPE (AFTER SOPHIE, 2007)

Country	Certification scheme	Mandatory	Start
Germany	UBA (Umweltbundesamt) Type Approval Scheme	Yes	1975
France	Association for the Certification of Measuring Instruments for the Environment (ACIME)	Yes	2003
UK	The Environment Agency of England and Wales (EA) Monitoring Certification Scheme (MCERTS)	Yes	1998
European Union (EU)	CEN* (European Committee for Standardization) Standard: Certification Scheme	Yes	2009

* CEN (Comité Européen de Normalisation), the European Committee for Standardization, is an association that brings together the National Standardization Bodies of 34 European countries. CEN provides a platform for the development of European Standards and other technical documents about various kinds of products, materials, services, and processes

As shown in Table 1, initially some European countries had national standards for accreditation. This was unfavourable for international trading as it required a fresh accreditation each time products from one European country entered another. To solve this problem, a single accreditation scheme for Europe was developed in 2009 under CEN. For this, the original standard BS EN–15267, produced in the UK, was restructured to certify CEMS devices and to give them international (European) recognition. This standard is now an integral part of the Monitoring Certification Scheme (MCERTS) in the UK. Sira Certification Service (SCS), under the Canadian Standards Association (CSA) Group Testing UK Ltd, is the certification body which runs the MCERTS scheme in the UK. In the EU certifications are typically handled by the various TUEV organisations in Germany under observance of the German EPA (Umweltbundesamt).

Responsibility for, and the cost of, certification tests lie with the CEMS manufacturer. Certification requires both field and laboratory tests as well as management audits of manufacturing quality. However, once a technology and respective model is certified, all the devices produced for that type of certified technology and model are approved for the defined industries in the EU. So, although the EU certification scheme can be costly for the CEMS manufacturer, certified systems are then sold as ready-to-use devices with a guarantee of functionality. It is this assurance of suitability for use that makes many Indian users prefer EU-certified equipment to non-certified US systems and may explain why European CEMS are currently more prevalent than US CEMS in India.

The CPCB guidelines clarify that the Indian government plans to develop an indigenous certification system for India, and once ready, new CEMS produced and imported into India will undergo the indigenous certification system to be acceptable in the Indian market.

2.2 THE US APPROACH

There is no type-approval or equipment certification process in the USA. The methodology for CEMS implementation is spread across several separate but related and interconnected regulations. The US Environment Protection Agency (USEPA) Code of Federal Regulation (CFR) 40, Part 75, addresses the emissions monitoring requirements of thermal power plants under the US sulphur dioxide (SO_2) and nitrogen oxides (NO_X) emission allowance trading programs. CEMS regulations addressing other industries and some additional provisions affecting thermal power plants and the associated CEMS performance specifications and procedures are covered in CFR 40, Part 60, which includes the compliance requirements under Standards of performance for New Stationary Sources (polluting sources). Other air pollutants, such as mercury emissions, are addressed in 40 CFR Part 63, which establishes the 'National Emission Standards for Hazardous Air Pollutants' for various industries (for example, the requirements for mercury CEMS on thermal power plants are found in Appendix A in Subpart UUUUU of 40 CFR, Part 63).

US air pollution emission regulations are complex and fragmented. For example, Part 75 has eight different subparts (Subpart A to H) and seven appendices (Appendix A to G) which cover procedures related to CEMS implementation, data handling and record keeping. Part C and Appendix B are specific to the quality assurances and testing provisions needed for CEMS. The different regulations all require operators to develop written QA/QC plans, which are considered 'living documents' and are required to be updated as necessary. Table 2 compares the QA/QC of CEMS in the EU and the USA.

TABLE 2 COMPARISON OF CEM APPROVAL SYSTEMS IN THE EU AND USA (CURTIS, 2017)

	Selection of CEMS	Installation	Stability before calibration	Valid calibration	Ongoing instrumental stability	Ongoing calibration stability
EU	QAL1* (EN15267 parts 1 to 3) with appropriate certification range	EN15259	QAL3*	Functional test and QAL2*	QAL3* plus annual linearity	Functional tests and annual surveillance tests (AST)
USA	None (onus on the operator to provide valid data)		7-day drift test	Correlation tests for PM (at 3-PM loads) RCA (Relative Correlation Audit) for PM CEMS Initial Gas RATA	Daily Zero and span plus quarterly linearity test	Annual Relative Accuracy Test Audits (RATA) and annual Relative Response Audits with 5-year or 3-year Relative Correlation Audits (for particulate)

* QAL 1, 2 and 3 are levels of quality assurance applied to installed CEMS. They are discussed in Chapter 3.

Unlike in the EU, a CEMS installed in the USA does not need type approval prior to installation for the intended source. This leaves the operator free to select the CEMS equipment from any available in the international market. Under the US approach, each individual CEMS analyser must undergo a series of performance tests after installation and notification to the USEPA (as well as the development of an associated QA/QC plan). A range of tests are required which include RATA (relative accuracy test audit), linearity checks, calibration error tests (such as daily calibration), 7-day drift tests, and cycle time tests (*see* Chapter 5).

2.3 THE COMBINED INDIAN APPROACH

India initiated the use of CEMS in February 2014, and the CEMS guidelines were first published by the CPCB in August 2017. The guidelines recommend a hybrid of the EU and US quality assurance requirements for CEMS in India. The CPCB's draft guideline document suggests that the CEMS selected shall preferably have a Certificate of Product (COP) through MCERTS, TÜV – Technischer Überwachungsverein (German Technical Inspection Association) or any equivalent international agency. Indigenous CEMS without a COP must satisfy the performance requirements which are largely equivalent to the requirements of certified products. This means either passing tests equivalent to the EU QAL2 standard (*see* Chapter 3) or meeting the USEPA performance standard criteria (RATA) as detailed for respective parameters (*see* Chapter 4).

For instruments without a COP, the performance demonstration test period may take from two weeks to one month. The expenditure for conducting this performance demonstration is borne by the manufacturer or vendor of the system/instrumentation. The performance demonstration requirements are case-specific and cannot be granted for identical CEMS on similar stacks at the same source or industry. This is why non-certified CEMS are often seen as more complicated than certified systems in India.

The use of certified CEMS is intended to maintain the credibility and quality of technologies within the system. However, the aim of allowing non-certified CEMs with performance tests is to encourage the development of an indigenous technology manufacturing market while maintaining quality assurance.

2.4 COMMENTS

Any CEMS should meet regulatory requirements and be proven fit for purpose. The EU and USA approaches each have their advantages and disadvantages:

- The EU approach is expensive for CEMS vendors, but vendors cannot sell into the EU market without certification. Once certified, CEMS can be used on any approved application within the EU (and India).
- US operators can use any CEMS, regardless of certification status, once they demonstrate that it is fit for purpose on-site through specified testing. This testing is rigorous and linearity tests and drift checks are more frequent, which can be expensive and time-consuming for plant operators.

Indian regulators permit both EU and US approaches, opening the market to all international vendors and allowing the evolution of a new domestic sector for indigenous Indian CEMS development. The downside of this all-inclusive approach is that guidelines on best practices for CEMS in India must include both EU and US methodologies and that the, often complex, decision on which approach to use lies with the operator.

3 BEST PRACTICE IN CEMS SELECTION

CEMS are to be installed in different categories of industries in India in compliance with the respective regulations and directives. These industries and processes have stipulated emission limit values (ELVs), norms or standards, to be complied with, and the CEMS are a tool to monitor emissions and report them to the respective regulators (CPCB, 2017).

The regulatory requirements relevant to the type of monitor which can be used (certified or non-certified) were discussed in Chapter 2. This chapter summarises the types of CEMS available, focusing on the chemical and/or physical parameters that they use to measure accurately emissions from stationary sources.

3.1 CEM OPTIONS AS DEFINED BY THE CPCB

Table 3 lists the most recent instructions for parameters to be monitored by India's 17 categories of industry using CEMS, according to the CPCB guidelines. In addition, different Indian states have also mandated CEMS installation in industries in 60 red categories of industry including 17 highly polluting ones. For further information, refer to the CPCB document 'Modified directions to SPCBs/PCCs on Revised Classification of Industrial Sectors Under Red, Orange, Green and White Categories' published in March 2017 (CPCB, 2017).

TABLE 3 POLLUTANTS WHICH MUST BE MONITORED FROM THE 17 CATEGORIES OF INDUSTRY IN INDIA (CPCB, 2018)

1	Aluminium	pH, BOD, COD, TSS, flow	PM, fluoride, flow
2	Cement	–	PM, NOx, SO_2, flow
3	Distillery	pH, BOD, COD, TSS flow	PM, flow
4	Dye and dye intermediate	pH, BOD, COD, TSS, Cr, flow	–
5	Chlor Alkali	pH, TSS, flow	Cl_2, HCl, flow
6	Fertilisers	pH, flow, ammonical nitrogen, fluoride	PM, fluoride, ammonia, flow
7	Iron and steel	Ph, phenol, cyanide, flow	PM, SO_2, flow
8	Oil refinery	pH, BOD, COD, TSS, flow	PM, CO, NOx, SO_2, flow
9	Petrochemical	pH, BOD, COD, TSS, flow	PM, CO, NOx, SO_2, flow
10	Pesticides	pH, BOD, COD, TSS, Cr, As, flow	–
11	Pharmaceuticals	pH, BOD, COD, TSS, Cr, As, flow	–
12	Power plants	pH, TSS, temperature	PM, NOx, SO_2, flow
	Thermal power plants	pH, TSS, temperature	PM, NOx, SO_2, total mercury (gaseous), flow
13	Pulp and paper	pH, BOD, COD, TSS, AOx, flow	–

14	Sugar	pH, BOD, COD, TSS, flow	–
15	Tannery	pH, BOD, COD, TSS, Cr, flow	–
16	Zinc	pH, TSS, flow	PM, SO_2, flow
17	Copper	pH, TSS, flow	PM, SO_2, flow
18	Textile (GPI)	pH, COD, TSS, flow	–
19	Dairy (GPI)	pH, BOD, COD, TSS, flow	–
20	Slaughterhouse	pH, BOD, COD, TSS, flow	–
21	Boiler	–	SO_2, NOx, flow

Notes:

a) CEM systems must have a flow (velocity) measurement device installed

b) Direct measurement systems for O_2 or CO_2 as prescribed in respective standards shall be installed

c) For hazardous waste incinerators and biomedical waste incinerators O_2, CO_2 and CO are important parameters to be monitored online

d) Any dilution extractive system must have a CO_2 measurement facility at the source and measuring point to prove the correctness of the selected dilution ratio

CEMS selection includes consideration of its features and performance specifications. The regulatory requirements and guidance documents produced by CPCB suggest some basic qualifying criteria of CEMS, which specify that the equipment must:

- Be quality assured and able to function unattended for extended periods, for example, three consecutive and uninterrupted months;
- Be able to produce valid, direct results in concentration (ppm or mg/m^3 or volume % as per regulation) with precision and repeatability and a response time of less than 200 seconds;
- Be fit for application and purpose and have lower detection limits (less than 0.5% of full scale);
- Be robust and rugged enough to function with precision in varying process environments and harsh meteorological conditions;
- Have an analyser display of pollutants along with the functional parameters needed for checking the analyser's maintenance status;
- Have an in-built facility for checking zero drift and span drift (less than 1% of full-scale per week), linearity (less than 1% of full scale) and other relevant tests;
- Have a data validation facility, the capability to store and transmit raw and standardised data and instrument diagnostics to the regulator's central server through RS232/RS485/Ethernet/USB communication ports;
- Have features which allow it to be remotely accessed securely by the relevant regulatory authority;
- Be capable of multi-server data transmission without an intermediate PC or server;
- Be able to send an alarm to the central server if there is any change in configuration or calibration;

- Have the facility to create log files for O&M, calibration, and validation in the analyser or in the remote system, and store data for long periods; these data must be accessible on a real-time basis to the central server;
- Have a non-volatile system memory to record data for at-least one year of continuous operation. This is often provided by the data acquisition and handling system (DAHS);
- Have provision for independent analysis, validation, calibration, and data transmission for the pollutant parameter;
- Have provision for plant-level analogue data access though Ethernet, Modbus and USB; and
- Have low O&M requirements (spares, consumables, and cost).

The suitability of a CEMS for a particular industry unit depends on a range of parameters including the process; the flue gas characteristics (such as temperature, moisture levels, other gases, flow rate); installed air pollution control systems (such as particulate and acid gas control systems); emission levels; and the emission limits. Thus, one CEMS technology may not be appropriate for two similar industrial units or processes, if any of the above characteristics vary. Therefore, the selection of suitable CEMS technology is specific to the particular industry or process which must be analysed in advance of any decision. Incorrect technology selection will result in poor data quality and regulatory non-compliance issues.

Predictive emission monitoring systems (PEMS) are an option for real-time 'monitoring'. PEMS use operational data to estimate emissions using theoretical and empirical methods and provides data on a real-time basis. PEMS are generally considered suitable for the process where variations are limited. The type and consistency of the fuel(s) used particularly influence the applicability and accuracy of PEMS. However, since they do not actually measure emissions, they are not discussed further in this report.

3.2 THE SELECTION PROCESS

Best practice should include four steps for the selection of suitable CEMS:

Step 1. Understand the regulatory compliance requirement for the CEMS installation.

Step 2. Identify the pollutants and accessory parameters for which CEMS are needed.

Step 3. Decide which CEMS technology is most suitable.

Step 4. Prepare a tender/project order preparation for CEMS and consider the various vendor options.

Each of these steps is explained in more detail below.

3.2.1 Understanding the regulatory compliance requirement

The operator should refer to the regulatory instructions regarding CEMS installation requirements, in terms of process units, essential and accessory parameters and monitoring units, data acquisition and transfer and so on. The instructions for Indian industries may include the following:

- Environmental clearance (EC) conditions;
- Consent to establish (CTE) conditions;
- Consent to operate (CTO) conditions;
- Specific regulatory programme requirements; and
- Other specific instructions/directions/orders from the CPCB/SPCB.

If the operator is installing CEMS on a voluntary basis or for process control rather than for compliance monitoring, then the selection process can start from Step 2.

3.2.2 Identifying the pollutants and accessory parameters

Operators should refer to the following steps to identify the parameters to be monitored and associated equipment requirements:

- Environment compliance conditions under EC/CTE/CTO/specific regulatory programme/instructions/directions/orders;
- Accessory parameters such as oxygen, CO_2, or water vapour, temperature, or pressure for data standardisation in order to express the emissions in terms of the applicable limit;
- Flow monitors, if the emissions are required to demonstrate compliance with a mass emission per output-based limit (for example kg/Mt);
- Data handling and reporting requirements;
- Remote calibration set-up requirements; and
- Automation level requirements (such as internal calibration, auto zero and span check, internal alarm set-up and auto diagnosis).

3.2.3 Deciding on suitable CEMS technology

Decisions should be made based on the suitability of the CEMS technology for the particular process/operation. Some key points to assess include:

- Pollutant to be monitored;
- Emission concentration expected;
- Present and expected emission limits;
- Flue gas composition and other characteristics such as temperature, and flow stratification;
- Installation, operation, and maintenance requirements and
- Accessibility at the location of installation.

Further, the operator must:

- Refer to the latest regulatory guidelines on CEMS to confirm the recommendations on suitable technology for the process;
- Discuss suitable options with credible CEMS technology providers;
- Discuss with consultants and experts; and
- Assess the internal capacity and expertise needed for the CEMS technology operation and maintenance to ensure that it will be operated correctly.

The decision on whether to select an extractive-type CEMS or an in situ system depends largely on the monitoring site, the parameters to be monitored and the preference of the operator. Particulate matter (PM) CEMS are often in situ, such as cross-duct or path (for example, opacity monitors) and point source systems (such as optical scatter or tribo-electric options). For gaseous CEMS, both in situ and extractive systems are equally popular. Generally, if the installation site is not readily accessible for regular maintenance, extractive gaseous CEMS are preferred. Extractive systems often offer easier O&M and the CEMS are less at risk from harsh environmental conditions within the plant. However, in situ CEMS can offer a lower cost of installation, fewer heated sample tubes and sample conditioning issues, and simpler O&M, since all the accessories are installed at the site and fewer consumables are required.

For some pollutants such as hydrogen chloride (HCl) and hydrogen fluoride (HF), which can be present in low concentrations in sources such as coal utilities and waste incinerators, the concentration can be affected during sample transfer, and so in situ CEMS are preferred. Conversely, extractive CEMS allow an opportunity to condition the sample gas for proper monitoring which may not be always possible in in situ CEMS. For example, dust monitoring at the flue-gas exit from a wet flue gas desulphurisation system (FGD) with a high moisture content will require an extractive type of PM-CEMS which is capable of removing excess moisture from the gas or diluting the raw sample gas to reach a low dewpoint. Both in situ and extractive CEMS have their own benefits and limitations; therefore, selection should be case specific.

For any CEMS technology selected, the ultimate purpose remains to have uninterrupted representative sampling, and proper and regular O&M. Figure 1 shows the CEM options based on the characteristics of the source and sampling conditions.

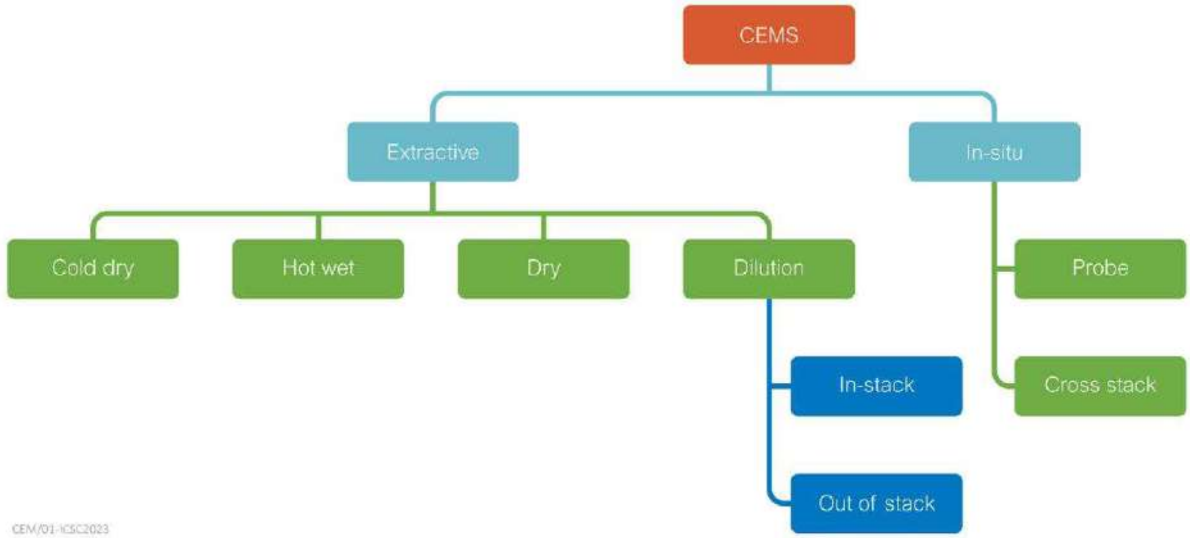

Figure 1 CEMS technology options based on installation conditions and preferences (Kanchan, 2019)

The Indian guidelines for CEMS recommend the basic application of PM and gaseous CEMS, including a summary of how these systems operate, and for which sources they should be used. Tables 4 and 5 below show these CPCB recommendations.

TABLE 4 PM CEM TECHNOLOGY APPLICATION AND SUITABILITY (CPCB GUIDELINES, 2018)

Measurement Technology		Stack diameter, m	Concentration, mg/m^3		APC device	Sensor contamination check	Zero and span	Dry	Humid	Wet	Velocity dependent
			Min	Max							
Probe electrification	Electrodynamic	0.2–4	0.05	1000	Bag, cyclone, drier, scrubber(5), none(6)	√(7)	√(7)	√	√	X	No
	DC triboelectric	0.2–2	1	1000	Bag, cyclone, ESP(10), none(6)	X	X	√	X	X	Yes
	Combination AC/DC triboelectric	0.2–2	1	1000	Bag, cyclone, none(6)	X	√(7)	√	X	X	Yes
Transmissometry	Dynamic opacity	1–15 (1,2,7)	10(3)	1000	Bag(1), cyclone, ESP, none	√	√(7)	√	X	X	No
	Dynamic detection principle	1–10 (1,2)	20	1000	Bag(1), cyclone, ESP, none	√	X	√	X	X	No
	Opacity	2–10(1,2)	30(4)	1000	ESP, none	√	√	√	X	X	No
	Non-compliance transmittance	2–10(1,2)	30(4)	1000	ESP, none	X	X	√	X	X	No
In situ light scatter	Forward scatter	1–3(2)	0.1	200	Bag, cyclone, ESP, none	√	√	√	X	√(9)	No
(Extractive type scatter for wet gas)	Backward/side scatter	1–4(1,2)	25	500	Bag(1), ESP, none	√	√	√	X	X	No

Notes:
(1) Concentration dependent; (2) Representative flow dependent; 3) Application specific; (4) Stack diameter dependent; (5) No water droplets; (6) No filter-not advised; (7) Model specific; (8) Varying velocity range 8–20 m/sec; (9) Using extractive wet stack monitoring system; (10) Advised with Faraday Shield/edge
(All transmissometry and scattered light instruments must be provided with constant clean air purge supply)

TABLE 5 GASEOUS CEMS TECHNOLOGY APPLICATION AND SUITABILITY (CPCB, 2018)

Technique	Type	Gases measured	Comments
Chemiluminescence	Dilution extractive	NO, NO_X, NO_2 (not suitable for SO_2, CO_2, CO etc)	• Indirect method for NO_2 measurement • NOx = NO + NO_2 *(Indian regulatory norms are in NO_2 as mg/Nm^3)* • Accessories required – dilution probe, sample transfer line, dilution air, pumps and ozone generator • Quench effect of CO_2/water vapour etc maintaining low pressure becomes important • Advantageous in industries where heating probe and transfer lines are avoided ie refinery, petrochemicals
UV fluorescence	Dilution extractive	SO_2, H_2S, TRS (total reduced sulphur) (not suitable for NOx, CO_2, CO etc)	• H_2S, TRS cannot be measured simultaneously with SO_2 • Direct method for SO_2 • Accessories required include – dilution probe, sample transfer line, dilution air, pumps etc • Quench effect of CO_2/water vapour etc maintaining low pressure becomes important • Advantageous in industries where heating probe and transfer lines are avoided ie refinery, petrochemicals
NDIR (IR GFC, CFM-NDIR and NDIR) Basic principle follows IR (infrared) spectroscopy. GFC or CFM are applied techniques only	In situ extractive	CO, CO_2, SO_2, NOx, CH_4, HCl, H_2O etc	• A direct continuous measurement of multiple gases without any dilution • Suitable for high concentrations • IR technology can measure only NO. For NOx measurement a converter is required to reduce other oxides of nitrogen to NO • In situ NDIR analyser uses internal optical filters (GFC) for removal of interferences of other gases • In extractive NDIR, issue of dissolution and stripping of CO_2/ SO_2 can affect measurement, in case calibration does not include sampling line • Maintaining low pressure becomes important
NDUV	In situ extractive	SO_2, NO, NO_2, NH_3, Cl_2, CS_2, etc	• A direct method for continuous monitoring of multiple gases (up to 2–3 gases) without any dilution • Popular in harsh applications in wide spectrum of industrial processes • For NH_3 only hot wet extractive system is suitable
Fourier transformed infrared (FTIR)	In situ extractive	CO, CO_2, SO_2, NO, NO_2, N_2O, NH_3, HF, HCl, CH_4, moisture (H_2O), VOC, etc	• A direct method for continuous monitoring of multiple gases (up to 5–12 gases) using high end spectroscopy technique • H_2O measurement in FTIR spectroscopy is necessary for moisture correction

			• Uses hot wet preferred technique for complex stack gas matrix like waste incinerators or waste to power plants, alternative fuels fired cement plants, with high moisture and soluble gases • High price, however, with multi- complex gases and integrated modules like VOC, O_2 makes it cost-effective over-all solution • Also use as in situ/path type installation • Ideal for very low concentration of NH_3, HF, HCl
Differential Optical Absorption Spectroscopy (DOAS)	Open path cross duct	DOAS- UV for NO, NO_2, SO_2 NH_3, Hg DOAS-IR for CO, CO_2, HCl, CH_4, VOC, H_2O, HF etc	• Suitable for monitoring of multiple gases • Suitable for trace measurements • Indirect measurement technique • Stable, comparatively low calibration requirements • Measurement of Hg requires its conversion to elemental form for DOAS-UV with accessories required- heated gas probe, heated sample transfer line and heated measurement cell. Removal of SO_2 interference is essential in case of UV measurement of mercury
Flame Ionization	Extractive	Total HC (VOC)	• Very selective technique for Total HC/TOC/VOC • Requires H_2 gas for flame and as carrier gas • Integrated with extractive Hot-wet/cold/dry techniques
Tunable Diode Laser	Path	CO, CO_2, NH_3, moisture (H_2O), HCl, HF, CH_4, O_2 and H_2S etc	• Selective laser technique • Costly for single component monitoring • Limitation in measuring SO_2 and NOx due to lack of selectivity • Measurement of H_2O for moisture correction is necessary
Electrochemical	Extractive	O_2, CO/CO_2 etc	• Not accepted for online stack emission monitoring in industries • Electrochemical sensor is a consumable sensor, requires regular replacement and is influenced by process stack background gas matrix • Also gets influenced by moisture, dust, temperature etc
Zirconium oxide cell	In situ extractive	O_2	Widely used for boiler/ Stack O_2 correction
Paramagnetic	Extractive	O_2	Stable and accurate

Notes:
(a) CEMS must have flow (velocity) measurement device installed
(b) Direct measurement systems for O_2 or, CO_2 as prescribed in respective standards shall be installed
(c) For hazardous waste incinerator and biomedical waste incinerator O_2, CO_2, and CO are important parameters to be monitored online
(d) Dilution extractive system must have CO_2 measurement facility at source and measuring point to prove the correctness of the selected dilution ratio

3.2.4 Tender/project order preparation for CEMS

Each industry or company may have its own established process for procurement. However, there are common requirements for all. While preparing a CEMS tender/project order or purchase order, the operator should ensure that the order includes the following:

- Clear compliance requirement with reference to CEMS selection, installation, O&M, and data handling;
- For extractive CEMS: detailed description of the entire sample handling system (heated sample probe, heated sample line, sample conditioning system/sample gas cooler);
- Clear CEMS specification and other expectations;
- Request site visit and inspection by the possible vendors before preparing their quotation;
- Assessment of the supplier's credibility and experience;
- Quality assurance of CEMS;
- Durability of CEMS with respect to local operating/environmental/meteorological conditions;
- Supplier's capability for after-sales support (online and onsite);
- Requirement for and availability of spare parts;
- Include two years' supply of consumables and spare parts in the quotation;
- Include the cost for a one-year annual maintenance contract (AMC) for the first year after the warranty period;
- Proper and detailed actual operation/process/pollution control conditions and installation position/location/requirement;
- Consideration of worst-case scenario of process/operation with respect to the expected ruggedness and performance of the CEMS;
- Provision of bank guarantee deposit against minimum performance requirement; and
- Provision of site visit for selected suppliers before order confirmation.

3.3 BEST PRACTICE IN CEM INSTALLATION

On purchase of a CEMS, the operator, vendor and support staff should focus on the following:

- Match the delivered product with the order description in detail;
- Study and store the detailed quality assurance certificates and instruction manual;
- Check that all the components and accessories required for respective CEMS installation, O&M and compliance are present;
- Confirm the availability of spare parts and consumables, possibly setting up an ongoing maintenance and support contract with the vendor;
- Cross-check the expiry dates of the consumables (such as gas cylinders);
- Gain familiarity with the product components;

- Operator to receive training (from the vendor) on measurement technology, operating principles and related regulatory requirements, preferably before installation.

Product installation is one of the most critical parts of CEMS implementation. This includes the selection of a suitable location and position of installation, as per the guidelines, along with confirmation of the CEM compatibility with any supporting technology. The key points for installation are:

- Assess and check the correct installation, the appropriate location/point, accessibility, alignment with respect to guidelines (CEMS Guidelines and Emission Regulation – Part III) and following the manufacturer's instruction manual.
- Carry out QAL2 tests (for certified CEMS) and performance tests (for non-certified CEMS) during installation by an accredited laboratory/agency (see Chapter 4). Collect and store the test certificate and related reports.
- Prepare and maintain a register/folder to document all CEMS tests/events/actions immediately from the installation with proper time-stamping.
- Ensure the proper functioning of CEMS, analyser shelter, data handling system, registration at regulator's server (CPCB/SPCB) and other required checks in order to pass commissioning approval by the regulator.
- Ensure on-site training of responsible CEMS team by the vendor or equipment supplier during commissioning and follow up regularly with continued training.

Correct installation is one of the most critical factors of proper CEMS implementation – CEMS will not perform correctly if it is not installed correctly. As discussed in the previous section, CEMS installation, location and position should be decided during the early part of the technology selection to avoid the purchase of CEMS which cannot be installed or operated correctly.

The operator should note the following key points about installation:

- PM CEMS installation should ideally be in the stack 500 mm below the manual sampling port. This ensures that during calibration when both the PM CEMS and the manual reference sampling system are run simultaneously, the operation of the manual sampler will not affect the reading of the PM CEMS.
- The manual monitoring platform is generally available at 8D/2D (8x internal stack diameter downstream and 2x internal stack diameter) upstream from the last disturbance. This is required by the Indian regulation for manual monitoring (Emission Regulation Part-III). In the EU, 5D/5D spacing is followed.
- Some stacks may not have sufficient height for 8D/2D, in which case, manual monitoring is generally carried out with an additional number of sampling traverse points.

- In the case of a rectangular stack or duct, equivalent diameter (De) is calculated by Length (L) and Width (W) with the formula De= 2 (L x W)/ (L + W).

Figure 2 shows the required location of CEMS according to the Indian regulations (Emission Regulation Part-III) (CPCB, 1985).

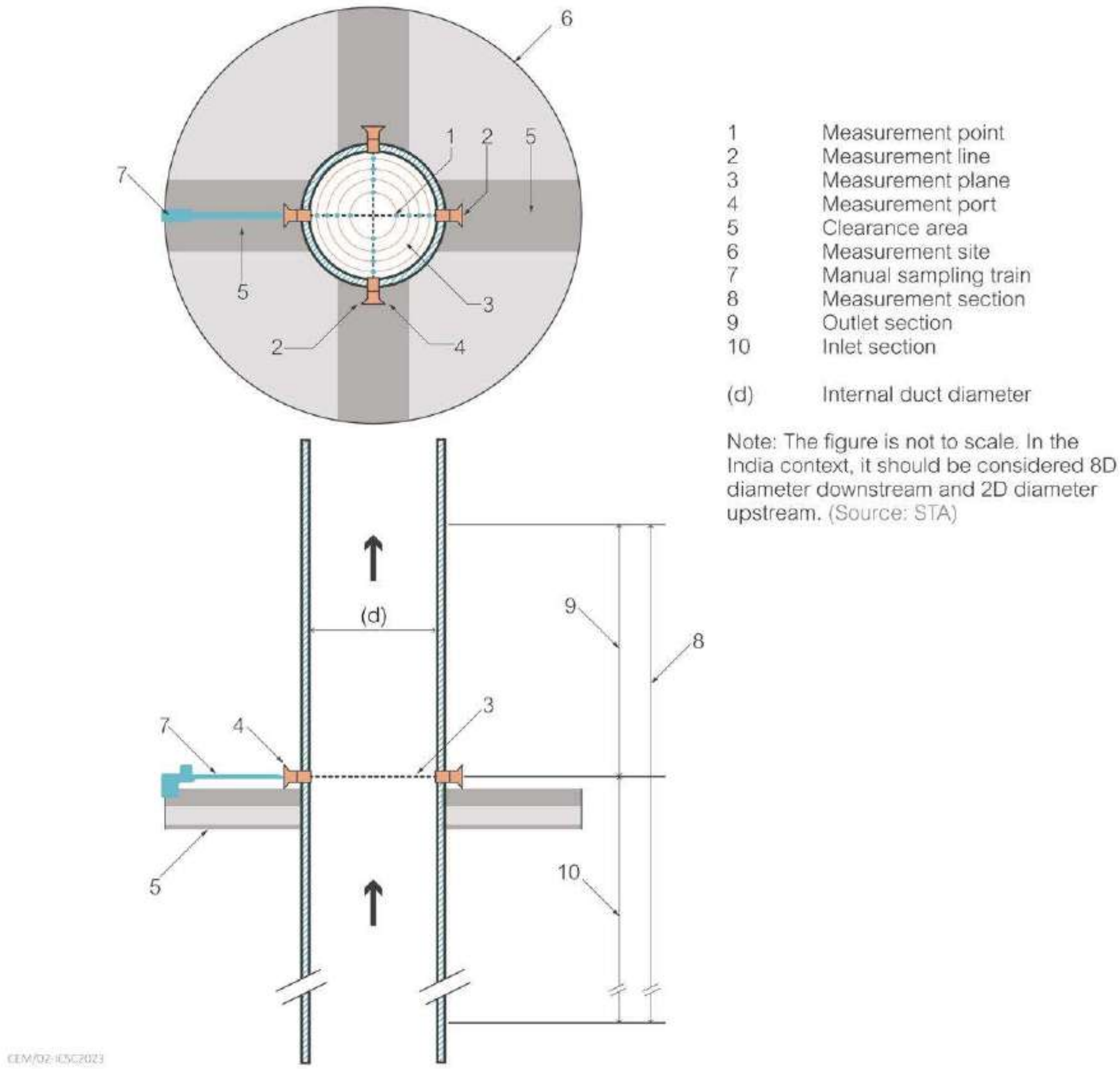

Figure 2 Measurement site and sectioning of stack for CEMS installation (CPCB, 2018)

If the correct position in the stack is not available or approachable, a suitable position in the flue gas duct can be explored using 8D/2D (D=hydraulic diameter). For the installation of in situ analysers in large ducts, the gas profile at the proposed sampling point must be checked for stratification to confirm that the gas composition is homogenous. The stratification test must take into account variations in boiler load, gas composition and flow with time.

Gaseous CEMS installations should also be in the stack at the same available platform for stabilised flow, easy maintenance, and homogenous gas conditions. In the absence of such conditions, another installation location in stack or duct can be explored if it provides homogenous gas conditions, stability of gas flow and compliance with the regulatory conditions. Figure 3 shows the lines and planes across the duct. If there is any stratification or unevenness of flow, this should be corrected in the plant. If this is not possible, it may be necessary to measure at many points to determine which sample point or points will produce the most representative results.

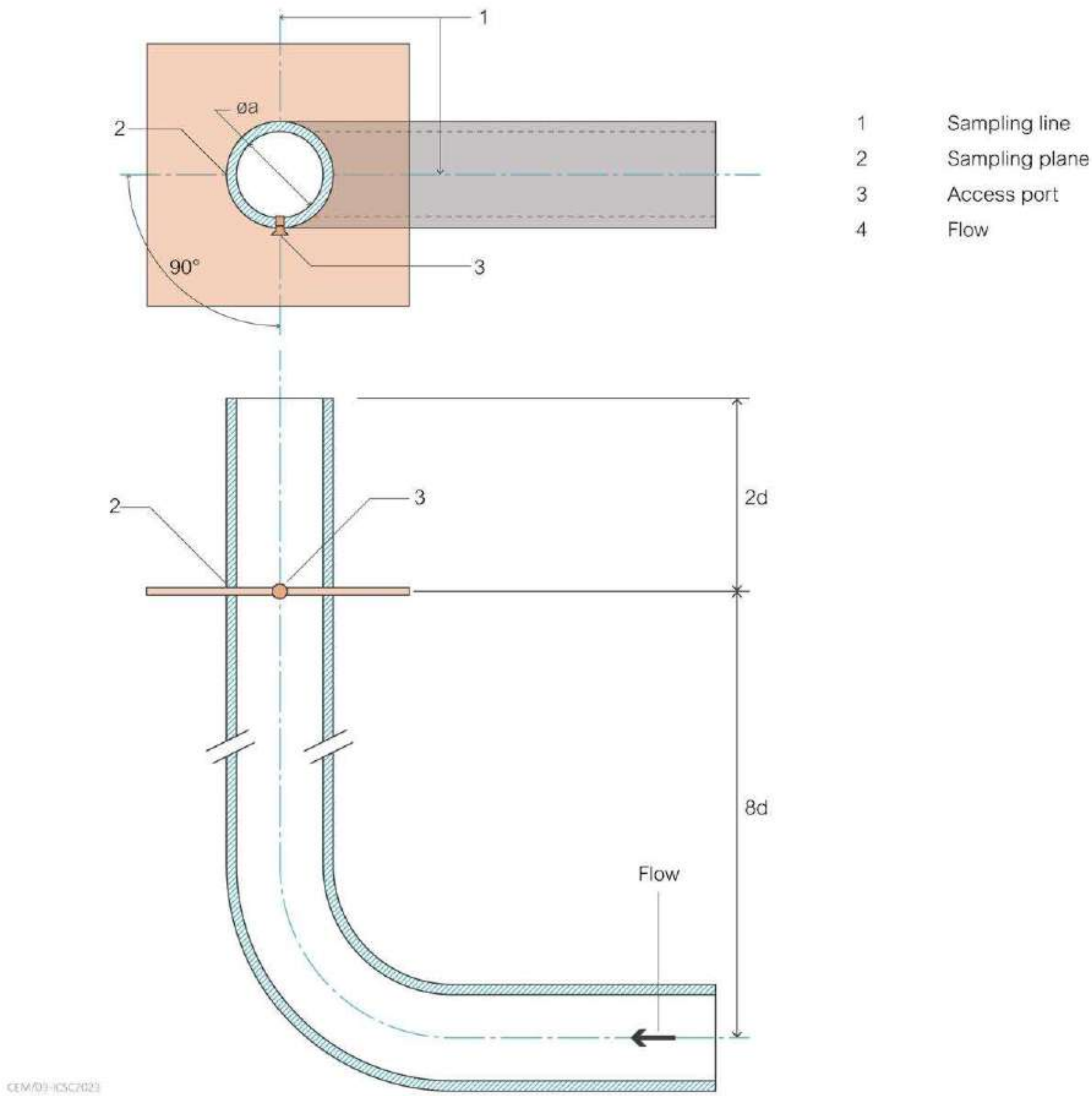

Figure 3 Measurement site and section of duct for CEMS installation (CPCB, 2018)

In the EU, EN 15259 sets the criteria for the selection of measuring point and port locations. Determining the suitable location and position requires the use of gas flow monitors and other supporting methods.

PM CEMS calibration is performed by manual isokinetic sampling as per BS EN 13284-1, IS: 11255 Part 1 or EPA method 17 or EPA method 5 or BS ISO 9096:2003. During the construction of the stack itself or during the application of provisions to install monitoring systems, the operator must follow the prescribed guidelines (Emission Regulation Part-III) of the CPCB.

Since the installation of multiple CEMS may be required in a stack for monitoring various pollutants, multiple port holes in a plane may be needed. This must be achieved without affecting stack stability. The installation of multiple systems must be coordinated to ensure that each does not affect any of the others due to proximity effects. Therefore, as a best practice, CEMS and other monitors are installed at a defined plane, distance, and angle to ensure correct implementation. Figure 4 shows the recommended mounting location and position of CEMS in the stack.

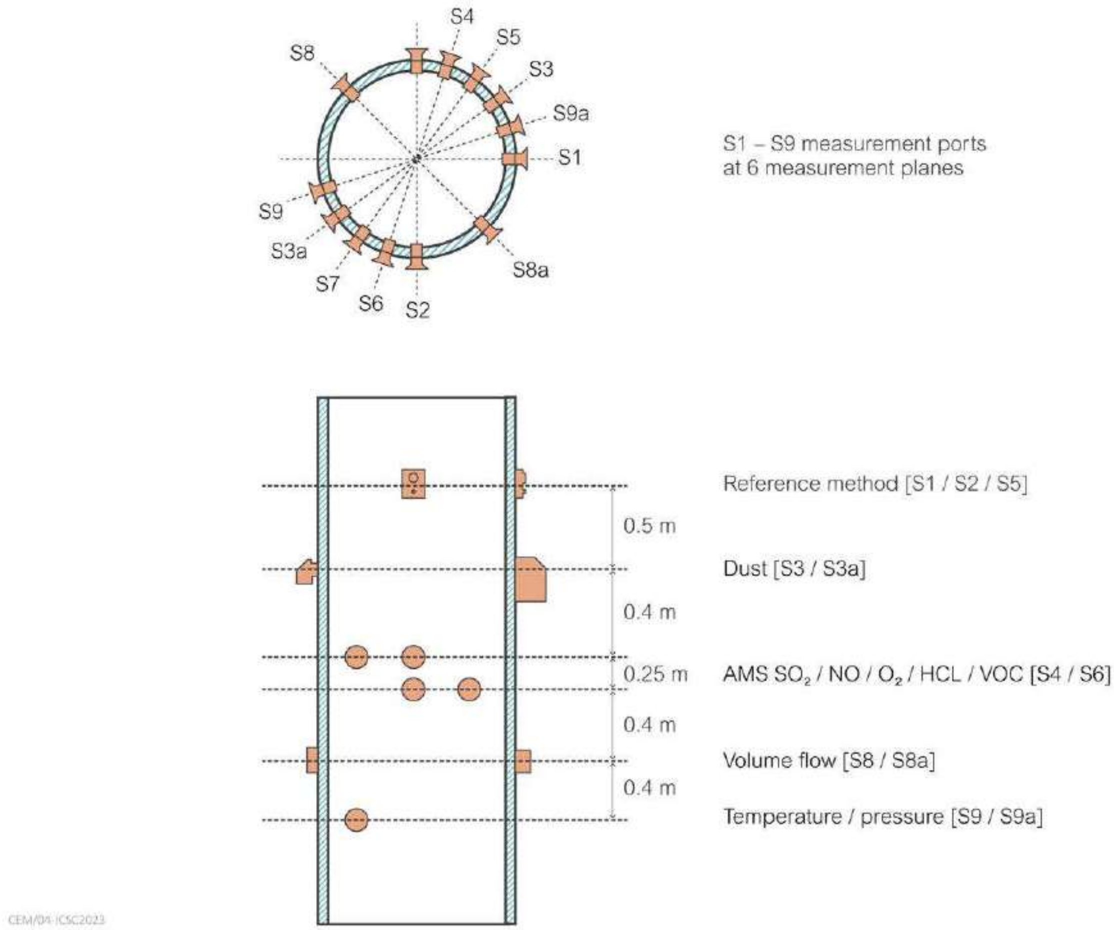

Figure 4 Schematic of mounting location and position of CEMS (CPCB, 2018)

As shown in Figure 4, there are clear instructions for the positioning of CEMS and reference methods in a stack. In situations where access may be limited for CEMS maintenance and manual sampling, the manual sampling port may be shifted 30–50 cm to the right or left at the horizontal plane of the CEMS port. For gaseous CEMS the same plane can be shared. In situations where a different location is chosen, the homogeneity of the flue gas should be confirmed by a stratification study and approval of the identified location must be confirmed by the relevant regulatory body (SPCB/PCC).

The PM sampling point or plane should be in a straight length of stack or duct, ensuring that the angle of gas flow is less than 15 degrees, no local negative flow is present, the minimum velocity is higher than the detection limit (3 m/sec) of the method used for the flow rate measurement (for pitot tubes, a differential pressure larger than 5 Pa) and the ratio of the highest to lowest local gas velocities is less than 3:1 (CPCB, 2018).

The physical installation of the CEM system should be carried out using proper sample ports and flanges to ensure that the system is safely and firmly installed, with no risk of becoming displaced or damaged. CPCB's Emission Regulation Part-III (CPCB, 1985) recommends the number of sampling ports (standard flanged pipe of 0.10 m of inner diameter and 0.15 of bolt circle diameter) required for manual sampling and monitoring:

- Two sampling ports (mutually orthogonal) for a circular stack of less than 2 m diameter; and
- Four sampling ports (mutually orthogonal) for a circular stack of more than 2 m diameter.

CEMS installation should not occupy the ports reserved for manual monitoring. These sampling ports fulfil the requirement for the minimum number traverse points (4 to 52 number) to be covered during manual monitoring, depending on the internal diameter of the stack. As per Emission Regulation Part-III (CPCB, 1985), the monitoring platform should be equipped with the required facilities and provisions in terms of strength, loading access, safe approach, number and position of sampling ports, proper and safe power supply, and all appropriate safety measures. Some of the general points to remember for an adequate monitoring platform (CPCB Guidelines) include:

- A strong platform with a safe approach/ladders/stairs;
- If the mounting location is >45 m high, then a proper staircase/elevator is required;
- Monkey ladders are not preferred for heights > 30 m from the ground;
- In stacks with vertical ladders, they should be caged with a landing platform at every 10-12 m;
- The ladder must be strong and well maintained and should continue through the platform to some distance above to allow for safe access and landing;
- The platform must be fitted with a railing at least reach 1.2 m in height;
- The minimum platform width for metallic stacks is 800 mm and for concrete stacks it is 1000 mm;
- All the cables and instrument air tubing should be properly laid and clamped;
- The power supply must be secure, uninterrupted, properly earthed and fitted with lightning arrestor wire line; and
- A proper instrument air connection is required.

The operator should ensure adequate protection of the CEMS from harsh climatic conditions (such as high temperature, direct sunlight, and rain) by providing a cover, weather shield or other form of protection a safe distance above the instrument(s) or the platform. Alternatively, the system can be installed away from direct interaction with ambient weather. PM CEMS should not be exposed to direct strong sunlight to avoid any interference.

The correct positioning of a CEM system should be confirmed after installation:

- Installation at the correct position and location with proper approach;
- Correct alignment of equipment;
- PM CEMS installed in a horizontal plane and gaseous CEMS protruding downwards in the flow direction of the flue gas;
- Proper setting of equipment and components;
- Correct setting-up of measuring range (span value of 2.5–3 times that of emission limit value);
- Properly connected and terminated heated sampling line where applicable;
- Provision of clean, dry instrument air supply where required;
- No leakage in the sample tube;
- Reading clearly visible at equipment/analyser and attached data handling system PC;
- Heating of probe and analyser where required;
- System of cooling and condensate discharge where required (safe discharge of the highly acidic condensate into a waste water treatment facility);
- Controlled temperature environment for analyser where required;
- Data transfer system architecture as per regulatory requirement. Direct data transfer from CEMS to server through data logger/IoT (Internet of Things) without any intermediate PC or any other device having the potential to manipulate the data;
- Properly connected calibration system with calibration gas cylinders where applicable;
- Remote calibration facility installed for gaseous CEMS;
- Flow meter must be installed; and
- Temperature monitor must be installed.

3.4 BEST PRACTICE IN OPERATION AND MAINTENANCE

CEMS are automated systems for emission monitoring. However, CEMS must be operated properly and maintained well to guarantee valid results. There are two forms of guidance to be followed to achieve this: the manufacturer's manual, which details the equipment's O&M requirements and the timelines for them; and the regulatory requirement for O&M, especially zero and span drift checks and periodic calibration. It is also important to understand that if the CEMS operates in a harsh environment and tough conditions, they require more frequent maintenance than that outlined in the manufacturer's manual or the regulatory guidelines.

In larger plants where there are many CEMS installed, the operator often hosts a staff member who works on behalf of the CEM supplier or manufacturer to carry out O&M. This, however, is not true for the majority of the plants in India. In most of these plants, there will be an internal CEMS team of technicians to look after the CEMS. However, in all instances it is advisable for the responsible team to be trained in CEMS O&M processes. The operator and responsible team need to be familiar with the manufacturer's instruction manual for CEMS to understand the product and its minimum O&M requirements. AMC with the CEMS supplier is suggested.

The CEMS team must perform zero and span drift checks, comparison with the standard reference method (SRM), calibration and recalibration according to the national guidelines, which currently require:

- Full calibration (drift, linearity, detection limit, output, operating temperature, and other relevant parameters) before installation of certified CEMS (see previous section).
- Demonstration of meeting the performance specification for both certified and non-certified CEMS. The performance specification is recommended by the CPCB and shown in Table 6.
- Gaseous CEMS: recheck health and data accuracy and reliability, following multi-point calibration (at least 03 span concentrations, that is three different calibration gas concentrations using SRM.
- PM CEMS calibration using iso-kinetic sampling: 9 points calibration (3 loads x 3 points/samples) during installation, after every one year and on any change in solid fuel and other process conditions. Installation that does not fit in 8D/2D criteria should follow 4D/4D criteria and, in this case, 09 points calibration (3 loads x 3 points/samples) is required.
- PM CEMS - monthly (for example the first Friday of the month at 10 am) value comparison with SRM value (replicate sample). In case of deviation in dust factor or more than 10% deviation from SRM value, recalibration using a triplicate sample is required.
- PM CEMS: dust factor changes only after full calibration and on approval from CPCB/SPCB or one week of intimation (request submission) to them.
- Gaseous CEMS - data comparison and calibration verification every six months by approved laboratories (until laboratories are approved or empanelled for CEMS work, EPA accredited and NABL accredited laboratories for regular environmental monitoring can carry out this work).
- Gaseous CEMS: daily zero drift check. If the daily drift exceeds the limit (as per instrument manual) continuously for five days, recalibration is required.
- Gaseous CEMS: zero and span drift checks to be carried out every fortnight (Friday, 10 am), recorded and the drift should be adjusted to the appropriate value.
- Gaseous CEMS: zero and span check using only certified zero air, instrument air, span gas/gas filled cuvette, built-in analyser-specific zero/span modules, or gas diluters, and not using ambient air.
- Gaseous CEMS: calibration verification every six months and after changing the lamp for DOAS, NDUV, NDIR, and laser-based CEMS.

- Both PM and gaseous CEMS: recalibrate after any major repair and replacement of component.
- Intensity check of lamp every fortnight for both PM and gaseous CEMS.
- Data capture, ensuring >85% data capture.

The operator must establish requirements for the frequency of cleaning and other maintenance of CEMS in consultation with the supplier's after-sales support team, taking site-specific issues into account, such as high dust situations. The CEMS data must be monitored with respect to process conditions and in relation to the SRM/manual monitored data. If necessary, remedial action should be taken according to the guidelines. If a CEM system becomes out of order:

- Immediately consult the supplier/manufacturer's after-sales support team and take immediate corrective actions;
- Immediately communicate the issue to the regulators through the proper channel (through data handling software, text, or email, as per respective regulatory instruction) and clarify ongoing or upcoming data gaps or inconsistencies; and
- Inform the regulators immediately, and in advance where possible, in cases of abnormal conditions such as plant start-up, shut-down or air pollution control malfunction. This will inform the regulators of possible emission exceedance situations and allow them to be treated appropriately.

TABLE 6 PERFORMANCE SPECIFICATION RECOMMENDATION FOR CEMS (CPCB, 2018)

SI No	Specification	Tolerance range
For CEMS – PM		
1	Zero drift between two servicing intervals	≤ ± 2% of full-scale
2	Reference point drift between two servicing intervals	≤ ± 2% of the reference value range
3	Linearity	Difference between analyser value and reference value ≤ ± 2 of full scale (for 5 points check)
4	Accuracy	≤ ± 10% of compared SRM value
For CEMS – SO_2, NOx, CO		
1	Zero drift (Weekly)	≤ ± 1% of the span
2	Span drift (Weekly)	≤ ± 1% of the span
3	Linearity	≤ ± 1% of the span from the calibration curve
4	Accuracy	≤ ± 10% of compared SRM value
For CEMS – O_2, CO_2		
1	Zero drift (Weekly)	≤ ± 1% of O_2
2	Span drift (Weekly)	≤ ± 1% of O_2
3	Linearity	≤ ± 1% of O_2
4	Accuracy	≤ ± 10% of compared SRM value or within 1% of O_2

The operator must be aware of any CEMS alarms in order to avoid abnormal operating conditions, non-compliance, and other issues to facilitate quick corrective action. They must also maintain a record for every CEMS O&M event with a time stamp.

The CEMS team must understand the basic O&M processes, recognise problems and handle issues as they arise. This should be a continual learning process to allow the internal team to solve simpler problems inhouse and without being dependent on the supplier/manufacturer's technical team. However, it is advised that the operator should resolve significant problems in coordination with the manufacturer and seek guidance when required.

The CEMS team must also stay updated with technology development, changes in regulatory requirements and other necessary information to ensure the correct ongoing performance of CEMS at the facility.

3.5 MAINTENANCE RECOMMENDATIONS FROM THE MANUFACTURER

In addition to meeting regulatory requirements for compliance, CEMS users must also follow the manufacturer's manual for O&M of CEMS. Different technologies have different components and therefore require individual O&M processes. The design and level of automation will determine the electronics, electrical components, and software and this may vary widely among manufacturers and models.

The operation of the device is specific to the technology, so the requirements vary with CEMS models and the manufacturer. Once a suitable technology is selected and installed correctly, the device should work automatically without manual intervention until a maintenance problem arises. Every deviation from the normal operation of the CEMS should be regarded as a serious indication of functional impairment. The deviations include:

- CEMS switched-off or non-functional;
- Warning/malfunction displays;
- No display on multipoint control unit (MCU) LCD;
- LED light of the sender/receiver is not ON;
- Significant drifts in measured results;
- Increased power consumption;
- Higher temperatures of system components;
- Monitoring devices triggering;
- Smells or smoke emissions;
- Heavy contamination;
- Drop or variations in sample gas flow to the analysers; and
- Where applicable: excessive or very low, to no, condensate from sample gas cooler.

Some models have in-built automated alarm and maintenance systems (such as fail-safe shutters, purging, cleaning and alignment correction) which require low manual intervention but are sensitive to mishandling. Others may be less automated and require more manual handling during maintenance. While carrying out O&M there will be equipment sensitivity to be considered – equipment safety against moisture, high temperature, fire, electric discharge, and dust contamination. But there is also a safety requirement for the operator to avoid potential health hazards (such as electric shock, exposure to hot and toxic flue gas, fire, and hot metallic components). It is therefore essential that only skilled, trained technical staff with adequate personal protection equipment (PPE) carry out this work. The following are recommended for the maintenance of CEMS:

- Take note of potential malfunctions from the possible indications – errors, warnings, malfunction messages, maintenance alarms and so on, and diagnose the problem either manually or using in-built diagnostics.
- In situations of concern, the operator should immediately switch off the device, as long as it does not lead to collateral malfunction or damage.
- Measures should be taken to assess and avoid the potential hazard of electric shock and exposure to hot and toxic flue gas, hot metallic equipment and fire.

For sensitive components which may suffer serious damage, only an authorised technician, preferably from the manufacturer/supplier, should handle the situation. This should be under maintenance contract conditions.

Some of the fundamental maintenance requirements of CEMS and the respective recommendations from manufacturers are summarised in Table 7.

TABLE 7 MAINTENANCE RECOMMENDATIONS (SICK S700 EXTRACTIVE GAS ANALYSER – OPERATING INSTRUCTIONS)

Equipment/technology	General components	General maintenance recommendations
PM CEMS – **Transmissometer scatter**	Sender/receiver unit, Flange with tube Connection cable and reflector Multipoint control unit (MCU) Lght and dust protection tube Fail-safe shutters MCU integrated or external purge air unit and hose Duct Operating and parameter programme in PC Power supply External purge air unit (option) Data connectivity system/components	**Maintenance of sender/receiver unit** Clean the outside of the sender/receiver unit and reflector at regular intervals, removing deposits with water or mechanically using suitable auxiliary means. Clean the optical interfaces when deposits can be seen or excess contamination is indicated or alarmed by the device automatically. For sender and receiver maintenance: put the equipment in maintenance/adjustment mode (or as it's called for that particular model) following the steps in the instrument manual, remove or open the enclosure, detach sender/receiver electronics from the mounting attachment (or in automated one, bring the shutter into cleaning position) and clean the glass plane with optics cloth. While removing or swivelling the attachment off the mounting flange, cover the flange. Post cleaning, following the instructions, bring the components to original position and resume the measuring mode. **Maintenance of reflector** To clean the reflector: follow the instructions in the manual, in the maintenance mode, swivel enclosure cover, detach the purge air system, (and where required put the shutter in cleaning mode), remove the reflector and clean the glass plane and reflector optics using an optics cloth. Post-cleaning, put the components back in position and resume measurement mode. If available, use the equipment trigger function check to evaluate any contamination. Repeat the cleaning and process until the system functions as it should before returning it to original set-up and measuring mode. **Maintenance of purge air supply** Check the running noise of the blower at regular intervals (an increase in the noise level can indicate a blower failure), check for any damage in hoses, and check the filter element for contamination which may reduce the purge air volume. The filter element can be exchanged if severe contamination is visible. Dust load and wear and tear on filter element depend on ambient air ingress, which may vary for every installation- a frequent check (fortnightly) is advised in the beginning which can later be optimised. Filter housing and cover should be cleaned with a cloth and brush. For wet cleaning, a wet cloth should be used followed by a dry cloth. If the MCU has an integrated purge air supply, thisshould be cleaned following the instruction manual. Immediately shut down the CEMS when the purge air supply fails.

		If the equipment is to be put out of operation for a longer period of time (eg one week), dismantle the sender and receiver, disconnect the electricity connection, loosen the MCU, turn-off and remove the purge air supply (never interrupt the purge air supply when sender /receivers are fitted/online) and close and secure the hose, flange cover and opening. If the equipment cannot be dismantled, continue to purge the air flow. Wherever the flange is opened, be cautious about the potential hazard of hot, pressurised, and toxic flue gas. In the case of specific malfunctions and warning messages – the operator must refer to the manufacturer's manual and take corrective actions accordingly (online or onsite depending upon the criticality of the problem) with the after-sales support team of the manufacturer. **Maintenance of scattering PM CEMS** Generally, maintenance work is limited to cleaning and securing the purge air supply function. Maintenance should be carried out as guided by the manufacturer's manual. Normally the manufacturer suggests a maintenance interval and the operator should either use this interval or set a more frequent intervalThe interval should be set depending on existing operating parameters such as dust content and state, gas temperature, how the equipment is run and ambient conditions. In harsh Indian conditions, more frequent maintenance is usually required. In general, maintenance involves connecting the MCU to PC, getting access (following the instruction manual) and setting-up maintenance mode. The cleaning is then carried out, as described above, the equipment is reassembled, and measurement mode is resumed. **Maintenance of electrodynamic PM CEMS** Check the instrument, controls, and indicators for visible damage. Check the purge air flow, if a purge air unit is installed. Remove the instrument with the measurement rod from the stack. Inspect the rod for mechanical or corrosive damage; clean dirt from the rod using a cloth or paper towel; a mild detergent or isopropyl alcohol can be used, if necessary. Uncoated steel rods can be cleaned using a steel brush. PTFE-coated rods must only be cleaned using a cloth or paper towel. Re-install the instrument in the stack and tighten the screws on the flange. Power-up again
Gaseous CEMS	Sampling probe Flanges	The technology of gaseous CEMS varies widely by parameter and manufacturer. They are complex and sensitive to mishandling which may result in serious damage and a safety hazard. For proper functioning and maintenance of CEMS, the operator/ CEMS team must maintain: • sufficient ventilation in the analyser cabinet to avoid overheating/burning

	Heated sample line (for extractive type) Sender/receiver unit (path/cross duct type) Analyser cabinet Analyser modules with display and control panel Chiller Condensate trap Inbuilt calibrator/cuvette in analyser and /or gas cylinders connected with calibration system MCU integrated or external purge air unit and hose Operating and parameter programme in PC Power supply, external purge air unit (optional) Data connectivity system/components (Gaseous CEMS components may vary widely depending upon the parameters and technology of measurement)	• proper mounting with clean and suitable connectors, gasket and glands etc. or it may damage the CEMS • no-vibration environment or it may loosen the fitting, causing a gas leak, and damage the CEMS. • no direct sunlight or exposure may make components brittle, and cause overheating and related damage • caution for fire hazard eg not removing cables, plugs or lamps when power is on. Use of suitable technology and cabinets (eg ATEX, IECEx compliance) and extra precautions for an explosive environment • proper electrical connection and circuit breaker as per the requirement certification, in compliance with the relevant regulation to avoid dangerous electric shock • connections free from loose parts, dirt, oil and grease and solvent which may cause ignition in a particular environment, such as if exposed to oxygen The operator or CEMS team responsible for maintenance must beware of dangerous voltage from open devices, hot/toxic/corrosive process media, electrostatic discharge, radiation, use of impermissible spare parts and, most importantly, impermissible repairing and maintaining of sensitive components without authorisation, expertise and consultation with manufacturer/supplier's technical support. Only authorised maintenance people, equipped with PPE and means for protection from hazards should be allowed to work. All maintenance should be carried out with due reference to the manufacturer's manual and authorisation and the same must be recorded. For any repair and change of location of the analyser – switch off power to CEMS, stop gas flow through the analyser, switch off external pumps, purge the sample gas path, switch the analyser off, disconnect the power plug, disconnect all hoses/tubing connections from the rear of the analyser, empty condensate trap, unscrew all pipes, as and if applicable for the particular technology and system configuration. Clean the display gently with a moist cloth. Doors and panels should also be cleaned with a moist cloth /sponge with washing liquid, avoiding any chemically and mechanically aggressive cleaning agents. The CEMS cabinet interior can be cleaned with a compressed air gun to remove dirt. The replacement of any internal spare part must be done by authorised and expert technicians. It may require various corrections and compensations (eg temperature compensation) or replacement of certain parts, which must be performed by an expert in a suitable environment. Incorrect fitting/replacement and missing components may lead to inaccuracy. Replacement of fuses (using only suitable and acceptable models) must be done carefully, only after the power supply is off.

		Filter contamination/choking may lead to reduced gas flow. For the replacement of filters (both fine and coarse), follow the advice from the manual; open the filter housing, replace the contaminated filter in the right direction of gas flow with a new one and reassemble. Dispose of the old filter as residual waste. Flow reduction may also result from lower pump capacity (which can be increased) or a faulty pump (which needs immediate replacement). The condensate trap should be emptied from time to time, following switching off the pump and disconnecting the analyser power supply. The condensate should be discarded carefully depending on its composition. If the condensate trap is not emptied or if it is not maintained, condensate may spill into the analyser and destroy it. When a chemical sensor gets consumed or reaches its end of life, it needs to be replaced (generally a plug-and-play set-up), with a suitable new one, or faulty data will result. Chemical sensors often contain toxic chemicals and therefore safety measures should be taken when handling them. The sample gas line may also need to be flushed using nitrogen or ambient air before changing the sensor. The used sensors are hazardous/electronic waste (depending on the parameter they measure; an O_2 sensor contains acetic acid, and an H_2S sensor contains sulphuric acid). Therefore, they should be disposed of appropriately, as per the regulatory mandate. Some of the sensors (such as paramagnetic O_2 sensors) should be replaced by trained technicians. It is advised that they are changed at the manufacturer/supplier's facility, or it may lead to an inaccuracy in reading. Gaseous CEMS systems are automated and therefore if any abnormal situation occurs, it is displayed as errors, faults and warnings on the display panel (eg temperature beyond tolerance, voltage beyond tolerance, AUTOCAL drift beyond tolerance, sensor status, low flow and faults) which indicate that maintenance and replacement are required. The terminologies and message/alarm formats may be different for each technology and manufacturer, but they should be followed by the operator and responsible team in a timely manner. Any disposal of sensors and CEMS (hazardous and electronic waste) must be as per the regulatory guidelines. Analyser manufacturers recommend a maintenance plan for the particular CEMS, based on their field and laboratory tests and certification tests etc. which should be followed. The frequency of various maintenance routines may be customised later as per the practical operating experience, keeping the regulatory requirements in mind. An example of the maintenance plan for a gas analyser by SICK is presented below for reference:

MAINTENANCE PERIOD	MAINTENANCE WORK
1–2 days	Make a visual inspection to check the operating state of the analyser, cable connections and peripherals, drift checks
1 week–1 month	Run calibrations, check important electrical connections and signals, and check the flow meter. • These checks can be carried out using in-built hardware check tools • The connected stations should be informed of checks beforehand • External processing of the analyser can be terminated during this time
3 months	Check leakage in gas lines for hazardous gases • Check for gas leakages which may be toxic, corrosive and explosive • Stop the gas feed • Take the analyser out of operation • Remove the escaping gas (purge/vent/suction-off) systematically • Check gas pressure at various points on gas-path (eg hose, tube etc) • Perform leak test • Check for leaks and confirm the integrity of the enclosure (for explosive environments)
6 months	Check leakage in gas lines, built-in gas pump, and internal safety filter
1 year	H_2O calibration
1–2 years	Full calibrations (for internal cross-sensitivity compensation)
1–5 years	Replacing O_2 sensor module

Note: these are minimal maintenance requirements recommended by the manufacturer; the actual need for maintenance, both the type of maintenance work and the frequency, comes from experience. In addition, if the regulatory requirement is for more maintenance and at a higher frequency, this must be followed. For instance, Indian CEMS guidelines ask for full calibration every six months.

- There are a few general troubleshooting options for the operator when the analyser does not work at all. However, it is wise to follow the manufacturer's instructions for troubleshooting, if they offer different recommendations.
  - Power cable is not connected; check the power cable and its connections.
  - Main switch is off; check the (external) mains power switch.
  - Power supply has failed; check the power supply (eg, power socket, external fuses)
  - Internal power fuse is defective; check the internal power fuses
  - Internal operating temperatures are not correct; check relevant malfunction messages
  - The sample gas delivery is not working correctly
  - The internal software is not working correctly. It can only occur with complex internal malfunctions or after strong external influences (eg strong electromagnetic interfering pulse); switch off the analyser, wait for a few seconds, then switch on again.
  - An internal overheat protection (usually a circuit breaker) has triggered; rectify/replace circuit breaker and consult the manufacturer's support team.
- The operator must follow the system messages, errors and take corrective action. The messages may include calibration active, sensor failure, calibration cuvette fault, temperature fault, temperature compensation fault, condensate fault, gas flow fault, flow signal fault, internal voltage fault, pressure

<table>
<tr>
<td></td>
<td></td>
<td>
<table>
<tr>
<td></td>
<td>signal fault, IR/UV source fault, drift fault, no reports and remote PC control active etc.

Similarly, the manufacturer's instructions for a particular device should be followed in case of abnormal, incorrect and unstable data.
For the shut-down procedure, the specified instructions must be followed. The process operator and the regulator should be informed and marked appropriately in the system, so the data during the shut-down period is not taken for analysis.
</td>
</tr>
</table>
</td>
</tr>
<tr>
<td>Mercury gaseous CEMS</td>
<td>Thermal converter and cell
Optical unit
Electronics with data interfaces and heater control
Power supply
Fuse
Ejector
Sample gas line (inlet and outlet)
Vaporiser for test gas generator
Pressure control module
Valve block
Instrument air conditioning
Test gas generator
(mercury CEMS components may vary widely depending on the monitoring technology used)</td>
<td>Mercury CEMS is highly sensitive and designed to monitor gaseous mercury emissions at an ultra-low concentration. Therefore, specific care is required for maintenance which is recommended by the manufacturer of the particular technology. A sample maintenance schedule suggested for Mercury CEMS from SICK Gmbh. (MERCEM300z) is as follows:
<table>
<tr>
<th>Maintenance frequency</th>
<th>Actions (Maintenance schedule for MERCEM300z</th>
</tr>
<tr>
<td>At least weekly</td>
<td>
Visual check of the plausibility of measured values in each device and the control room.
Visual check for any pending or active status signals.
Check lines, hoses, exhaust line and connections.
</td>
</tr>
<tr>
<td>At least quarterly</td>
<td>
Visual check of the cabinet for corrosion, noise and unusual odour
Visual check of the gas sampling line system
Check air-dryer LED
Clean air conditioner
Check sample gas flow
Check drift
</td>
</tr>
</table>
</td>
</tr>
</table>

Half-yearly	• Check test gas generator solution level, unusual odour and replace etc. If the solution is kept for longer than the prescribed time, it may contaminate the device. • Post replacement of the test gas generator, carrying visual inspection of leaks from the hose connection should be checked and then one calibration is carried out. • Test gas generator solution contains mercury which is toxic and therefore, shall only be changed by an expert or the manufacturer's technical support team.
At least once a year	• Replace expendable and wearing parts such as the spare parts of lamps, thermal elements, ejector blocks, sampling filters, filter elements of instrument air conditioning, hose filters, housing etc.
At least every two years	• Replace parts such as heating cartridges, resistors etc.
At least five-yearly	• Replace spare parts of the lamp assembly, optic housing, bellow seal-valve

Note: As for other CEMS, the maintenance schedule must follow the minimum regulatory mandate of maintenance frequency.

- Actual replacement frequency depends upon the wear and tear of the particular spare part
- Only suitable and original parts should be used
- While carrying maintenance, the device should be kept in maintenance mode
- For Mercury CEMS equipped with a catalytic converter: check converter efficiency at least half-yearly
- Post-maintenance, while resuming the operation, the cabinet door should be closed, or else external temperature may affect the reading. Post-maintenance, the device takes some time to stable the reading

- In case of non-functioning of the device, the power switch and fuses should be checked. For troubleshooting, the main switch of the device can be switched off, and should be restarted after a brief pause.

		• In the case of abnormal data, the operator should check the installation, measuring path and valves etc and then adjust the device correctly. • Error and malfunction messages should be checked on display and appropriate recommended actions taken to rectify the problem. These messages such as – configuration error, communication error, beyond tolerance (temperature, cell flow, cell pressure, vaporiser temperature, ambient pressure, ambient temperature and lamp energy etc), lamp ignition failure, drift fault, operation check and logbook problem etc – may vary from technology to technology and manufacturer to manufacturer. • All the maintenance activities of the Mercury CEMS must be recorded.

Note: Maintenance recommendations have been prepared based on operation manuals for various CEMS technologies across different technology providers.

3.6 COMMENTS

For a CEM system to be reliable as a compliance tool and for evaluating plant performance, the CEM must be fit for purpose, installed correctly, and maintained adequately to ensure ongoing reliability. This requires the operator plan to follow the guidelines even before any purchase is made, that records are kept confirming that all is well and, if not, to help identify where errors have occurred, and to allow inspection by third parties at any point to ensure that all standards have been met.

4 QA/QC – THE EU APPROACH

Once a source has selected the CEMS to use, based on the regulated requirements summarised in Chapter 2, the operator must follow stringent guidelines for quality control and quality assurance (QA/QC) to ensure that the equipment is installed and operated correctly over its lifetime. The approaches for this are different for the EU and the USA and India allows the use of both approaches. This chapter focuses on the EU approach and Chapter 5, will describe the US approach.

The European Committee for Standardization (CEN) Technical Committee 264 (CEN TC 264) produced the first standard which addressed the quality assurance of CEMS in 2004. EN 14181; Stationary source emissions - Quality assurance of AMS/CEMS. The standard describes the procedures required to ensure that CEMS used in Europe are capable of meeting the 'uncertainty' requirements on measured values defined by the legislation (the relevant EU Directives or national legislation) (CEN, 2004).

'UNCERTAINTY' RELATES TO THE MARGIN OF DOUBT THAT EXISTS FOR THE RESULT OF ANY MEASUREMENT, AS WELL AS THE SIGNIFICANCE OF THE DOUBT. FOR EMISSION MONITORING, MEASUREMENTS ARE REPORTED WITH A PERCENTAGE CONFIDENCE RANGE, WHICH IS CALCULATED BASED ON THE EQUIPMENT USED AND THE APPLICABLE CONDITIONS AT THE TIME OF MEASUREMENT.

Only suitability-tested measurement and data acquisition systems can be used for statutory measurement and monitoring in Europe. Under European standard EN 14181, the quality assurance procedure for CEMS is defined in three different Quality Assurance Levels: QAL 1, QAL 2, and QAL 3, in sequence, summarised as follows:

- QAL 1 covers the suitability of equipment, before or during the purchase period of the CEMS. QAL1 is therefore covered under the EU certification process described in Chapter 2;
- QAL2 covers the validation of the CEMS in the correct position and conditions following installation; and
- QAL3 covers the quality control of the CEMS during ongoing operation at the site.

Annual surveillance tests (AST) confirm the completeness of the QAL 3 activities and the calibration functions/factors taken during QAL 2. It is performed by an authorised agency or laboratory.

Figure 5 shows the flow of QAL testing.

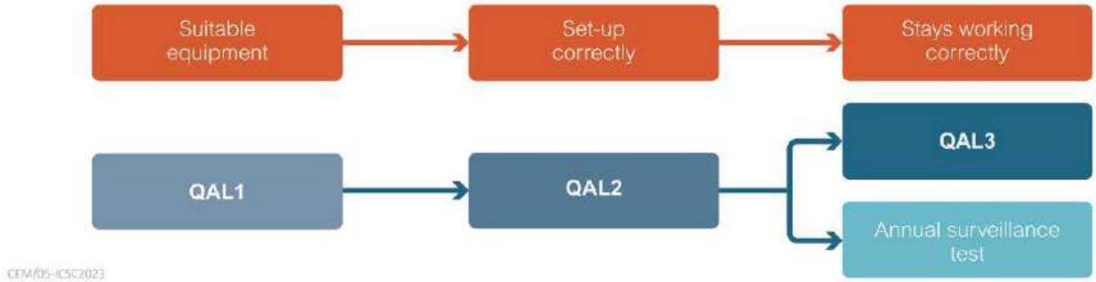

Figure 5 Process flow representation of QAL levels under EN 14181 (CEN, 2021)

UK M20 GUIDANCE

The UK Environment Agency (UKEA) produced a method implementation document (MID) called M20 (EA UK, 2021). M20 supports the application of EN 14181, and a related standard, EN 13284-2 (Stationary source emissions - Determination of low range mass concentration of dust. Part2: Automated measuring systems) by providing elaboration on the following topics:

- Monitoring requirements for large combustion plants and waste incinerators
- The selection process to ensure CEMS meet the performance requirements of the EC Directives
- Demonstration of CEMS suitability through MCERTS product certification
- Confirmation that CEMS meet uncertainty allowances
- Assuring that CEMS are positioned correctly
- Applying functionality tests to confirm correct installation and operation
- Calibration using a standard reference method (SRM)
- On-going surveillance to assure the correct operation of CEMS, by examining drift and precision
- Annual surveillance tests.

Also included within the M20 document is the associated Method Implementation Document (MID) for EN 14181. For anybody carrying out work under EN14181 and 13284-2, this information is required in conjunction with the standards. M20 supplements and supported EN 14181 but it does not re-state all the provisions of the standard. M20 also covers the requirements for EN 13284-2 which is an application of EN 14181 for particulate monitoring CEMS. The M20 document is used as a basis for accreditation to the requirements of EN 14181 under the MCERTS scheme for manual stack emissions monitoring in the UK.

To be acceptable for use at installations covered by EU Directives, CEMS must be proven suitable for the measurement task, including confirming that it can perform over the expected range of emissions, and can operate effectively on the specific process application (some CEMS can be affected by site-specific factors such as moisture, heat, or vibration).

EN 14181 is used to confirm that the total uncertainty of the results obtained from the CEMS meets the specification for uncertainty stated within the applicable regulation. The following sections outline the minimum requirements under QAL 1, 2 and 3 and AST in Europe.

4.1 QAL 1

Under EN 14181, QAL1 is the instrument type approval performed by an accredited laboratory or authorised agency such as the TÜV in Germany or SIRA in the UK (*see* Section 2.1). It is the manufacturer's responsibility to have their equipment tested and approved.

The evaluation of suitability or uncertainty calculation for type approval is estimated during certification using procedures described in European standard EN 15267; CEMS are certified only if the certification is performed according to this standard.

Before focusing on EN 15267, it is useful to consider the guidance provided by the UK. The UK Environment Agency (UKEA) has produced a document, M20, which summarises the requirements under

EN 15267 in a simplified manner which helps users to follow the more complex EN 15267 guidance document. More detail on M20 is shown in the box.

The sections below summarise the EU requirements under QAL 1, 2 and 3.

4.1.1 EN 15267

EN 15267 is the European standard which ensures that a CEMS is fit for purpose when installed on a source. This is the standard that forms the basis of certification (QAL 1; CEN, 2017). It has four parts:

- Part 1 – the general principle
- Part 2 - the manufacturer's quality management
- Part 3 - the methodologies for all tests and evaluations
- Part 4 - portable or mobile automated emission measuring systems.

EN 15267 Part 1 specifies the general principles for the product certification of CEMS for monitoring emissions from stationary sources and ambient air. Part 1 also defines the responsibilities of the bodies that are part of the accreditation process: the manufacturer; the testing laboratory where the devices are tested; and the competent authorities and certification bodies. Following certification, the relevant bodies ensure that surveillance of the continued manufacturing and performance of certified CEMS is carried out periodically.

In some CEN member states, the competent authority delegates the responsibility for approval of CEMS to a Certification Body which has been accredited to EN ISO/IEC 17065 by national accreditation agencies/bodies. These approaches have evolved over many years and reflect the different administrative and legal arrangements that exist in different EU member states. In recognition of these different approaches, EN 15267-1 uses the collective term 'relevant bodies' when referring to competent authorities and certification bodies. For example, MCERTS for CEMS in the UK is an official certification scheme that falls under European Standard EN ISO/IEC 17065. CSA Group Testing UK Ltd, the certification body, runs this scheme on behalf of the UK Environment Agency (UKEA). CEMS equipment must be tested by laboratories and test organisations that have the EN ISO/IEC 17025 qualification, which is the internationally recognised standard for testing laboratories. CSA examines the results of the laboratory and field tests using a group of independent experts known as the Certification Committee.

The product certification process under Part 1 consists of sequential steps:

- Performance testing of CEMS;
- An initial assessment of the manufacturing quality; and
- Certification and surveillance.

Figure 6 shows the flow of certification under EN 15267-1, as summarised within the UK MCERTS certification process.

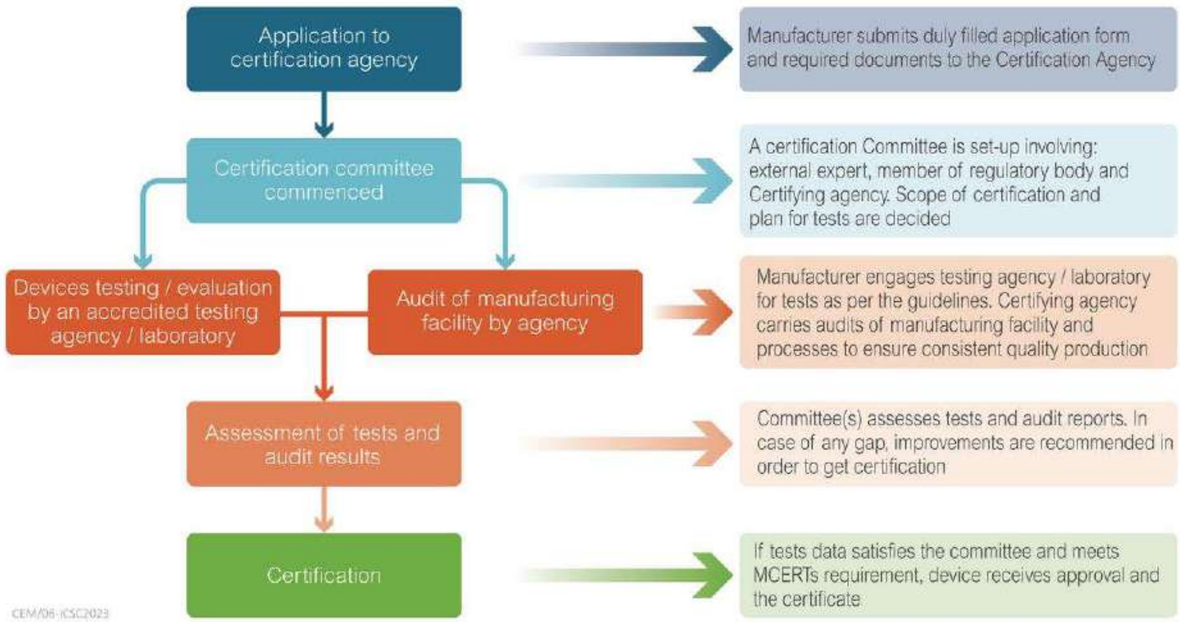

Figure 6 Process flow of the certification process under EN 15267-1 (CEN, 2017)

EN 15267 Part 2 covers the initial assessment of the manufacturer's quality management system and the post-certification surveillance for the manufacturing process. The quality management system ensures that the manufacturing facility can produce consistent products which meet the same standard of quality as the original model which was subject to testing and certification.

Since CEMS may undergo design changes during product life, it is important to ensure the changes do not alter their performance beyond that which has been certified. These design changes are defined as follows:

- Type 0 – Changes having no measurable influence on the performance of the CEMS
- Type 1 – Changes with a possible but insignificant influence which can be proved by testing
- Type 2 – Changes with significant influence on the CEMS.

Additional tests are required if Type 2 changes are implemented. The manufacturer must keep records and evaluations of any modification (software and hardware) of the certified CEMS. To control the changes, EN 15267-2 specifies the minimum requirements for the manufacturer's quality management system, for the initial assessment of the manufacturer's production control, and continuous surveillance of any effect of CEMS design changes on its performance.

EN 15267 Part 3 defines performance standards and test procedures under QAL1. These procedures are a combination of laboratory tests and field tests. Two identical sets of CEMS are evaluated. For extractive CEMS, this includes both the analyser and the complete sample handling system. The entire process may take from 6 to 30 months, depending on the performance of the device being tested. In the UK, it usually takes 1–2 months of laboratory tests and a minimum of 3 months of field tests. Test failures result in a requirement for extended testing.

EN 15267 Part 4 covers performance criteria and test procedures for CEMS which are only used for periodic measurements of emissions from stationary sources. This section of the standard was added in 2017 and only relates to discontinuous (periodic) measurements and/or portable/mobile CEMS for stationary source emissions. Performance testing comprises measurement techniques specified by a standard reference method (SRM) or an alternative method (AM), based on general performance criteria and test procedures. It includes the testing of the applicability and correct implementation of the QA/QC procedures specified in the method-specific standard.

4.2 QAL 2

QAL 2 begins during the installation of CEMS at the site, such as at the stack of a coal-fired utility. Even though a CEMS may be certified, it must still be tested to confirm it is fit for purpose when it is installed on the stack. This includes the calibration of the CEMS against nationally approved analytical methods which must be carried out by a test organisation accredited to EN ISO/IEC 17025 (or MCERTS in the UK), by a national body such as the German EA (Umweltbundesamt), or the UKEA (UKAS, 2023). The ISO/IEC 17025 standard specifies the general requirements for the competence, impartiality, and consistent operation of laboratories carrying out the calibration. It applies to all organisations performing relevant laboratory activities. Laboratory customers, regulatory authorities, accreditation bodies, organisations, and schemes using peer assessment all use this standard to confirm the competence of the relevant laboratories.

QAL 2 is carried out once during the installation of the CEMS and is then repeated every five years. QAL 2 covers:

- Installation of the CEMS;
- Functional test(s) of the CEMS;
- Parallel measurements with the SRM (standard reference method) for each parameter (as defined in the site's environmental permit);
- Data evaluation;
- Calculation of variability of the CEMS measured values;
- Testing of the variability of the CEMS measured values and validity of the calibration function;
- Reporting; and
- Storing of QAL 2 calibration factor(s) in the data acquisition handling system (DAHS) or analyser.

The test methods used in QAL 2 are outlined in Section 4.5.1.

4.3 QAL 3

QAL 3 refers to the ongoing monitoring of a CEMS, after QAL 2 and during normal operation. The industry or plant operators are required to monitor the stability and performance of their monitoring systems and perform the manufacturer-suggested maintenance and calibration procedures at the specified frequency as defined in the QAL 1 certificate. QAL 3 activities should strictly follow the recommendations in the instrument's operation manual. Active annual maintenance contracts (AMCs) from the instrument manufacturers are recommended for maintaining the functionality and accuracy of CEMS.

During QAL 3, operators can identify drifts in the zero/span levels, as compared to the levels determined during QAL 1, and can determine if the system has any additional needs for maintenance or service. If the measured drifts are beyond the specified limits, the CEMS must undergo maintenance/service. All the activities carried out under QAL 3 must be documented. All testing procedures are explained in more detail in Section 4.5.1.

4.4 ANNUAL SURVEILLANCE TEST (AST)

An AST is similar to the QAL 2 tests but it is carried out on a smaller scale by a similar agency as the QAL 2 activity. These mini-QAL 2 tests are functional 'spot tests' that map out the performance of a CEMS. The tests assess if the CEMS is functioning correctly, that its performance remains valid, and that its calibration function and variability remain as previously determined. These tests are carried out annually and full records must be maintained. The AST covers the following activities:

- Functional test of the CEMS;
- Parallel measurements with the SRM;
- Data evaluation;
- Calculation of variability of the CEMS measured values;
- Testing the variability of CEMS-measured values and validity of the calibration function;
- Reporting; and
- Confirmation of the completeness of the QAL 3 documentation.

If the CEMS fail to meet the performance requirements outlined within EN14181 for the AST, the problem must be rectified and a full QAL 2 undertaken. In the case of non-compliance with the requirement of EN 15267, the competent authority may withdraw the instrument certificate (CEN, 2017a). Issues such as changes to CEMS without sufficient documentation and without notifying the test house and competent authority, changes in the quality management process of the manufacturer which may affect the CEMs manufacturing process, and failure to conduct annual surveillance tests, may provide grounds for withdrawal of the instrument certificate.

4.5 QA/QC TEST PROCEDURES

As mentioned earlier, the calibration procedure required during the installation of a certified CEMS is referred to as QAL 2. Once the CEMS has been installed on the stack, a functionality test, including a check that the correct installation is performed to ensure that it is in full working order. Following this, the CEMS is calibrated.

Calibration of a CEMS during installation must be performed against a known or credible value; that is, the CEMS must produce an emission measurement value which agrees with a value which has been measured independently by a separate and trusted methodology. The calibration method varies for PM CEMS and gaseous CEMS.

For PM monitors, the QAL 2 procedure involves correlating the CEMS output with the dust concentration as determined by an SRM (standard reference method). This means comparing the results of the CEMS with data from a manual isokinetic sampling method, EN-13284-1 (CEN, 2017b). The calibration function is obtained by performing a statistical analysis of the resulting data points from the SRM method compared with the data from the CEMS. This is known as a variability test. The more data available across the range of potential PM concentrations, the more accurate the calibration will be. If it is possible to change the dust levels (concentrations) in the plant, 15 data points are obtained. If it is not possible to change the dust level and the emissions are below 30% of the emission limit value (ELV), then a 5-point calibration is performed. The same calibration procedure applies for gaseous CEMS except that different concentration tests of gas from gas cylinders are introduced for calibration purposes. It is important that the complete CEMS (including the sampling system) is calibrated and not just the analyser in isolation.

Following successful installation and commissioning checks, the CEMS system should be allowed to 'settle' in the installation, especially if it is a new process. Weekly zero and span checks should be carried out to ensure the stability of the CEMS. The zero and span checks confirm that the CEMS is operational over the entire range of emission concentrations that it must cover. The Indian guidelines specify a daily zero check and a fortnightly span check. These checks can either be performed by introducing surrogate samples, such as test gases, or by internally produced stability reports.

After a suitable period (up to six months after installation), a full calibration of the system can be undertaken. The initial calibration sets the system up according to the operating conditions of the process. If this initial period is carried out too early, there is a possibility that the system could drift due to process variance. After the initial calibrations (during installation and then once the process is settled), there should be an annual system check (Annual Surveillance Test, AST) to allow for further adjustment of the calibration range if required. The AST can be carried out in one day.

The system functionality test is one of the most important checks within QAL 2 and the AST. These tests are normally carried out by the equipment supplier under scrutiny from the process operator or test laboratory. The following sections outline the testing requirements for QAL 2 and 3 in Europe.

4.5.1 QAL 2 – initial calibration

Initial calibration starts on installation, and covers the following:

1. Functionality test of the CEMS including a check that installation is correct, according to EN 15259, EN ISO 16911-2, and the manufacturer's instructions.
2. Parallel measurements with the SRM and data evaluation.
3. Establishing the calibration function.
4. Determining the validity of the calibration function.
5. Calculation of the variability of the CEMS measured values.
6. Test of the variability of the CEMS measured values.
7. QAL 2 reporting.
8. QAL 2 calibration factor(s).

If the QAL 2 is not the first or initial QAL 2 (that is if it is a calibration which takes place after the detailed calibration performed during installation), then an AST may be performed instead, provided that at least 95 % of the CEMS values since the last AST are less than the maximum permissible uncertainty. At least every five years a complete QAL 2 test procedure must be performed. Each of these test procedures is discussed in the following sections.

Function or functionality tests

Function, or functionality, tests require that the installation and the measurement site meet the specified criteria. The functionality tests ensure that the CEMS is commissioned satisfactorily as defined in the supplier/manufacturer's instructions. The CEMS should show zero when a zero-test gas is passed through the system. If it does not, then the CEMS must be removed and zeroed using a test bench or similar system. If removal is not possible, a measurement path can be installed within the stack to enable a zero test. The functionality test is performed before calibration, preferably not more than one month before parallel measurements are performed by a recognised testing laboratory.

Attention must be given to the selection of the location for the CEMS installation, especially for particulate measurements. Since CEMS and SRM measured values are standardised against temperature, pressure, oxygen or CO_2 values by respective monitors or peripherals, the uncertainties in the peripheral parameters will be attributed to the CEMS in the variability test. Therefore, the functionality test for the measurement systems for the peripheral parameters (temperature, pressure and so on) are also carried out to minimise these uncertainties.

The functionality tests vary depending on whether the CEMS is an 'in situ' analyser (where the pollutant concentration is monitored within the stack) or an 'extractive' analyser, where a sample of the flue gas is withdrawn and delivered to a measurement system outside the stack. Table 8 summarises the functionality tests for each type of analyser.

TABLE 8 FUNCTIONALITY TESTS FOR QAL 2 AND AST (EA, 2021)

	Activity	Extractive CEMS	In situ CEMS
	Servicing	X	X
A	Alignment and cleanliness		X
B	Sampling system	X	
C	Documentation and records	X	X
D	Serviceability	X	X
E	Leak test	X	
F	Zero and span check	X	X
G	Linearity	X	X
H	Interferences	X	X
I	Zero and span drift (QAL 3 audit)	X	X
J	Response time	X	X
K	Report	X	X

The servicing requirement is covered by the manufacturer. The remaining tests are discussed in more detail below (EA UK, 2021).

A. Alignment and cleanliness

A visual inspection must be carried out (with reference to the CEMS manual) on the following:

- Internal control of the analyser;
- Cleanliness of the optical components;
- Flushing-air supply; and
- Obstructions in the optical path.

If there is any re-assembly of the equipment at the measurement location, the following must be checked:

- Alignment of the measuring instrument;
- Contamination control (internal control of optical surfaces); and
- Flushing air supply.

B. Sampling system

A visual inspection of the sampling system, especially the following components, is carried out:

- Sampling probe;
- GAs conditioning systems;
- Pumps;
- All connections;
- Sample lines;
- Power supplies; and
- Filters.

The sampling system must be in good condition and free of any visible faults.

C. Documentation and records

Proper documentation of all the processes in detail, including noting the timing of inspection and any relevant records, must be maintained, controlled, updated, and made readily accessible as and when needed. Key documentation may include:

- General arrangement and schematic of the CEMS;
- All manuals (such as maintenance and user manuals);
- Logbooks;
- A record of all possible malfunctions and actions to be taken;
- Service reports;
- QAL 3 documentation;
- Actions taken as a result of out-of-control situations;
- Management system procedures for maintenance, calibration, and training;
- Training records;
- Maintenance schedules; and
- Auditing plans and records.

D. Serviceability

Minimum provisions are required for the effective management and maintenance of CEMS which include:

- A safe and clean working environment with sufficient space and weather protection;
- Easy and safe access to CEMS; and
- Adequate supplies of calibration materials, tools, and spare parts.

E. Leak test

Leak testing is performed according to the CEMS manual. The test covers the entire sampling system, including any tubing and probes, as well as the CEMS itself.

F. Zero and span check

Reference zero and span materials are used to verify the corresponding CEMS readings. The zero and span procedure (QAL 3) is used to check drift and precision. This confirms that the CEMS is under control during its operation so that it continues to function within the required specifications for uncertainty. Periodic zero and span checks are based on those carried out in QAL 1 and the results obtained are evaluated using control charts. Zero and span adjustments or maintenance of the CEMS may be necessary depending on the results of this evaluation.

Negative values should be recorded as such and not forced to zero. Some CEMS use reference materials other than test gases. In this case, the reference material and the QAL 3 procedure in the manufacturer's instruction manual may be used, provided they comply with EN 15267-3 during the QAL 1 certification process. In the case of test gases, there can be a shift in the expected concentration value when the reference gas cylinder is changed. If this happens, then a new QAL 3 baseline may be established, following adjustment of the CEMS to account for previous drift. Inspection of the gas quality is also recommended to ensure that this adjustment is appropriate.

CEMS operators must plot zero and span data using control charts. The application of control charts requires regular and ideally frequent zero and span measurements. The maintenance interval defined during the performance testing of CEMS is considered the minimum frequency of zero and span checks. However, the plant operator may perform more frequent zero and span checks. It is recommended that these checks are carried out weekly after the initial installation and before the first QAL 2 calibration. In most CEMS, the maintenance interval is typically between eight days and one month. Some CEMS have much longer maintenance intervals; intervals of 3-6 months are permissible when the CEMS has proven long-term stability and high availability.

For CEMS without certification, the frequency of zero and span checks should be at least every four weeks unless there are reasons to extend the period between tests. In multi-component analysers, which monitor several components using one device (such as Fourier transfer infrared, FTIR), a QAL 3 test for one pollutant gas is made at least every four weeks.

Any change in the CEMS calibration can be monitored using a Cumulative Sum Chart (CUSUM). The CUSUM is a control chart used to monitor small shifts in the process mean. The CUSUM procedure requires frequent zero and span checks (weekly is recommended).

For **extractive CEMS**, the following options for performing zero and span checks may be applied:

- Use of test gases - nitrogen (N_2) or ambient air without measured components can be used as the zero gas. To perform QAL 3, it is not always necessary to inject the test gas through the complete sampling line. If the sampling line serving the extractive CEMS is relatively long, the zero and span procedures can consume large amounts of gas and time, leading to lower availability of the CEMS. Instead, the test gas can be injected directly in front of the analyser, preferably in front of the sample conditioning system.
- Use of reference materials - reference materials other than test gases can be used to perform QAL 3 for extractive CEMS, provided they comply with the respective QAL 1 certificate according to EN 15267-3.

For, **in situ gaseous CEMS,** the following options for zero and span checks may be applied:

- Use of test gases - some in situ CEMS include a sintered tube allowing the injection of test gases. This can be used to perform zero and span checks.
- Use of reference materials - for in situ CEMS where it is not possible to inject test gases, QAL 1 certified reference materials (EN- 15267-3) to perform QAL3 can be used.

For **PM CEMS**, several technologies are available. Regardless of the technique employed, zero and span readings are typically carried out using reference materials such as optical filters with varying densities. The reference materials should be certified in QAL 1 according to EN 15267-3.

Documentation of control charts: The control chart calculations are performed according to the EN standard. Documents for auditing must be maintained during the AST or a new QAL 2 which detail the history of the checks made and any appropriate actions taken in situations where the control limits are exceeded. This is especially important if the QAL 3 is performed automatically or internally within the CEMS. The control charts must be stored for at least five years.

The operator must ensure that any internal checks or compensation systems are operational and that plant personnel are aware of the status of any CEMS instrument alarm. This is to ensure that action is taken in the case of instrument malfunction between QAL 3 tests.

G. Linearity

Linearity is a measurement of how closely one variable relates to another. For CEMS, linearity relates to how accurately the measurement values follow the actual concentrations. The linearity of the analyser's response is checked using five different traceable reference materials – zero concentration and four span concentrations obtained from different gas cylinders or using a single cylinder fitted with a calibrated dilution system. The reference material concentrations, other than zero, are used at approximately 20%, 40%, 60% and 80% of the full range of twice the emission limit in a randomised manner. The values of the ratios of these concentrations must be known precisely to avoid a failure of the linearity test. After each change in test concentration, the first instrument reading is recorded after a period of at least three times the response time of the CEMS. For each test concentration, at least three readings are made. The period between the start of each of the three readings must be separated by at least four times the response time. The dry test reference material is applied at the inlet of the CEMS. The linearity is calculated and tested as per standard EN14181. If the CEMS does not pass this test, then the problem must be identified and resolved and then the test must be repeated.

H. Interferences

Chemical species other than the target species being measured can sometimes interfere with CEMS. A test must be undertaken if the process gases to be monitored contain components that are known interferences, as identified during QAL 1. This may not be required if the process concentration of the interferents is within those tested during certification. That is, a CEMS can be certified to operate in situations where interferents are within defined and acceptable concentrations.

I. Zero & span drift (audit)

The CEMS must be demonstrated to show zero accurately. The span drift is a proportional increasing or decreasing shift of the measured value away from the calibrated values as the measured value increases or decreases. The zero point and span drift must be evaluated based on the records of QAL 3 and corrected accordingly.

J. Response time

The response time of the CEMS is defined by the time it takes for the system to measure the concentration of a pollutant and record the result. It is checked by feeding the reference material in at the end of the sampling probe. The response time must not exceed the measured value that has been identified during QAL 1.

K. Report

The report of the functionality test must include a record of all the individual tests and faults. If the faults affect the data quality, the operator must carry out necessary corrective action.

Parallel measurements with the SRM and data evaluation

Parallel measurements using the CEMS and the SRM are performed to calibrate and validate the CEMS. This calibration cannot be done automatically, remotely or using reference material. However, if the variation between the results from the CEMS and the SRM is limited, and the measured concentrations are well below the emission limits, an extrapolation of the calibration function to the limit value may be verified using appropriate reference materials, taking possible interferences into account. The following are the key points for this process:

- The sampling requirement for SRM should fulfil the requirements of EN 15259 for representative sampling at the correct sampling point, as close as possible to the CEMS. An optimum sampling time must be established for parallel measurements.

- The SRM equipment and CEMS must not influence or disturb each other.
- In the case of varying plant operating modes/loads, the calibration function must be established for every operational mode; otherwise, it must be demonstrated that the calibration function is valid for a large range of concentrations within normal operation. Variability tests must also be carried out for each operating mode and calibration function.
- For each calibration, a minimum of 15 valid parallel measurements must be made, uniformly spread over at least three days, normally for 8–10 hours each day, and must be performed within a period of four weeks. Each sampling time should be at least 30 minutes or four times the CEMS response time (including sampling) carried out during QAL 1, whichever is greater. The averaging time should be significantly higher (at least 4 x) than the response time. The time interval between the start of each sample must be at least one hour.
- Each SRM and CEMS value obtained must be expressed under the same conditions (in terms of pressure, temperature, moisture and so on).
- If calibrated CEMS values for moisture concentration are available, these may be used to convert the SRM data to a dry or wet basis. When wet abatement techniques are used (such as wet flue gas desulphurisation, FGD), conversion of the SRM data to a dry or wet basis, as required, may be carried out using the calculated water vapour value.

Establishing the calibration function

Regardless of the type of monitoring method, most CEMS present results in electrical units – in mA or volts, or as a concentration unit – ppm or mg/m^3. SRM values are also obtained at the same operating flue gas conditions. For an in situ CEMS, which measures the gas directly, the calibration function is reported at the operating conditions (that is, the temperature and pressure as it is in the stack). For extractive CEMS, which withdraw the sample for analyses, and which measure at user-specified conditions, the calibration function is reported at the respective specified conditions. The values obtained from CEMS and SRM are used to estimate the appropriate calibration function. The data sets obtained in the parallel measurements are checked for possible outliers to be excluded and, if this occurs, it should be recorded in the report.

The calibration function is considered linear and has a constant residual standard deviation. It can be estimated by the formula (ISO 11095) (ISO, 1996):

$$y_i = a + bx_i + \varepsilon_i$$

Where:

x_i is the i^{th} CEMS measured signal; i = 1 to N; N ≥ 15;
y_i is the i^{th} SRM measured value; i = 1 to N; N ≥15;
ε_i is the deviation between y_i and the expected value;
a is the intercept of the calibration function; and
b is the slope of the calibration function.

Generally, the procedure requires a sufficiently large range of measured concentration values (from the SRM) to produce a valid calibration of CEMS for the complete range of concentrations encountered during normal operations. This can be a challenge in some situations. In such cases, the calibration functions are decided based on whether the concentration range is lower or higher than the maximum permissible uncertainty (the difference between the maximum and minimum value of the SRM measurement, that is *s* the value of y_s, max – y_s, min). The justification for this must be provided in the QAL 2 report. In these situations, alternative formulae for establishing calibration functions are used.

If (y_s, max – y_s, min) is higher or equal to the maximum permissible uncertainty, the parameters of the calibration function shall be calculated using the following formula:

$$\hat{b} = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad \text{and} \quad \hat{a} = \bar{y} - \hat{b}\bar{x}$$

If (y_s, max – y_s, min) is lower than the maximum permissible uncertainty and y_s, min is greater than or equal to 15% of the emission limit, the parameters of the calibration function are calculated using:

$$\hat{b} = \frac{\bar{y}}{\bar{x} - Z} \quad \text{and} \quad \hat{a} = -\hat{b}Z$$

Where the offset *Z* is the difference between the CEMS zero reading and zero.

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \quad \text{and} \quad \bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$$

If appropriate reference materials are available at zero and close to the ELV (emission limit value), these are used to obtain two data pairs (the CEMS measured signal and the reference value), one at zero and one close to the ELV. The data pairs must be converted to the CEMS measuring conditions by using the average of the CEMS measuring conditions in the parallel measurements with the SRM. The user must form a combined data set consisting of the results of the parallel measurements and the data pairs obtained by use of the reference materials. The combined data set should be used to calculate the calibration function.

Determining the validity of the calibration function

The calibration function is estimated as:

$$\hat{y}_i = a + bx_i$$

Where:

$\hat{y}_i$ is the calibrated CEMS measured value

x_i is the CEMS measured signal

The calibration function is used to convert each CEMS measured signal - x_i - into a calibrated value -$\hat{y}_i$. This calibration function is then incorporated into the data processing system of the plant or source to ensure that the CEMS value is reported as the calibrated value. The calibration function $\hat{y}_i$ is valid when the plant is operated within the parameters used to establish the valid calibration range. That is, if the plant suddenly changes operational conditions significantly enough to produce emissions in a wider range than those tested during calibration, then the CEMS would need to be recalibrated accordingly. The valid calibration range is the calibration range from zero to the maximum value $\hat{y}_{s,max}$ of the calibrated CEMS measured values at standard conditions, determined during the QAL 2 procedure, plus an extension of 10%; or ELV's 20%, whichever value is greater. For PM CEMS the valid calibration range is 100% for particulates if the CEMS is demonstrably linear.

For measurements outside the valid calibration range, the calibration curve must be extrapolated to determine the concentration values which exceed the valid calibration range. This is why the calibration must be accurate – measurements outside the calibrated range will be estimated from the calibration function. For greater confidence, when the plant has emission concentrations outside its calibration range, reference materials at zero and at a concentration close to the ELV are used. This extension of the calibration procedure confirms the suitability of the linear extrapolation. Any deviation between the calibrated CEMS measured value at zero and the ELV and the corresponding SRM measured values must be calculated; the value should be less than the maximum permissible uncertainty. The deviation at zero must be less than 10% of the ELV. If these criteria are not fulfilled, then further investigation must be performed to establish the cause.

The validity of the valid calibration range must be evaluated by the plant owner every week. A new calibration should be performed, reported, and implemented within six months, if:

- More than 5% of the CEMS measured (standardised and calibrated) values calculated over the week are outside the valid calibration range for more than five weeks in a year (the period between two ASTs);
- More than 40% of the CEMS measured values calculated over the week are outside the valid calibration range for one or more weeks.

If the plant is not operated continuously then the percentage values may be calculated from the last full week period (168 operational hours) of continuous operation. If exceedances of the valid calibration range are caused by plant failures, a new calibration is not needed after fixing the plant failure. The existing calibration function can be used until the new calibration function has been implemented. Data from previous calibrations should not be combined with data from a new calibration exercise when calculating the calibration function.

Calculation of variability

The maximum permissible uncertainty for the CEMS measured values can be expressed or defined as 95% of the confidence interval, an expanded uncertainty, a standard deviation, or any other statistical formulation. The maximum permissible value can be converted into an absolute standard deviation σ_0.

If the uncertainty is expressed at a level of confidence of 95%, the value of an absolute standard deviation shall be determined using a factor of 1.96 (95% t-value; t0.025 for large values of *n* from t-table, estimated probability of exceeding the critical value) as the value for the coverage factor.

The variability test should only be based on the results of the parallel measurements and not on the measurement values from reference materials or alternative procedures. The variability test is performed on the measured values (calibrated and standardised values) of the CEMS. Hence, for every parallel measurement reported by the CEMS, a measured value $\hat{y}_i$ is calculated using the calibration function. The uncertainties in the peripheral parameters (such as moisture, temperature, and oxygen for standardising the measured values) are attributed to the CEMS in the variability test.

Variability is the extent to which data points in a statistical distribution or data set diverge, or vary from, the average value, as well as the extent to which these data points differ from each other.

If the CEMS fails the variability test due to errors arising from measurements in the peripheral parameters obtained from the plant instrumentation, the variability test can be repeated using the parameters obtained by the test laboratory from their peripheral SRM. This is only permitted if measures are taken to correct the faulty plant instrumentation.

For each data set (a minimum 15 pairs) for a given calibration function, the following parameters shall be calculated:

$$D_i = y_{i,S} - \widehat{y_{i,S}} \quad \text{and} \quad \overline{D} = \frac{1}{N}\sum_{i=1}^{N} D_i \quad \text{and} \quad S_D = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(D_i - \overline{D})^2}$$

Where:
$y_{i,s}$ = the SRM measured value at standard conditions
$\bar{Y}_{i,s}$ = the calibrated CEMS value calculated from the CEMS measured signal x_i at standard conditions

The CEMS passes the variability test when:

$$S_D \leq \sigma_0 k_v$$

Where:
σ_0 = absolute standard deviation
k_v = test values from a χ2-test, with a β-value of 50% (*see* Table 9).

TABLE 9 TEST VALUES AND T0.95; N–1 VALUES (EN14181, ANNEX 1) (CEN, 2004)		
Number of parallel measurements ‘N’	**Test values (k_v)**	**t0.95; N-1**
3	0.8326	2.920
4	0.8881	2.353
5	0.9161	2.132
6	0.9329	2.015
7	0.9441	1.943
8	0.9521	1.895
9	0.9581	1.860
10	0.9629	1.833
11	0.9665	1.812
12	0.9695	1.796
13	0.9721	1.782
14	0.9742	1.771
15	0.9761	1.761
16	0.9777	1.753
17	0.9791	1.746
18	0.9803	1.740
19	0.9814	1.734
20	0.9824	1.729
25	0.9861	1.711
30	0.9885	1.699

Note: For more than 30 pairs of data, the next lowest value (30) should be used for k_v and $t_{0.95;\,N-1}$ values

The measured values of the CEMS may only be used to demonstrate compliance with the ELV if the CEMS has passed the variability test. Once it has passed this test, the CEMS has demonstrated that it complies with the uncertainty requirement at the ELV for compliance with the legislation, since the variability is deemed as constant throughout the range.

QAL 2 report

The QAL 2 report should contain detailed information on:

- Description and validation of the complete installation including correct selection of the measurement range(s);

- The tests carried out – test description, date and time of measurement, procedure, standard, data and formulae, analyses, and results including calibration function;
- The plant - fuel use, operating condition; and
- The testing agency- name, testing person, accreditation, equipment used.

Annual Surveillance Test

The AST is similar to the QAL 2 tests but with fewer measurements. The AST should be performed by a competent authorised agency or laboratory. As with QAL 2, the AST also includes the following:

- Functionality test of the CEMS;
- Parallel measurements with the SRM;
- Data evaluation;
- Calculation of variability of the CEMS measured values;
- Test of the variability of CEMS measured values and validity of the calibration function as taken during QAL 2;
- Completeness of the QAL 3 documentation; and
- AST reporting and documentation.

As with QAL 2, the first step is the functionality tests. At least five valid parallel measurements must be performed with the SRM. The purpose of these comparative measurements is to verify that the calibration function of the CEMS is still valid and that the precision is still within the required limits. If the measurements include results outside the valid calibration range, this range may be increased with the use of these results. These measurements must be uniformly spread over the full day of measurement. A set of measurements is valid when all the requirements below are fulfilled:

- The SRM measurements are performed according to the appropriate standard;
- The SRM measurements meet all the requirements given in the appropriate standard;
- The period of each CEMS measured signal is larger than 90% of the averaging time - excluding any signals which are above 100% or below 0% of the measuring range of the CEMS, signals obtained during internal checks (auto-calibration), and signals obtained during any other malfunctioning of the CEMS;
- The sampling time for parallel measurement is similar to QAL 2 – it must be at least 30 minutes or at least four times the response time of the CEMS, including the sampling system, whichever is the greater. In general, it is recommended that the sampling time used is the shortest averaging time related to an ELV. If the sampling time is shorter than one hour, the time interval between the start of each sample must be longer than one hour.

The data sets obtained in the parallel measurements are checked for possible outliers which are then excluded and reported in detail in the AST report. However, at least five valid data points must be available for an AST. All the valid data points must be used in the variability test and the validity assessment of the calibration function. The CEMS measured values y_i (calibrated values) are calculated from the CEMS measured signals x_i using the established calibration function. The peripheral CEMS equipment is used to adjust the data to standard conditions and to calculate the standardised measured values. The results from the comparative measurements (AST) should not be used together with the measurements from the most recent calibration to determine a new calibration function (QAL 2), but they can be used to extend the valid calibration range.

As with the QAL 2 report, the AST report should contain the plant information, operating conditions, fuel use, testing agency, test details, methods, standards, and results. The CEMS is assigned a registration number, and specific files should be maintained relating to each specific CEMS, containing all the relevant information, and noting every occurrence which could significantly affect the CEMS during its life.

4.6 COMMENTS

The EU approach to equipment quality assurance has evolved over the years and from several separate national policies. The aim is to unify equipment certification and installation to ensure that all CEM equipment is certified as fit for purpose at the point of sale but also once installed and operational. This is achieved through three levels of quality assurance testing (QAL 1-3) during installation and initial operation, and through an annual surveillance test over the lifetime of CEMS operation. The official methodologies and EU standards for QAL 1-3 are detailed and complex but can be summarised as follows:

- **QAL 1 –** certification of the CEMS (instrument type approval) to confirm that the principal of the technology design and manufacture is appropriate and that this quality is maintained through all individually purchased units.
- **QAL 2 –** confirmation that the CEMS has been installed correctly on site and is providing accurate data, as confirmed by comparing results with a standard reference method.
- **QAL 3 –** ongoing zero/span checks and maintenance according to the manufacturer's operation manual including determination of drift and accuracy using CUSUM cards or Excel charts.
- **AST –** annual confirmation that the CEMS is operating accurately and reliably according to QAL 2.

5 QA/QC – THE US APPROACH

As noted in Chapter 3, the US does not have a CEMS-type approval process similar to that in Europe. Instead, the system is tested (certified) for its performance during the installation at the site. The responsibility of testing and receiving approval of the CEMS, therefore, lies with the industry/operator.

The US approach to CEMS implementation has evolved to monitor compliance and is built within the relevant regulations for emission control. It is therefore necessary to look at how these regulations were developed. In the USA, CEMS were initially required to demonstrate compliance with the emissions limitations that were established for new sources under CFR 40, Part 60. Part 60 includes many subparts defining the New Source Performance Standards (NSPS) and associated reporting requirements for different industrial sectors and types of emission units. It includes the performance specifications and on-going QA/QC procedures for operating the CEMS required under those regulations, as well as many of the reference method test procedures used in conjunction with those requirements. The NSPS emission limits are intended primarily to address 'criteria' pollutants (carbon monoxide, ozone, lead, NO_X, PM, and SO_2) for which the US Clean Air Act requires the EPA to set National Ambient Air Quality Standards. Other air pollutants, such as mercury emissions, are addressed under 40 CFR Part 63, which establishes the 'National Emission Standards for Hazardous Air Pollutants' for both existing and new emission sources for various industrial sectors.

In addition to the emission limits in Parts 60 and 63, the USEPA's Clean Air Markets Division (CAMD), operates several market-based programmes to improve the air quality (USEPA, 2022a). They include the Acid Rain Program and the Cross-State Air Pollution Rule (CSAPR). These allowance trading programs specifically address emissions from thermal power plants in the electric utility industry and establish national and regional caps on the total SO_2 and NO_X emissions from these sources. For these allowance trading programmes, which also require flue gas flow monitoring not required under most NSPS regulations, EPA established additional CEMS regulations under 40 CFR Part 75. The Part 75 CEMS requirements are similar in many ways to the Part 60 CEMS requirements (and thermal power plants can use CEMS certified under Part 75 for Part 60 reporting) but include some additional provisions to help ensure the accuracy of the emissions reported under the allowance trading programmes.

As electric utilities are a significant sector with respect to air quality issues in both the USA and India, this section highlights the Part 75 requirements for those sources. Under the CEMS Guidelines, sources in India can certify their CEMS equipment following either the Part 60 or Part 75 procedures, with the Part 75 requirement recommended for thermal power plant sources and the Part 60 requirements recommended for other source categories.

TABLE 10 USEPA PROGRAMMES THAT REQUIRE EMISSION MONITORING AS PER 40 CFR PART 75 (USEPA, 2009)

Programme	Affected sources	Parameters, units	Averaging period	Data use for compliance
Acid Rain Programme (ARP)	Power plants (Electricity Generating Units/EGU) and other combustion sources in the SO_2 cap & trade programme (48 states)	SO_2 (tons) CO_2 (tons) NOx (lb/MMBtu) Heat input (MMBtu) Opacity (%)	Annual (cumulative) Annual (cumulative) Annual (average) Annual (cumulative) Varies	Yes No Certain units* Some states No
Cross-State Air Pollution Rule (CSAPR) (Earlier known as Clean Air Interstate Rules; CAIR)	EGUs and non-EGUs (selected by the state)	SO_2 and NOx (tons)	Annual (cumulative) 25 states	Yes
		NOx (tons)	Ozone season** (cumulative) 25 states	Yes
Regional Greenhouse Gas Initiative (RGGI)	EGUs (10 states)	CO_2 (tons)	Annual (cumulative)	Yes

* Certain units as per 40 CFR Part 76
** Ozone season extends from 1 May to 30 September

CEMS are required in the US for monitoring, recordkeeping, and reporting of SO_2, NOx, and CO_2 emissions under the Acid Rain Programme pursuant to the Clean Air Act (CAA). Unlike Gaseous CEMS, PM CEMS is not required under Acid Rain Programme, but it is under other regulations depending upon the emission source. The regulations established under 40 CFR Part 75 explain the requirements for the installation, certification, operation, and maintenance of continuous emission or opacity monitoring systems and specific requirements for the monitoring of the above-mentioned parameter emissions and their removal by control technologies. The regulations also include specifications for the installation and performance of CEMS, certification tests and procedures, quality assurance tests and procedures, alternative monitoring systems, and provisions to account for and substitute missing data.

Regulation 40 CFR Part 75 Subpart C describes the process for the 'certification and re-certification of CEMS'. In this instance, the certification is not the same as the stringent type-certification used in the EU, rather it is confirmation of the CEMS being fit for purpose as it is installed and used on the site. This regulation also covers QA/QC requirements, defines 'out-of-control' periods, and requires bias adjustment of data from SO_2, NOx, and flow monitors. Appendix A describes CEMS installation and 'certification' test procedures and provides performance specifications for the CEMS and explains how to set the span and range of CEMS. Appendix B describes the required on-going CEMS quality assurance tests and procedures for CEMS and includes rules for data validation.

The CFR regulations are detailed and extensive. For the purpose of this report, these requirements are summarised, focusing on the principles which are most important for CEMS best practice (*see* Figure 7).

There are a number of variations in CEMS requirements in the USA based on the composition of emissions produced from the fuel consumed. For example, combustion of very low-level sulphur-containing fuels may not require CEMS, and oil- and gas-fired peaking units can opt for fuel use-based NOx estimations. Unless a source qualifies for any of these exceptions, CEMS are used to provide the emissions data. The selected monitoring methodology for each unit must be approved by USEPA through a 'certification' process.

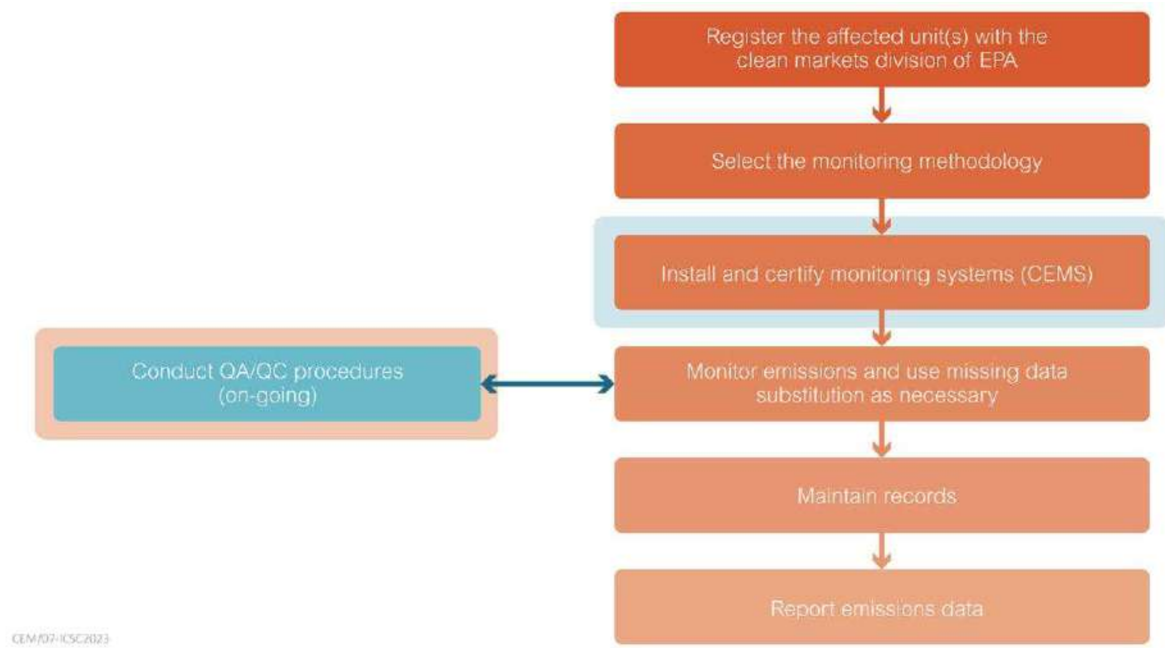

Figure 7 Overview of CEMS implementation requirement, as per USEPA in the USA (USEPA, 2009)

5.1 CEMS 'CERTIFICATION'

As discussed in Chapter 4, in the EU, CEMS are certified as fit for purpose by qualified and approved agencies and once certified, a CEMS technology is type approved for use on certain sources. In the USA, no such type of certification exists. Individual CEMS must be certified as fit for purpose in place on each source, on an individual basis. The onus for this lies with the industry/operator and must be carried out according to USEPA regulations.

The applicant must submit an initial monitoring plan to the USEPA and the appropriate State authority at least 21 days before certification testing begins (*see* Figure 8). The source provides written notice to CAMD, USEPA and the State at least 21 days before testing begins. The certification testing is carried out according to the procedures specified in 40 CFR 75, Section 6 of Appendix A. These requirements include seven-day calibration error tests, linearity checks, RATA, bias tests, cycle time tests, flow meter accuracy tests, and DAHS verification (USEPA, 2009).

Once the tests are completed, the application for certification is sent electronically to CAMD along with hard copies of documents that are incompatible with the electronic application system tools within 45 days. The hard copy application consists of the certification test report and changes (if any) in the monitoring plan, whereas the electronic copy consists of a complete, updated monitoring plan and the results of the certification tests. If the application is incomplete in any aspect, sufficient time is given to procure the missing information. An appropriate reviewing agency (USEPA for the Acid Rain Program and the state/local agency for the CSAPR programmes) issues a notice of approval or disapproval of certification of the CEMS within 120 days. If no such notice is issued, the device is deemed certified by default.

The Relative Accuracy Testing Audits (RATAs) for CEMS under Part 75 must be carried out by an Air Emissions Testing Body (AETB) that has been certified by demonstrating conformance to ASTM International (earlier known as ASTM – American Society for Testing and Materials) D7036-04. The operator or owner should obtain the AETB certification information to confirm that this requirement is met at the time of testing (Cornell, 2023). The owner and operator may do this if they have an in-house testing group; otherwise, they can retain an emissions testing firm to perform the RATA who will have the accreditation.

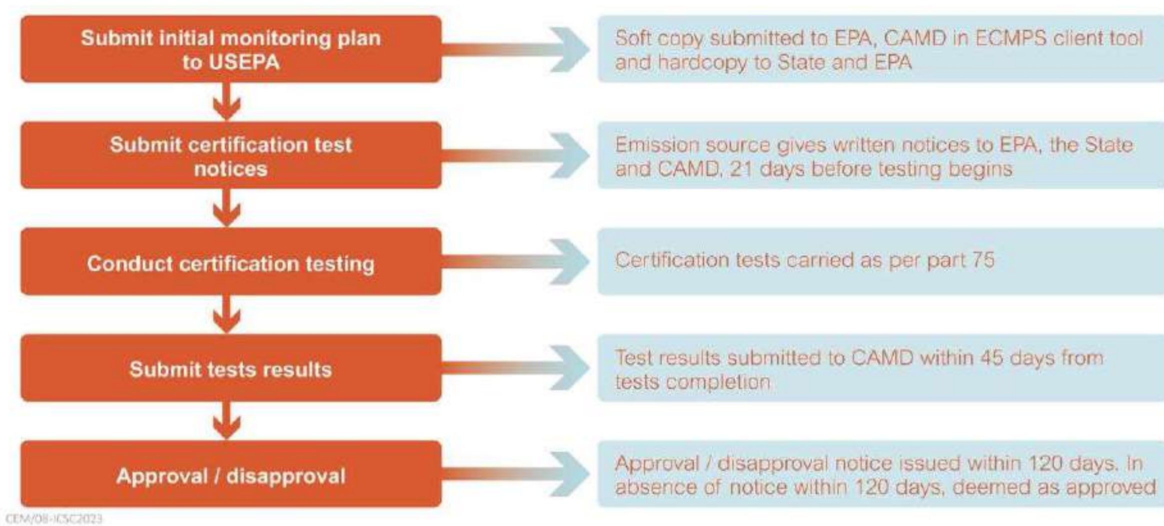

Figure 8 Process flow of CEMS testing and approval as per USEPA in the USA (USEPA, 2009)

The following sections consider the requirements for QA/QC testing in the USA in more detail.

5.2 QA/QC TESTS, PROCEDURE AND FREQUENCY FOR GASEOUS CEMS

The US approach for CEMS on industrial stacks focuses on QA/QC to ensure that the results are considered accurate for compliance under various regulatory provisions. The industry/operator must carry out a series of tests and compare the values with reference method tests. Generally, the following tests are required for the initial certification or the recertification process.

5.2.1 Part 75 CEMS QA/QC requirements

Seven-day calibration error tests are required as part of the initial certification process for gas concentration CEMS and flue gas flow monitors. For each gas concentration analyser, the operator must also perform a cycle time test to demonstrate that the response of the CEMS is less than 15 minutes. While required in situations where the CEMS must be recertified, neither of these tests are required on an on-going basis.

For the gas concentration CEMS the following QA/QC tests are performed as part of the initial certification (or recertification process) separately on each pollutant concentration monitor and diluent gas monitor. These tests must also be repeated at the frequency detailed below (under Part 75, the frequency of these tests is generally defined in terms of QA operating quarters, where a QA operating quarter is defined as a calendar quarter during which the associated emission unit(s) operate 168 hours or more during that quarter):

- A linearity-check for each gas concentration analyser - once every QA operating quarter (and at least once every four calendar quarters if the unit operates infrequently), except for any moisture monitors unless a different wet O_2/dry O_2 approach is used to determine the moisture concentration when a linearity test is required for each analyser.
- A RATA for each gas concentration analyser (or for NOx on a lb/MMBtu basis including the diluent measurement) – generally, provided the incentive criteria are met, at least once every four QA operating quarters (and at least once every eight calendar quarters if the unit operates infrequently).
- For a continuous moisture monitoring system consisting of a temperature sensor and a data acquisition and handling system (DAHS) software component, programmed with a moisture lookup table: a demonstration that the correct moisture value for each hour is being taken from the moisture lookup tables and applied to the emission calculations. At a minimum, the demonstration shall be made at three different temperatures covering the normal range of stack temperatures from low to high.

Tests for flow monitors

- Relative accuracy test audits: generally, provided the incentive criteria is met, a RATA is required at two load conditions at least once every four QA operating quarters (and at least once every eight calendar quarters if the unit operates infrequently) except that single-load RATA may be performed for a flow monitor installed on a peaking unit or bypass stack, or those exempted from multiple-level RATA testing by demonstrating that the unit operates at a single load level 85% or more of the operating time. Three-load RATAs are required during the initial certification (or re-certification) and at least once every 20 calendar quarters as well as whenever the monitor 'k-factors' are changed (that is, a new flowmeter correlation is applied).
- Quarterly flow-to-load test must also be performed each QA operating quarter in accordance with the requirements of Section 2.2.5 in Appendix B of Part 75.
- If a differential pressure-based flow monitor is used, a leak check must be performed at least once each QA operating quarter. For this test, the unit does not have to be in operation and the leak checks should be conducted no less than 30 days apart, to the extent practicable.

While a 'bias test' is required in conjunction with CEMS to report emissions for allowance purposes under Part 75, neither bias adjustment factors nor the missing data substitution procedures are used for compliance demonstration with emission limits under the US regulations. Likewise, the Part 75 bias adjustment factors or missing data procedures should not be applied for compliance demonstrations of any Indian emission limit under section 18(1)b of the Water and Air Acts.

5.3 TESTS FOR OPACITY MONITOR/PM CEMS

CEMS for particulate systems are more complex than for gaseous systems since they can be affected by the variability of the chemical and physical behaviour of PM in a flowing gas medium and may be affected by stratification and sample velocity effects. The following sections summarise the performance specification requirements for PM CEMS in the USA (PS-1 for opacity and PS-11 for PM CEMS, Appendix B to Part 60). The major difference between these two systems is that continuous opacity monitoring systems (COMS) quantify PM emissions based on the opacity of the flue gas, often at or near the stack exist whereas PM CEMS use more complex optical-based techniques such as light scattering, more direct approaches such as beta attenuation or, in certain applications, electrical interaction-based systems.

5.3.1 Performance specification 1 (PS-1) for COMS

Performance Specification 1 (PS-1) provides requirements for the design, performance, and installation of a COMS and data computation procedures for evaluating its acceptability (USEPA, 2022b). The operator must follow installation guidelines, including a set of field performance tests that confirm the acceptability of the COMS after it is installed.

ASTM D 6216-12 sets the design specifications, manufacturer's performance specifications, and test procedures. An opacity monitor must meet the specifications of ASTM D 6216-12, including a suitable data recorder or automated data acquisition handling system, calibration attenuators or optical filters (minimum of three). After the COMS is installed and calibrated, the owner or operator must test that the COMS conforms with the field performance specifications in PS-1.

The operator must install the opacity monitor at a location where the opacity measurements are representative of the total emissions from the facility. The measurement location must be at least four duct diameters downstream from all particulate control equipment or flow disturbances; at least two duct diameters upstream of a flow disturbance; where condensed water vapour is not present; and which is accessible in order to permit maintenance.

There is then a requirement for a series of field Audit Performance Tests after installation; the operator must perform the following procedures and tests on the COMS (USEPA, 2022c):

- Optical alignment assessment – to verify and record that all alignment indicator devices show proper alignment.
- Calibration error check – A three-point calibration error test is conducted using three calibration attenuators that produce outlet pathlength corrected single pass opacity values. The external audit device produces the proper zero value on the COMS data recorder. Separately, each calibration attenuator (low, mid, and high-level) is inserted into the external audit device and five non-consecutive readings are taken for each attenuator. At the end of the test, each attenuator insertion is correlated to the corresponding value from the data recorder. The single-pass calibration attenuator values corrected to the stack exit conditions are subtracted from the COMS responses. The arithmetic mean difference, standard deviation, and confidence coefficient of the five measurements value are calculated. The calibration error as the sum of the absolute value of the mean difference and the 95% confidence coefficient for each of the three test attenuators is calculated and reported.
- System response time check – Using a high-level calibration attenuator, the filter is installed and removed five times from the external audit device. For each filter insertion and removal, the amount of time required for the COMS to display 95% of the step change in opacity on the data recorder is measured. For the upscale response time, the time from insertion to display of 95% of the final value, the steady upscale reading is measured. For the downscale response time, the time from removal to display 5% of the initial upscale reading is measured. The mean of the five upscale response time measurements and the mean of the five downscale response time measurements are calculated.
- Averaging period calculation and recording check - After the calibration error check, a check of the averaging period calculation (for example, a six-minute integrated average) is conducted. Consecutively each of the calibration error check attenuators (low, mid, and

high-level) are inserted into the external audit device for a period of two times the averaging period plus one minute (for example, 13 minutes for a six-minute averaging period). The path length corrected opacity value of each attenuator is compared to the valid average value calculated by the COMS data recording device for that attenuator.

- Operational test period - Before conducting the operational testing, the operator must have successfully completed the field audit tests. The COMS is then operated for an initial 168-hour test period while the source operates under normal operating conditions, including routine shut down if appropriate. For a batch operation, the operational test period must include at least one full cycle of batch operation during the 168-hour period unless the batch operation is longer than 168 hours. For continuous operating processes, the unit must be operating for at least 50% of the 168-hour period. Unscheduled maintenance, repair, or adjustment to the COMS during this period will void the test. If the COMS fails to meet the specifications for the tests conducted under the operational test period, corrections are to be done and the same operational test period is to be restarted.
- Zero and upscale calibration drift checks are allowed during the operation test period. At the outset of the 168-hour operational test period and at each 24-hour interval, the automatic calibration check system must initiate the simulated zero device to allow the zero drift to be determined. At each 24-hour interval after the simulated zero device value has been checked, the operator must check and record the COMS response to the upscale calibration device. After each 24-hour period, the operator must subtract the COMS upscale reading from the nominal value of the upscale calibration device to calculate the 24-hour calibration drift (CD).

Procedure 3 for QA of COMS

Procedure 3 for Quality Assurance of COMS applies to COMS used to demonstrate continuous compliance with opacity standards specified in new source performance standards (NSPS) promulgated by EPA pursuant to section 111(b) of the Clean Air Act, 42 U.S.C. 7411(b)—Standards of Performance for New Stationary Sources (USEPA, 2022d). The overall data quality objective (DQO) of Procedure 3 is the generation of valid and representative opacity data. Procedure 3 provides requirements for:

- Daily instrument zero and upscale drift checks and status indicators checks;
- Quarterly performance audits which include the following assessments: (i) optical alignment, (ii) calibration error, and (iii) zero compensation; and
- Annual zero alignment.

The operator must develop and implement a QC program for COMS. The QC programme must, at a minimum, include written procedures which describe in detail complete step-by-step procedures and operations for:

- Performing drift checks, including both zero and upscale drift and the status indicators check;
- Performing quarterly performance audits;
- A means of checking the zero alignment of the COMS; and
- A programme of corrective action for a malfunctioning COMS.

5.3.2 Performance specification 11 (PS-11) for PM CEMS

The PS-11 defines the initial installation and calibration procedures for PM CEMS used to determine compliance with filterable PM emission limits under various US regulations. PS-11 requires:

- Correct selection and installation of CEMS which are appropriate for the source, considering the flue gas conditions, potential interferences, site-specific configuration, installation location, PM concentration range, and other PM characteristics. The installation should be accessible downstream of all pollution control equipment in a location considered to be representative, or with the potential to provide data that can be corrected to be representative, of the total PM emissions as determined by the manual reference method.
- Selection of the correct reference method location and traverse points. The operator must follow USEPA Method 1 to select appropriate manual reference method traverse points ideally at locations that are at least eight duct diameters downstream and at least two duct diameters upstream of any flow disturbance. Where necessary, testing can be conducted at a location that is two diameters downstream and half a diameter upstream of any flow disturbances, or the operator may obtain approval from USEPA to test at a location that does not meet those minimum downstream and upstream requirements.
- Installation of CEMS and preparation of the reference method test site according to the specifications. Before correlation between the methods, it is recommended that the operator familiarise themselves with the CEM operation and carry out daily zero and upscale drift and sample volume checks as appropriate.
- Completion of seven-day drift tests. These are required before the correlation test. The operator must check the zero drift (or low-level value between 0 and 20% of the response range of the instrument) and upscale (between 50 and 100% of the instrument's response range). This check must be performed at least once daily over seven consecutive days and must quantify and record the zero and full-scale measurements, drift, and the time of the measurements.
- Completion of an initial correlation test. The operator must use the reference method for PM (usually Methods 5, 5I, or 17) as prescribed by the applicable regulations. Other reference methods may need to be performed (such as Method 3A for oxygen and carbon dioxide) to complete the correlation test requirements, depending on the units in which the PM CEMS reports PM concentration. A minimum of 15 valid runs are required, each consisting of simultaneous PM CEMS and reference method measurement sets at three concentration

levels/loads (at least 20% data from each – 0-50%, 25–75% and 50–100% of maximum concentration). All data, including rejected values, should be reported. Three concentration levels or loads can be achieved by varying the process operating conditions, varying the PM control device conditions, or by PM spiking. Zero concentration levels can be obtained by removing in situ CEMS, such as by using a test bench with ambient air, sampling during process shut down with the fan running, or by using natural gas for combustion. The operator must calculate and report the results of the correlation testing, including the correlation coefficient, confidence interval, and tolerance interval for the PM CEMS response and reference method correlation data that are used to establish the correlation.

Once the above certification and initial correlation tests are completed, the operator must follow the ongoing QA/QC requirements in Procedure 2 for Quality Control measures of PM CEMS – 40 CFR 60, Appendix F.

Procedure 2 for QC of PM CEMS

The purpose of Procedure 2 is to establish the minimum requirements for evaluating the effectiveness of QA/QC procedures and to ensure the quality of data produced by the PM CEMS (USEPA, 2022e).

The QC programme must, at a minimum, include written procedures that describe in detail the complete step-by-step procedures and operations for the following activities:

- Procedures for performing drift checks, including both zero drift and upscale drift and the sample volume check.
- Methods for adjustment of PM CEMS based on the results of drift checks, sample volume checks (if applicable), and the periodic audits specified in this procedure.
- Preventative maintenance of PM CEMS (including spare parts inventory and sampling probe integrity).
- Data recording, calculations, and reporting.
- Relative correlation audit (RCA) and relative response audit (RRA) procedures, including sampling and analysis methods, sampling strategy, and structuring test conditions over the prescribed range of PM concentrations. The RCA comprises a series of tests to ensure the continued validity of the PM CEMS correlation. The RCA is carried out (at the frequency specified in the regulation and/or permit) according to the procedures for the PM CEMS correlation test described in PS-11 above, except that the minimum number of runs required is 12 in the RCA instead of 15 as specified in PS-11. The RRA comprises a brief series of tests conducted between consecutive RCAs to ensure the continued validity of the PM CEMS correlation. The RRA is carried out (at the frequency specified in the regulation and/or permit) by collecting three simultaneous reference method PM concentration measurements

and PM CEMS measurements at the as-found source operating conditions and PM concentration.

- Procedures for performing absolute correlation audits (ACAs) and, if applicable, sample volume audits (SVAs) as well as methods for adjusting the PM CEMS response based on ACA and SVA results. The SVA is an evaluation of the PM CEMS measurement of sample volume, if the PM CEMS determines the PM concentration based on a measure of PM mass in an extracted sample volume which requires an independent determination of the sample volume.
- An audit of the measured sample volume (for example, based on the sampling flow rate over a known period). This is performed once per quarter for applicable PM CEMS with an extractive sampling system, if the sample volume is used to calculate the emission concentration, such as with a beta attenuation monitor. The SVA is performed by independently measuring the volume of sample gas extracted from the stack or duct over each batch cycle or time period with a calibrated device. Measurement can be made either at the inlet or outlet of the PM CEMS, as long as it measures the sample gas volume without including any dilution or recycle air. The measured volume is compared with the volume reported by the PM CEMS for the same cycle or time period to calculate sample volume accuracy. Measurements must be made during three sampling cycles for batch extractive monitors (such as Beta-gauge) or during three periods of at least 20 minutes for continuous extractive PM CEMS. The user may need to condense, collect, and measure moisture from the sample gas prior to the calibrated measurement device and correct the results for moisture content. In any case, the volumes measured by the calibrated device and PM CEMS must be on a consistent temperature, pressure, and moisture basis.
- A programme of corrective action for handling a malfunctioning PM CEMS, including flagged data periods.

In addition to the above requirements for the PM CEM, there are associated requirements for the data acquisition and handling system:

- Appropriate computation of hourly averages for pollutant concentrations, flow rate, pollutant emission rates, and pollutant mass emissions; and
- Appropriate computation and application of the missing data substitution procedures in (subpart D, Part 75) and the bias adjustment factors (Appendix A, part 75).

5.3.3 Test procedure and frequency required

The ‘cycle time test’ is one of the certification and recertification test requirements for gas monitors. In this test, zero and span/upscale calibration gases are injected to determine the upscale and downscale cycle or response times. Starting with a stable stack gas concentration, zero gas is injected and the time it takes for 95% of the step change between the stack gas and zero gas concentrations to be achieved is defined as the downscale cycle time. The test is then repeated using the high reference gas to determine the upscale cycle time. The higher value for the upscale and downscale cycle times is reported as the cycle time for the monitor. The cycle time must not exceed 15 minutes.

In the seven-day calibration test, drift tests are performed over seven consecutive operating days. Operators are to perform a drift test each day that the unit operates, approximately 24 hours apart (unless the unit does not operate during a day when the period between calibrations may be longer). The test is intended to assess the drift over each 24-hour period to demonstrate that the daily drift does not exceed the performance specification. Accordingly, manual or automatic adjustments are only allowed immediately *after* the zero and upscale injections are made each day. Unadjusted values must be used to determine the calibration error. The calibration error limits for the seven-day test (2.5% of span for SO_2 and NOx monitors, 0.5% CO_2 or O_2 for diluent gas monitors, and 3.0% of span for flow monitors) are twice as stringent as the daily calibration error limits, which are 5.0% of span for SO_2 and NOx monitors, 1.0% CO_2 or O_2 for diluent gas monitors, monitors and 6.0% of span for flow monitors.

The calibration error formula for pollutants, diluent and flow monitor is:

$$CE = (R-A)/S \times 100$$

Where:
CE = calibration error as a percentage of the span of the instrument
R = reference value of zero or upscale calibration gas introduced into the monitor
A = actual monitoring system response to the calibration gas/ flow monitor
S = span of the instrument or flow monitor calibration span.

A linearity check is carried out with three calibration gases: – low (20–30% of span), mid (50–60% of span), and high (80-100% of span) in three runs through the entire sampling system including filters, scrubbers, conditioners, and as much of the sampling probe as practical. This check is carried out once every QA operating quarter (a calendar quarter in which there are at least 168 unit/stack operating hours), where the maximum interval between tests is four calendar quarters plus a grace period. The same gas may not be injected twice in succession. The unit must be combusting fuel during the test and must be operating at conditions of 'typical' stack temperature and pressure. However, it is not necessary for the unit to be generating electricity during the test.

For the NOx and SO_2 linearity check, the error shall not exceed or deviate from the reference value by more than 5.0%. The results are also acceptable if the absolute difference between the average of the monitor response values, and the average of the reference values is less than or equal to 5 ppm (13.1 mg/Nm^3 SO_2, 9.4 mg/Nm^3 NOx; at standard conditions of normal conditions of 760 mmHg and 25°C). For diluent oxygen or CO_2, the error shall not exceed or deviate from the reference value by more than 5.0%. The results are also acceptable if the absolute value of the difference between the average of the monitor response values, and the average of the reference values is less than or equal to 0.5% oxygen and CO_2, whichever is less restrictive.

The linearity calculation formula is:

$$LE = (R-A)/R \times 100$$

Where:
LE = percentage linearity error, based upon the reference value
R = reference value of low-, mid- or high-level calibration gas introduced into the monitoring system
A = average of the monitoring system responses.

The RATA tests the performance of the entire monitoring system of the emission source; therefore, it is the most important test. The testing criteria and appropriate reference method(s) to be followed by the particular type of industry/operation are recommended in Appendix B and A of 40 CFR Part 60, respectively. The RATA is generally carried out annually.

The RATA comprises a set of simultaneous measurements made by a CEMS and a reference method(s), in a 'head-to-head' run, to determine the relative accuracy (RA) of the CEMS. An outside consultant is generally used to complete a RATA test by comparing an emissions monitor operated in accordance with the procedures prescribed by the applicable reference method and comparing the results to the values obtained by the facility CEMS. The RA is calculated using:

$$RA = (\bar{d} + CC)/RM \text{ x } 100$$

Where:
RM = arithmetic mean of the reference method values

$\bar{d}$ = the absolute value of the mean difference between the reference method values and the corresponding continuous emission monitoring system values

cc = the absolute value of the confidence coefficient.

- A gas RATA is generally carried out once every two or four QA operating quarters – two QA quarters if the relative accuracy (RA) is 7.6–10% and four QA quarters if the RA is 7.5% or less. Some alternative RA specifications are available for low emitters. The maximum interval between successive RATAs is eight calendar quarters plus a grace period.
- Each RATA must consist of at least nine runs, and if more than nine are carried out, a maximum of three runs may be discarded to be used in the RA calculation. Each run of a gas or moisture monitoring system RATA must be at least 21 minutes in duration. A RATA is performed while firing the primary fuel for the unit.
- A gas RATA must be conducted at the normal load level (low, mid, or high), as identified in the electronic monitoring plan. If two loads are designated as normal, the test can be

performed at either load. For dual range analysers, the gas RATA is carried out at the range normally used for measuring emissions (in most cases, this will be the low range).

- The presence of stratification is determined prior to testing. The stratification test consists of a minimum of six points on each axis (12 points total), using EPA Method 1 criteria, or an alternative three-point traverse according to Part 60, Appendix B, Performance Specification 2 (located at 16.7%, 50%, and 83.7% of the diameter of the stack). The unit load must remain constant at +/- 3.0% during the stratification test. The amount of stratification for each pollutant and diluent present at the test elevation determines the number of sampling points for the reference method. It is acceptable to use a three-point traverse (based on PS-2) if the arithmetic average concentration for all traverse points is +/- 10%, if the standard deviation of the concentration is +/- 5%, or if no single point is +/-5 ppm (pollutant) +/-0.5% O_2 or CO_2 from the average. It is acceptable to use a single point traverse (1.0 metre from the stack wall) if the arithmetic average concentration for all traverse points is +/-5.0%, from, or if no single point is +/-3 ppm (pollutant) +/-0.3% O_2 or CO_2 from the average.

The bias adjustment factor (BAF) is the amount of systematic error within a system. It is a statistical analysis of the RATA reference method and CEMS test data to determine whether the CEMS measurements are biased low with respect to the reference method. The bias test is required for each SO_2 monitor, NOx monitor and flow monitor. BAFs are not required for CO_2, oxygen, or moisture monitors. If a bias test is failed, Part 75 requires that a BAF be applied to each hour of subsequent CEMS data.

$$CEM_i^{Adjusted} = CEM_i^{Monitor} \times BAF$$

Where:

$CEM_i^{Monitor}$ = data (measurement) provided by the monitor at time i

$CEM_i^{Adjusted}$ = Ddata value, adjusted for bias, at time i.

The BAF is defined by:

$$BAF = 1 + \bar{d} / CEM^{avg}$$

Where:

BAF = bias adjustment factor, calculated to the nearest thousandth

D = arithmetic mean of the difference obtained during the failed bias test

CEM^{avg} = mean of the data values provided by the monitor during the failed bias test.

In situations where the certification is not approved due to an audit test failure, or a significant repair or change is made to the monitoring system which can significantly affect the data accuracy, all the data produced during the recertification period are considered invalid and must be substituted, usually with maximum potential values. The operator must apply for recertification within 30 operating days from the failed approval. All the tests required for the initial certification must be carried out again in this case, unless otherwise approved by the administrator. Before recertification, a probationary calibration error test is required to establish the beginning point of the recertification test period. And then, each recertification test required shall be completed within a defined grace period:

- For a linearity check and/or cycle time test – 168 consecutive operating hours;
- For RATA – 720 consecutive operating hours; and
- For 7-day calibration error tests – 21 consecutive operating hours, with routine daily calibration throughout the recertification process.

5.4 COMMENTS

As US CEMS do not come pre-certified or pre-approved, a longer and more detailed process is required to ensure and demonstrate that the CEM selected is fit for purpose at the site where it is located. The US approach requires more test procedures than the EU approach. While this allows the operator to select any CEM system they feel is appropriate, including relatively new systems, it lays a 'burden of proof' on the plant to demonstrate that the system is accurate and reliable, by running comparative measurements against approved systems. This approach allows for innovation and encourages the use of new CEMS or those which have not paid for type-approval testing in the EU. However, the increased amount of work placed on the operator to demonstrate the suitability of the system may be prohibitive, especially in plants such as those in India where CEMS are a new feature.

6 DATA MANAGEMENT AND REPORTING

A correctly installed and operated CEMS will report data continuously and in real time. How that data is managed and reported varies nationally and even regionally. In some places, data are reported instantly to the regulatory authority whereas in others, the data may be processed and summarised (standardised, estimated as an emission load, or averaged over a stipulated time interval). In each case, the reporting format is determined according to the legislation to ensure that the data from the CEMS is appropriate for compliance reporting.

6.1 EUROPE

In Europe, one-minute average data are typically used as the basis for determining other reporting averages, such as half-hourly mean, hourly mean, and daily mean values. The period used depends on the specific reference conditions and the regulatory requirements. The data from the CEMS are recorded and stored with the respective plant-specific operating conditions/signals and are then supplied through an industry server to the regulator. If a facility moves out of compliance with the emission limits, the operator is required to report this to the relevant authority immediately. All measurement results must be kept on file by the operator for seven years (OEE, 2021).

Data acquisition and handling systems (DAHS), certified under the MCERTS and TÜV schemes, are commercially available. Different options are available to suit the requirements for data recording, data processing, integration with plant processes, and reporting according to the operating license. DAHS must comply with performance specifications, including European standard EN 17255 (Part 1, 2 and 3) in support of EN 14181. The use of DAHS in Europe are determined by various requirements:

- The requirements in the plant licence are used to select an appropriate DAHS. For example, a sophisticated system will be required for complex and sensitive operations, whereas a simpler system would be acceptable for a smaller, low-risk process or facility. The DAHS will be selected to cover the parameters required, such as the number of components to be recorded, the averaging periods (such as 30 minutes, hourly or daily), data conversion (such as ppm to mg/m^3), and any data corrections required (to reference conditions of temperature, pressure, moisture, and oxygen, where applicable). The DAHS supplier or the plant operator will configure the system as required to collect data and undertake the calculations needed to produce results which demonstrate compliance. The selection of an appropriate system is the responsibility of the plant licence holder. The MCERTS and TÜV certification systems which are used to certify CEMS can also certify DAHS and can confirm that certified models are appropriate to collect data in the manner required by the relevant EU directives.
- The basis of the regulatory requirements is one-minute averages. A minimum sampling period of one reading every 10 seconds is required. The minimum number of data points that make

up a one-minute average is six but can be as high as 30. The DAHS calculation steps are documented in sequence and made available for review by the regulatory authority during site inspections. The calculations should be reported in order from raw data through to the reported values. The one-minute average raw data (minimum of six data points) is reported in full and cannot be edited. Then the calculation of corrected values is recorded on a copy of the raw data. The process of the determination of averages (30 minutes, hourly, and/or daily) must also be documented.

- The verification of data during the installation and operation of the DAHS is critical to ensure representative data, which involves the CEMS supplier or a certified testing organisation. For this, the data on the analyser panel is checked against data collected from DAHS. This is especially important for older systems with analogue to digital converters. This verification is carried out during instrument commissioning, after any change to the CEMS or to the DAHS, and at regular intervals to confirm that the data are correct.
- CEMS are typically required to provide data availability over 95% of the operating time, although this can be extended based on a risk-based assessment. The Industrial Emissions Directive and other European regulations specify the availability requirements for CEMS. For a daily average value to be valid, an operator may discard a maximum of up to five half-hourly average values on any day if they are deemed invalid due to a malfunction, a calibration incident, drift checks, or any other maintenance requirement which will affect the CEMS.
- 20 minutes of data in any given half-hourly period is considered representative of the full half-hour. The same is true for 40 minutes of data in an hourly average period. This approach is deemed statistically acceptable for a validated data set and thus includes sufficient gaps for periods of calibration and drift checks.
- Data security is critical for both the operator and regulator to achieve this:
  - the raw data collected is securely stored in a format which cannot be edited;
  - the calculations are then undertaken on a copy of the secure data;
  - the calculations are in accordance with the licence requirements;
  - the calculations used are made available for review;
  - any changes made to the data are documented automatically with a date and time stamp so that these changes can be reviewed; and
  - a limited number of competent people have access to the DAHS set-up configurations, data, and calculations.
- Under licence conditions, the data must be kept secure, and a copy must be retained at another location for seven years. This should include raw, calculated, and reported data. In addition, any operational data that is required under the licence and impacts on emissions should be stored.

- Metadata accompanies the emission data from the CEMS that are recorded with the DAHS. These include data from the CEMS in calibration, any CEMS fault data and data collected during the CEMS maintenance mode. Besides these, any relevant situations or conditions which affect the plant process such as changes in fuel feed, temperature, and oxygen supply are also recorded clearly.
- All licence conditions relating to the CEMS must be understood and fulfilled. For example, if the licence requires that the process is shut-down when the CEMS is not operational, an interlocking system may be required which prevents plant operation until the CEMS is returned to full operational status. The operator may need to set warning and alarm limits (relative to the ELV, such as at 80% of ELV) based on the requirements for ensuring compliance.

6.2 USA

The requirements for CEMS data reporting by the industries in the US are mandated under many federal and state air quality regulations and programmes, including the state implementation plan, the state-specific administrative rules for air pollution control, the New Source Performance Standards (NSPS), the Acid Rain regulations in 40 CFR Part 75, and the Clean Air Act Amendments (CAAA) 1990. Depending upon the applicable regulatory and programme requirement, the data acquisition and reporting requirements may also vary. Once a CEMS is selected, a suitable DAHS must be identified, and the complete monitoring plan submitted to the Air Quality Division for performance testing and approval. The DAHS must be sufficiently flexible and equipped with features to provide data in the required units, formats, and intervals (MDEQ, 1998).

40 CFR Part 60 carries process/industry-specific compliance requirements, protocols, exceptions, and alternatives for different pollutants. For example, the reporting of PM is in the form of a percentage opacity whereas gaseous pollutants are reported as load in lb/MMBtu or ng/J and as concentrations in ppm. Gas flow is reported as standard cubic feet per hour (scfh), oxygen as a percentage, and CO_2 as a percentage as well as t/h as load.

40 CFR Part 75 also explains the requirements for CEMS implementation, from selection, installation, and quality assurance to data handling, data substitution and the notification of exceptions. Once the CEMS is installed, Part 75 requires hourly data recording, including during start-up, shut-down, and instances of malfunction. It requires quarterly reporting of all data to the USEPA.

The plant operator must record and submit the following as a minimum reporting requirement, although individual state and federal programmes may have additional specific requirements (ECFR, 2022):

- Initial certification and recertification applications;
- Monitoring plans;
- Quarterly reports;
- Other petitions and communications;
- Quality assurance RATA reports;
- Notifications and routine test and retest reports;
- Annual monitoring report (subject to Acid Rain emission limitations and State or federal NOx mass reduction programs); and
- Ozone season monitoring requirements (where applicable).

Under regular pollution monitoring provisions, the plant operator must submit quarterly data electronically for the relevant operating period. The operator must record hourly data on the unit operating time, heat input rate, and load for each unit or group of units which share a common stack and a common monitoring system, or which share a common pipe header and a common fuel flowmeter. The submitted information must include the date and hour, the unit operating time, the hourly gross unit load (MW, steam load in 1000 lb/h or MMBtu/h of thermal output), the operating load range, the hourly heat input rate (MMBtu/h), the identification code for any formula used for heat input, the *F* factor for the heat input calculation, and an indication of any diluent cap used for the hour. The State or local air pollution control agency may specify which data are recorded. Otherwise, the requirements will follow those in the CFR Part 75, ensuring the reporting of the monitored data, notification of any outage, the reason for the outage and details of corrective action taken. In addition to the component/system identification codes and the specific date/time, certain basic information must be recorded, depending on the pollutant, as summarised below.

For PM monitoring:

- The average opacity of emissions for each six-minute averaging period (in % opacity) must be reported;
- If the average opacity of emissions exceeds the applicable emission standard, then a code indicating that an exceedance has occurred must be sent; and
- The monitor data availability (as a percentage recorded to the nearest tenth of a per cent) is calculated according to the requirements of the procedure recommended for the relevant State Implementation Plan.

For gas monitoring:

- Monitoring is generally carried out during unit operation and is commonly supported by a certified back-up monitor or other approved method of determining emissions. For each monitor or method, a record must be kept of the component ID and the date and time.

- For emissions such as SO_2 and NOx, the data collected must include:
    - the hourly average concentration (ppm);
    - the hourly average concentration (ppm) adjusted for bias if bias adjustment is applicable (while required for SO_2 and NO_X reported for allowance trading purposes, BAFs are not used for emissions values reported to demonstrate compliance with emission limits);
    - the percentage monitor data availability; and
    - the method of determination/calculation for the hourly average concentration.
- The flow rate during unit operation, as measured and reported, must be recorded for each certified primary monitor, certified back-up monitor, or other approved method of emissions determination.
- The hourly average flow rate (in scfh), adjusted for bias factor, if applicable, must be reported with the percentage data availability and the method of determination of the hourly average flow.
- The flue gas moisture content should be recorded as an hourly average (as a percentage), along with the percentage data availability and the method used for determining the hourly average percentage moisture.
- SO_2 mass emissions, reported hourly in lb/h under Part 75, should be recorded and adjusted for bias if required. The code of the emission formula used to calculate the mass emission must also be reported.
- The NOx emission rate (in lb/MMBtu) can be measured by a NOx-diluent monitoring system, or the NOx concentration (in ppm) can be measured by a NOx concentration monitoring system. Both can be used to calculate NOx mass emissions. In addition to the component ID and the ID of the associated moisture monitor, the following data must be measured and reported:
    - the hourly average diluent gas concentration (for NOx-diluent monitoring systems) in units of % O_2 or % CO_2);
    - the hourly average moisture (%) content, if applicable;
    - the hourly average NOx emission rate. For NOx-diluent monitoring systems only, this will be in units of lb/MMBtu), adjusted for bias if required;
    - the data availability (%) for the NOx-diluent or NOx concentration monitoring system, and, if applicable, for the moisture monitoring system;
    - the method of determining the hourly average NOx emission rate or NOx concentration and the hourly average percentage moisture, if applicable; and
    - the identification codes for the emissions formulas applied, and (if applicable) the F-factor used to convert NOx concentrations into emission rates.
- The operator must install a monitor for CO_2, except for low mass emission units. The operator must record hourly average concentrations and volumetric flow, the hourly average

moisture content, hourly average mass emission rates, data availability for the CO_2 and moisture monitors, the method of determination, and any relevant emission formula identification codes.

- CO_2 mass and concentration emission can also be monitored using a continuous oxygen monitor, fuel F and Fc factors, and a moisture monitor, if oxygen is measured on a dry basis.
- As an alternative, CO_2 mass emission can also be measured based on the combusted fuel carbon content. For units with wet-FGD or other add-on emission controls generating CO_2, both combustion-related and sorbent-related (based on sorbent consumed) emissions need to be measured. The operator must calculate daily, quarterly, and annual CO_2 mass emissions (in tons).
- General recordkeeping provisions require the operator to maintain a file of all measurements, data, reports, and other information at the source in a form suitable for inspection for at least three years from the date of each record, right from the provisional or final certification or from the compliance deadline, whichever is applicable.

The reported emission data from sources in the USA are considered public information. Any other information that the reporting party or operator considers confidential (such as proprietary business information) must be negotiated with the relevant authority during submission with substantiation (ECFR, 2022).

6.3 INDIA

In India, the system of data collection, transfer and use for compliance checks is defined by the regulatory requirement.

6.3.1 Online data reporting

The Indian system of data acquisition and handling for CEMS is among the most automated and advanced in the world. The data, collected in real-time, are reported directly from the CEMS to the relevant authority with data from flow meters. At many sources, live streaming from cameras is also required. All this information and data is delivered using a single integrated network to the regulator's server (CPCB and relevant SPCB). The source access to CEMS data is also accessed via this central shared server. The system is summarised in Figure 9.

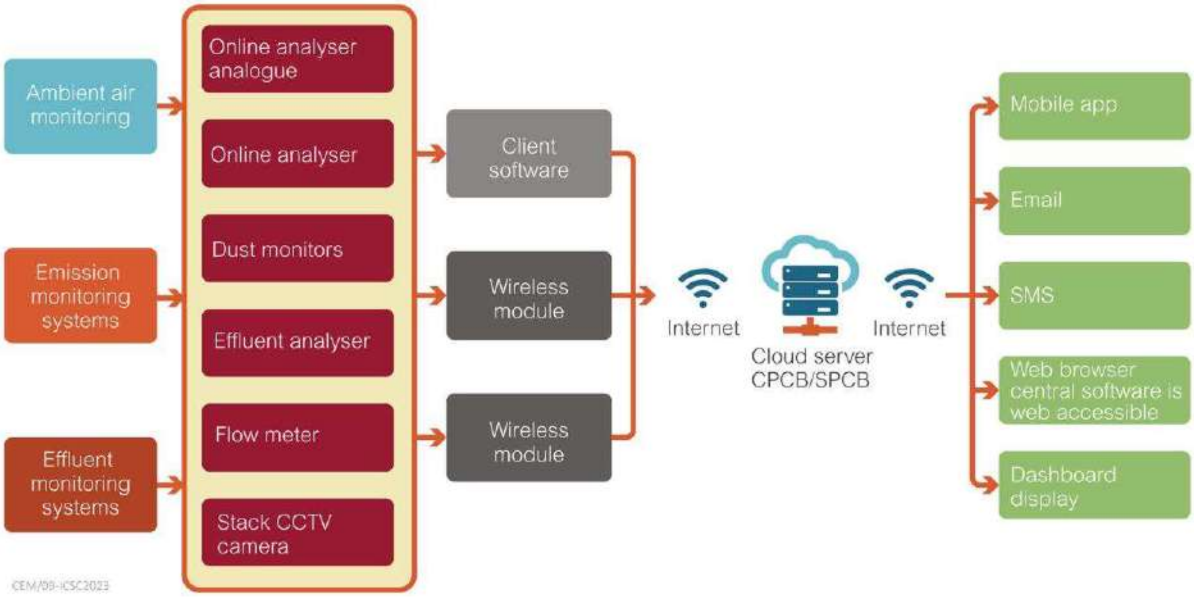

Figure 9 Real-time data handling system in India (Kanchan, 2019a)

The important features of the Indian real-time data acquisition and handling system include the following:

- An integrated system which can capture the data directly from the CEMS, encrypt it and send it to the regulatory servers at both the CPCB and respective SPCB simultaneously through an Internet of Things (IoT);
- No intermediate server, system or computer is allowed to prevent any chance of data manipulation or human intervention;
- Two-way persistent connectivity and video streaming capability;
- Scalable network system which can support any future addition of monitors;
- Architecture based on IoT protocols and push technology with local polling and logging to prevent data loss in the absence of internet connectivity;
- Internet (4G, GPRS, ethernet, wi-fi connectivity) as a backbone network for connectivity between the gateways/remote terminal units and the cloud servers;
- The data acquired from the devices are wrapped in ISO standardised and secure protocols to make the data standardised, uniform, and free of monopoly, for better utilisation of bandwidth with lower data latency;
- Data, highly secured through encryption, is pushed to the cloud server using GSM/GPRS data connectivity. Data access is authorised appropriately by the regulator;
- The cloud software platform receives the data from the gateways/remote terminal units directly from the CEMS;
- Powered by real-time IoT technology for communication and Big Data for data storage and analytics;

- Software and networking system equipped with site and device diagnostics, network management facilities, alarm systems, user authentication systems, audit logs and data flag systems;
- Big Data support for vast scalable storage and access of data; and
- Dashboard with many useful facilities for analysis (such as statistical analyses, calibration records, exceedances, data gaps, non-compliances, and live data) and generation options for various reports.

The data acquisition and handling system is registered with the CEMS installation and carries equipment ID information. The regulator server receives real-time data from the CEMS device which can be seen both as raw data and as data presented in, for example, mandated 15-minute rolling average data in the tabular form or as graphs demonstrating concentrations over the desired period of time. The data can be compared with the prescribed standards for every stack and parameter. The system can then communicate any exceedances as SMS alerts and emails to the relevant officials at a source, as well as report these exceedances to the relevant SPCB and CPCB.

6.3.2 Remote calibration system for gaseous CEMS in India

One of the important features of India's real-time data acquisition and handling approach is the potential for remote calibration for gaseous CEMS. Since 2018, the CPCB have initiated random 'remote calibration' procedures to check the reliability of the installed gaseous CEMS at various sources. The direct connectivity and two-way communication between the analyser's diagnostic control and the regulator's server make this possible.

Since the regulator monitors the CEMS data in real-time, it can also carry out checks during instances of repeated and prolonged abnormal data transmission from a CEMS at a specific source. To cross-check the reliability of the specific CEMS in question, the regulator can carry out remote calibration. This is not a recalibration of the CEMS but rather a means to challenge the CEMS with a known concentration of the specific pollutant in order to confirm that the CEMS is reporting accurate data.

The regulatory authority coordinates with the source operator to ensure that all the calibration systems are intact and connected to all the CEMS on site to facilitate the remote calibration. However, the source operator is not told which specific CEMS system will be tested; this information is kept confidential to minimise the chance of human interference. A remote zero check and span check command is sent remotely from the regulator through the server software and the response data are received directly from the CEMS. If the CEMS does not respond accordingly, appropriate action is taken. A schematic of the remote calibration system is shown in Figure 10.

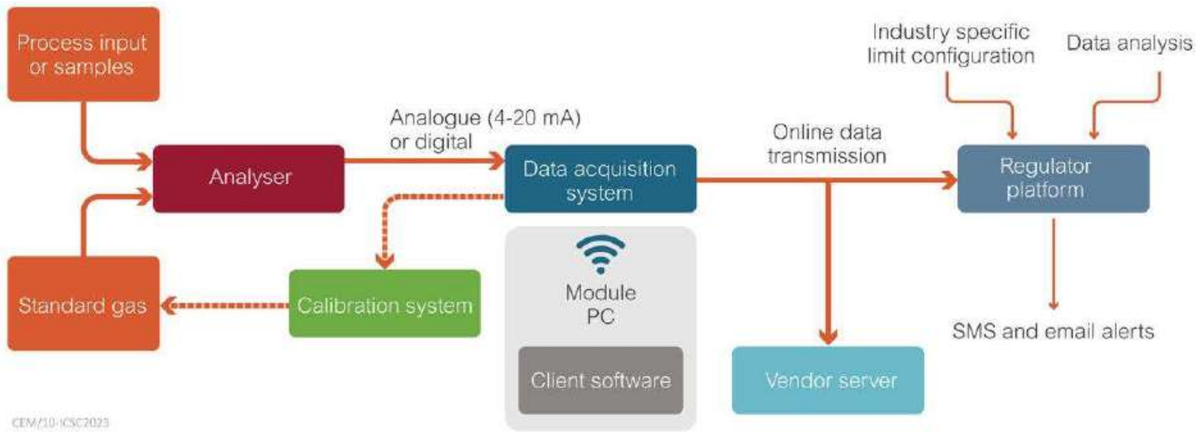

Figure 10 Direct data transmission set-up for remote calibration of CEMS (Kanchan, 2019a)

The logs of the calibration or remote calibrations are maintained in the server which can be accessed when required. According to the ICSC report on the status of CEMS implementation in coal-fired power plants in India (Sloss and others, 2021), the option for remote calibration is available on most commercial CEMS. It is not commonly used in Europe or the USA, other than occasionally for remote troubleshooting by the CEMS manufacturer. The EU and USA are hesitant to introduce remote calibration due to concerns over allowing direct remote access to any CEMS system. These concerns include:

- The potential for hacking/disruption of the automated system;
- The need to ensure that the correct calibration gases are available and installed correctly before any calibration is initiated;
- Plants would need to be aware of when remote calibration is likely to happen to ensure that everything is in place to facilitate the event; and
- Reluctance by CEMS manufacturers to allow access to CEM operating systems, since some CEMS operational information is proprietary.

In India, the remote calibration system has focused the attention of the operator on valid CEMS operation and maintenance. This has reduced the chances of human tampering and manipulation of the system and, at the same time, has improved the transparency and trust between the regulator and operator, which is an important step towards a self-monitoring regime.

6.3.3 Compliance reporting

A Compliance Reporting Protocol was published by the CPCB in March 2018. The protocol includes the general information relating to plant operation, emissions, relevant CEMS and CEQMS installations, and the IT protocols for data submission. The protocol also advises quarterly information submissions from the source on the operation and calibration procedures which have been adopted. Importantly, this compliance reporting protocol proposed an Automated Alerts Generation Protocol which must be followed by all the industries (initially this was only for the cement and pulp and paper industries).

According to the protocol, there are four levels of alert (yellow, orange, red, and purple) in order of increasing severity of departure from the emission standards as well as any issues associated with connectivity, malfunction, and the overall frequency of malfunctions (CPCB, 2018c). The alerts are issued automatically by the server software. Some key points of this system are shown in Table 11.

TABLE 11 AUTO ALERTS GENERATION PROTOCOL FOR INDIAN INDUSTRIES (CPCB, 2018)

Alert levels generation	Reasons	Remarks
Yellow (Level 1) alert	PM, SO_2 or NOx exceed the emission limit by >25% of the 15-minute average parameter from the permissible limit more than eight times per day. PM emissions deviate from the limit by >60% for eight consecutive readings. SO_2 or NOx emissions deviate from the limit by >25%, for eight consecutive readings. Internet failure/power failure/sensor failure for up to four hours, six times in a 30-day rolling period. when emission parameters are stable, with less than 2% deviation, for more than 48 hours.	Yellow alerts autogenerate an alert letter or email. If these alerts are generated due to plant start-up or shut-down, an event log must be created, and a special note should be sent to the CPCB regarding this within 24 hours. In the case where data are not being reported at the server, but are being sent, the CPCB must be informed, with the evidence.
Orange (Level 2) alert	More than 36 alerts are issued during any 30-day rolling period. PM concentration deviates from the limit by >60% for 32 consecutive readings. SO_2, or NOx deviate from the limit by >25% for 32 consecutive readings or there are four yellow alerts for >60% exceedance or >25% exceedance. Connectivity (power or internet) is lost for 72 hours continuously. Connectivity (power or internet) is lost for 4 hours for more than 12 times over a 30-day rolling period. Emission parameters are stable (less than 2% deviation) for more than 72 hours.	Orange alerts trigger autogenerated alert letters or emails which require a reply by mail. The facility must act immediately to correct any issues with air pollution control systems or connectivity and must inform SPCB/CPCB of actions taken.
Red (Level 3) alert	More than 72 yellow alerts are issued during any 30-day rolling period. Connectivity (power or internet) is lost for four hours or more, up to 18 times over a 30-day rolling period. Connectivity (power or internet) is lost for 144 hours or more. PM concentration deviates from the limit by >60% for 96 consecutive readings (12 yellow alerts for >60% exceedance). SO_2, or NOx deviate from the limit by >25% for 96 consecutive readings. When emission parameters are stable (less than 2% variation) for more than 144 hours.	Red alerts trigger autogenerated alert letters or emails which require a reply by mail. The source must act immediately to correct any issues with air pollution control systems and must inform SPCB/CPCB of actions taken. The source must also report any issues with emissions or effluent and must explain the reasons for the poor performance of air pollution control systems.

Purple (Level 4) alert	More than one red alert has been issued during any 30-day rolling period. Connectivity (power or internet) is lost for four hours, more than 24 times over a 30-day rolling period. Connectivity (power or internet) is lost for more than seven days. PM concentration deviates from the limit by >60% for 192 consecutive readings (24 yellow alerts for >60% exceedances). SO_2, or NOx deviate from the limit by >25% for 192 consecutive readings and when emission parameters are stable (less than 2% deviation) for more than 144 hours.	Purple alerts autogenerate a letter seeking an explanation within 15 days. Corrective measures must be taken immediately, which may mean the closure of the plant. Root-cause analyses and action must be reported to the SPCB and CPCB and a third-party investigation may be assigned.

6.4 COMMENTS

CEMS guidelines in India require data to be reported on a 15-minute average basis for compliance checks, although all the raw data are supplied directly, continuously and in real-time from the CEMS to the server. The data are used to assess and analyse the performance of industrial sources. The legal basis for the use of this data for compliance purposes depends on the situation. Currently, there are still issues in the implementation of CEMS to meet compliance monitoring requirements in India, including:

- Amendments in the Air (Prevention and Control of Pollution) Act of 1981, the Water Pollution (Prevention and Control of Pollution) Act of 1974, and the Environment (Protection) Act of 1986, which each provide a legal basis only for manual sampling and monitoring processes.
- The current Indian CEMS guidelines require that a national system is established for the identification and implementation of qualified laboratories to carry out independent checks of CEMS installation, performance checks, calibration, and other tests and to provide independent assurance. To date (May 2023), this system is not in place in India.
- The guidelines also call for the establishment of an indigenous certification system for CEMS and this is still missing.
- A compliance check mechanism is still lacking and faces potential implementation issues, including:
  - the US and EU apply a rolling average (95% data) for CEMS data against compliance emission limits. The use of strict 15-minute averaged data in India is not realistic;
  - data validity conditions are undefined;
  - data availability compliance conditions are undefined;
  - the mechanism for data substitution in case of data gaps remain undefined;
  - rules for dealing with exceptional compliance conditions (such as data recorded during shut-down and start-up period) are not yet defined; and

- improved data security mechanisms are required to maintain data quality and to secure and protect remote access.

Data reporting in the EU and USA has evolved to suit emerging technologies and relevant emission limits. Operators must record all data and make these available on request. However, they must only present some of the data to the regulator, for example, hourly averages and monthly averages. This allows plant operators to analyse and understand their own data and it, importantly, allows them to flag and 'justify' or explain any exceedances or extended periods of non-compliance. In some situations, this will be due to an error with the CEM, an unexpected plant shut-down or some other incident which can be explained. This allows the plant to present a report to the regulator which already explains issues of concern so that action against the plant is only taken when necessary.

In India, all CEM data are reported live and unedited to the regulator. This results in a high level of command and control, allowing the swift identification of plants of concern, but it also means that relatively common, arguably unimportant, periods of non-compliance, which may arise due to common CEM or plant issues, also result in plants being flagged as being of concern. There is a risk that excessive warnings may mean that real incidents of concern are lost in the noise. It is therefore important that, as the Indian system evolves, options become available for some data management by the source, including, for example, the cancellation of alarms which result from CEM malfunctions rather than real plant issues.

7 ONGOING TRAINING AND CAPACITY BUILDING

As CEMS systems evolve and new monitors become available, it is important that QA/QC requirements evolve accordingly. However, it is also crucial that the personnel operating CEM are also demonstrated to be appropriately trained in this QA/QC. This will include the vendors, those installing the CEMS, and those operating the CEMS on a daily basis. It should also include any regulators or independent bodies who are responsible for auditing CEMS operations.

CEMS training must cover the following key topics:

- Available technology and its suitability;
- Selection of the right technology;
- Correct installation and setting;
- Calibration, O&M, and troubleshooting;
- Data acquisition and handling;
- Regulatory requirements;
- Best technology and practices; and
- Self-inspection and analysis.

The UK and the USA have established systems for official training and certification for individuals who carry out emissions monitoring. These qualifications, specific to each country, are generally seen as essential for anyone performing stack testing. The training and certification cover CEMS and additional areas of stack testing, including manual monitoring, wet chemical methods, data handling and health and safety on site.

In the UK, the MCERTS scheme established by the UK Environment Agency (UKEA) covers all areas of emission and effluent monitoring. This training is commonly delivered via the UKEA or through the UK Source Testing Association (STA). The relevant courses for those who handle CEMS include CEM operation, data management, and competence certification for personnel. Certification can be obtained both at the individual level and the organisation level. Individuals can advance through three levels of competency from trainee to team leader. Similarly, in the USA, the US Source Evaluation Society (SES) has established the Qualified Source Testing Individual (QSTI) and Qualified Source Testing Observer (QSTO) certification scheme to demonstrate that qualified staff have the knowledge and skills required to apply source testing methods correctly. The qualification is voluntary but is approved by the USEPA (SES, 2021).

India does not currently have any such training system for CEMS operation. Following the launch of CEMS requirements in India, only a few generic training courses have been organised by the CPCB, SPCBs and some independent research and advocacy organisations. This is not sufficient to ensure that CEMS are operated correctly, and that the data are consistently valid for compliance reporting. This lack of training and capacity building across stakeholder groups will contribute to serious implementation challenges ultimately resulting in poor data quality. Training and capacity building is essential to delivering best practices for CEMS.

The ICSC, under a US Department of State (DOS) funded programme, delivered four training workshops in India in 2022 (Bhubaneswar, Bhopal, Visakhapatnam, and New Delhi). The training materials from these courses are available from www.sustainable-carbon.org and through CEEW. However, for these legacy materials to remain valid and useful, it is critical that Indian stakeholders take ownership of this initiative and work together to establish a nationally recognised training scheme for CEMS in India. To this end, the ICSC, with approval from the USDOS, has established CEM-India, a stakeholder working group which focuses on the advancement of CEM training and use in India. As this initiative grows, information will be made available on the ICSC website.

CEM-INDIA

8 REFERENCES

CEN, Comite European de Normalisation (2004) *Stationary source emissions – quality assurance of automated measuring systems: EN14181.* Available from: https://www.g2datasystems.co.uk/continuous-emissions-monitoring-software/en-14181/82/ (2004)

CEN, Comite European de Normalisation (2017) CSN EN 13284-1. Stationary source emissions – determination of low range mass concentration of dust – Part 1. Available from: https://www.en-standard.eu/csn-en-13284-1-stationary-source-emissions-determination-of-low-range-mass-concentration-of-dust-part-1-manual-gravimetric-method/ (2017).

Cornell (2023) Legal Information Institute website, 40 CFR Part 75, Appendix A to Part 75 - Specifications and Test Procedures. Available from: https://www.law.cornell.edu/cfr/text/40/part-75/appendix-A (accessed April 2023)

CPCB, Central Pollution Control Board, India (2017) Guidelines for Continuous Emission Monitoring Systems. Available from: https://cpcb.nic.in/upload/thrust-area/Guidelines_on_CEMS_02.08.2017.pdf (Jul 2017)

CPCB, Central Pollution Control Board, India (2018a) 1st Revised Guidelines for Continuous Emission Monitoring Systems. Available from: https://cpcb.nic.in/upload/thrust-area/revised-ocems-guidelines-29.08.2018.pdf (Jun 2018)

CPCB, Central Pollution Control Board, India (2018b) Compliance Reporting Protocol for Online Continuous Effluent & Emission Monitoring Systems (OCEMS). Available from: https://cpcb.nic.in/upload/thrust-area/Common_Protocol_final-13.03.2018.pdf (2018)

CPCB, Central Pollution Control Board, India (2016) Modified directions to SPCBS/PCC on Revised Classification of Industrial Sectors Under Red, Orange, Green and White Categories. Available from: https://cpcb.nic.in/categorization-of-industrial-sectors/ (Mar 2016)

CPCB, Central Pollution Control Board, India (1985) COINDS: Emission Regulation Part-III Available from: http://www.cpcbenvis.nic.in/scanned%20reports/EMISSION%20REGULATIONS%20PART_3.pdf (1985)

Curtis D (2017) CEMS: A technical Guidance Manual. New Delhi, India, CSE Centre for Science and the Environment, 94 pp (2017)

ECFR, US Code of Federal Regulations (2022) Title 40, Chapter-I, Subchapter C- Part 75, Subpart G. Available from: https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-75#subpart-G (as viewed in September 2022)

ISO, International Standards Organisation (1996) ISO 11095:1996 Linear calibration using reference materials. Available from: https://www.iso.org/standard/1060.html (1996)

Kanchan S K (2019) Presentation: CEMS and CEQMS Implementation https://www.jspcb.nic.in/upload/uploadfiles/files/JSPCB-%20Sanjeev%20Kanchan-CEMS,%20CEQMS%20implementation%20in%20India%20(1Merged.pdf)

Kanchan S K (2019a) *Real-time Monitoring-a Step Ahead.* Available from: https://blogs.knowledgelens.com/index.php/2019/05/23/real-time-monitoring-a-step-ahead/ (May 2019)

MDEQ, Michigan Department of Environmental Quality (1998) Guidance For Continuous Opacity and Emission Monitoring Systems, p3-5 (1998) https://www.michigan.gov/-

/media/Project/Websites/egle/Documents/Programs/AQD/Compliance/fact-sheet-coms-cems.pdf?rev=28056e50f39d495cb0b9e6a6a704164a

MPCB, Maharashtra Pollution Control Board, India (2021) Available from: https://mpcb.gov.in/sites/default/files/standing_orders/enforcement_policy/highlyPollutedindustries_selfMonitoringCompliance_cpcbDirections.pdf (as viewed on 30th August 2021)

OEE (2021) Air Emissions Guidance Note on CEMS maintenance and operation requirements (AG13). Available from: https://www.epa.ie/publications/compliance--enforcement/air/air-guidance-notes/AG13-CEMS-Guidance_.pdf Environmental Protection Agency Office of Environment Enforcement (OEE), p 50–54 (Dec 2021)

Rolling C (2023) Change Management of certified AMS according to EN15267(QAL1). Available from: https://www.ilmexhibitions.com/pdf/change-management-of-certified-ams-according-to-EN15267.pdf TÜV Rheinland, Germany (accessed April 2023)

Sloss L L, Kanchan S K, Jozewicz W (2021) Status of continuous emission Monitoring systems at coal-fired power plants in India. Available from: https://www.sustainable-carbon.org/download/40177/ London, UK, International Centre for Sustainable Carbon, 75 pp (2021)

Sophie L (2007) JRC Scientific and Technical Reports, 2007: Environmental Technologies Verification Systems. Available from: http://ec.europa.eu/environment/archives/ecoinnovation2007/2nd_forum/pdf/publication.pdf p 57 (2007)

UKAS, Accreditation Service, UK (2023) *ISO 17025 – laboratory accreditation.* Available from: https://www.ukas.com/accreditation/standards/laboratory-accreditation/?gclid=CjwKCAjw_YShBhAiEiwAMomsEN5RD6gVyRm2eleqpsr4oXuZLHYszCuohB-BQM4w-xgGNMJgHssuYxoCiJYQAvD_BwE (accessed April 2023)

UKEA, Environment Agency (2021) *M20 – Technical Guidance Note (Monitoring): Quality assurance of continuous emissions monitoring systems – application of EN 14181, version 5*. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/977200/TGN_M20_-_Quality_assurance_of_continuous_emission_monitoring_systems.pdf London, UK, Environment Agency (2021)

USEPA, US Environmental Protection Agency (2009) Plain English Guide to the Part 75 Rule. Available from: https://www.epa.gov/sites/default/files/2015-05/documents/plain_english_guide_to_the_part_75_rule.pdf (2009)

USEPA, US Environmental Protection Agency (2022a) Clean Air Market – Emission Monitoring. Available from: https://www.epa.gov/airmarkets (as viewed in Jul 2022).

USEPA, US Environmental Protection Agency (2022b) Performance Specification 1 - Specifications And Test Procedures For Continuous Opacity Monitoring Systems In Stationary Sources. Available from: https://www.epa.gov/sites/default/files/2019-06/documents/performance_specification_1_0.pdf (as viewed in Dec 2022)

USEPA, US Environmental Protection Agency (2022c) Procedure 3—Quality Assurance Requirements For Continuous Opacity Monitoring Systems At Stationary Sources. Available from: https://www.epa.gov/sites/default/files/2017-08/documents/procedure_3.pdf (as viewed in Dec 2022)

USEPA, US Environmental Protection Agency (2022d) Specifications And Test Procedures For Particulate Matter Continuous Emission Monitoring Systems At Stationary Sources. Available from: https://www.epa.gov/sites/default/files/2019-06/documents/performance_specification_11.pdf (as viewed in Dec 2022)

USEPA, US Environmental Protection Agency (2022e) Procedure 2—Quality Assurance Requirements For Particulate Matter Continuous Emission Monitoring Systems At Stationary Sources. Available from: https://www.epa.gov/sites/default/files/2018-08/documents/procedure_2.pdf (as viewed in Dec 2022)

USEPA, US Environmental Protection Agency (2023) National Archives: Code of Federal Regulations, Title 40. Available from: https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-75?toc= (accessed 2023)