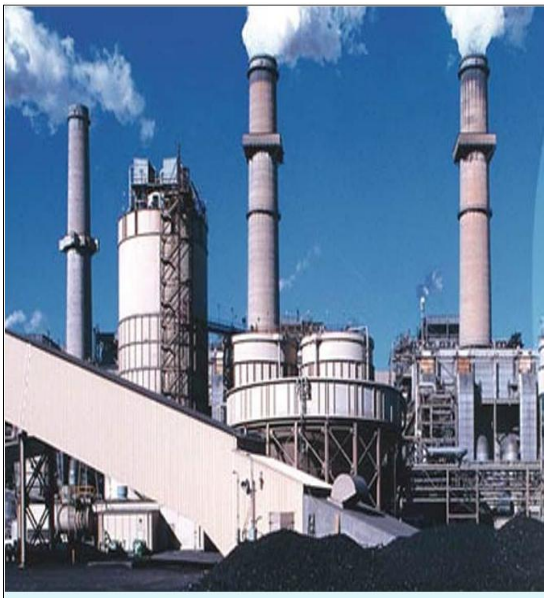
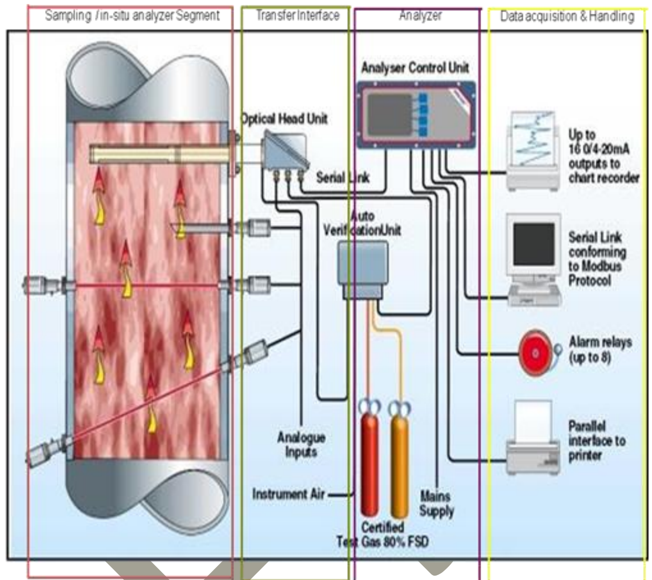
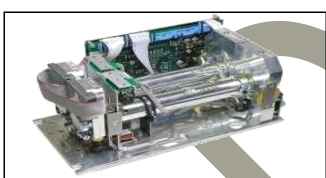
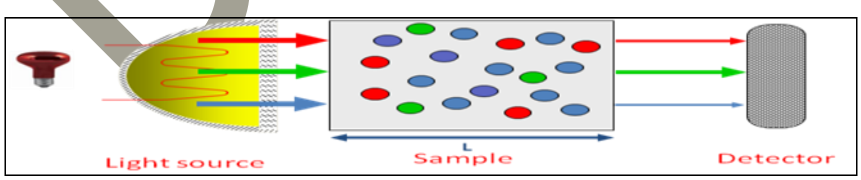
GUIDELINE MANUAL FOR CONTNUOUS (REAL TIME) EMISSION MONITORING (CEM) IN INDUSTRIES









Central Pollution Control Board

(Ministry of Environment & Forests & Climate Change, Govt. of India)

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List of Abbreviations

APCD	Air Pollution Control Device
CEM	Continuous emissions monitor
CEMS	Continuous Emissions Monitoring System
CGA	Cylinder gas audit
Cl_2	Chlorine
CPCB	Central Pollution Control Board
CO	Carbon monoxide
CO_2	Carbon di-oxide
COP	Certificate of Product
EE	Excess emission
EER	Excess Emission Report
EPA	Environment Protection Agency
ESP	Electrostatic precipitator
HCl	Hydrogen chloride
HF	Hydrogen fluoride
Hg	Mercury
MCerts	Monitoring Certification Scheme for equipment, personnel and organisations
mg /Nm^3	milligram per normal cubic meter
m^3	Cubic meter
MDT	Monitor Down Time
Nm^3/h	Normal cubic meters per hour
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Oxides of Nitrogen
O_2	Oxygen
%	Percent
% m/v	Percent Mass by Volume
% m/v	Percent Volume by Volume
PM	Particulate Matter
ppm	Parts Per Million
ppb	Parts Per Billion
QA	Quality Assurance
QC	Quality Control
RAA	Relative Accuracy Audit
SO_2	Sulphur dioxide
SOP	Standard Operating Procedure
SRM	Standard Reference Method
STP	Standard Temperature and Pressure
TÜV	Technischer Überwachungsverein (German: Technical Monitoring Association)

Definition of Terms

As-found (Unadjusted Value):
With regard to CEMS response during an audit, calibration or performances check. An "as-found" check is the status of current instrument / monitor output.

Audit:
An as-found accuracy assessment of CEMS components using a certified / best available standard conducted by authorized personnel of empanelled laboratory.

Calibration:
It is the process of establishing the linearity in the selected measurement range through adjustment, so that its readings can be correlated to the actual value being measured.

Calibration Error:
It is the difference between the responses (signal) of the instrument for pollutant, at same conditions maintained in calibration against a known value of the appropriate reference without adjustment.

Calibration Gas:
Best available Calibration gases suitable for declared measurement ranges with precision and accuracy shall be used. National or international traceability of the calibration gas is desirable otherwise best available standards are also acceptable.

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

Continuous Emissions Monitoring System:
Equipment used to collect representative sample, transport the gas to analyser including pre-conditioning, analyse and provide permanent record of emissions or process parameters.

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

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

***Downstream*:** In the direction of the stack gas flow (e.g. a point near the top / exit of the stack would be downstream of a point near where the gases enter the stack).

Equivalent Diameter:
A calculated value used to determine the upstream and downstream distances for locating flow to pollutant concentration monitors in flues, ducts or stacks with rectangular cross-sections.

Excess Emissions:
The amount by which recorded emissions exceed those allowed by regulations (limits specified)

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

Emission Load:
It is defined as quantity of pollutants being emitted through stack against time.

***Extractive Monitoring System*:**
A system that withdraws gas sample from the stack and transports the sample to the analyzer, i,e; analysis takes place in different condition from emission.

Flow Monitor:
It is a component of the CEMS that measures the velocity and volumetric flow rate of the exhaust gas.

Full-Scale Range:
The absolute calibrated maximum value of a pollutant monitor's measurement ability that may equal or exceed the span value (provided linearity in extrapolated range exists).

In-Situ Monitor:
CEMS design that measures source-level gas emissions directly inside a stack or duct at actual conditions. For pollutant or combustion gas measurements, the source emission gas is not conditioned, so it is considered a 'wet' measurement.

Industrial Premises / Facility:
Any applicable stationary air contaminant emission source (institutional, commercial, industrial structure, installation, plant, source or building) approved by the MoEF & CC or consented to establish and operate by SPCB.

Inspection:
A check for the conditions that is likely to affect the reliability of the system.

Internal Diameter:

The inside diameter of a circular stack, or the equivalent diameter of a rectangular duct (4 times the inner duct area, divided by the inner duct perimeter).

Monitor Malfunction
Any interruption in the capture of data due to the failure of any component of the CEMS to operate as par the protocol of the manufacturer and or performance requirement shall be considered as Monitor malfunction.

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

Monitor Downtime:
Periods of CEMS operation in which invalid CEMS data or no data is captured due to any appropriate reason. This includes periods of calibration, preventive maintenance, malfunction, audits, process shutdown, start up etc.

Operational Test Period:
A minimum specified period, as designated by MoEF & CC, CPCB, or SPCB, over which a measurement system is expected to operate within performance specifications without unscheduled maintenance, repair or adjustments.

Out-of-Control Period:
Any period when the CEMS is operating outside specifications and criteria for daily calibration and stipulated Quality procedure the system generated data will be considered as out of control.

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

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

Quality Assurance:
An integrated system of management activities involving planning, implementation, assessment, reporting and quality improvement to ensure that a process, item or service is of the type and quality needed and expected by the end users.

Quality Assurance Plan (QAP):
A formal document describing in comprehensive detail the necessary quality assurance procedures, quality control activities and other technical activities that need to be implemented to ensure that the results of the work performed will satisfy the stated performance or accepted criteria.

Quality Control:
The overall system of technical activities that measure the attributes and performance of a process, item or service against defined standards to verify that they meet the specifications established by the customer, operational techniques and activities that are used to fulfill the need for quality.

Reference Method:
Any emission test method having international reference.

Relative Accuracy:
The absolute mean difference between the gas concentrations by a CEMS and the value determined by an appropriate Reference Method is taken to calculate relative accuracy. The relative accuracy provides a measure of the systematic and random errors associated with the data from the CEMS.

Source Shutdown:
The cessation of operation of an emission source for any purpose with prior intimation to the regulator or intimation within specified period allowed by respective SPCB or CPCB are to be considered as source shutdown.

Source Startup:
The starting in operation of an emission source for any purpose is referred as Source startup.

Span Value: A design value that represents an estimate of the highest expected value for a parameter, based on the applicable emission limit. Span is calculated as a percentage range of the emission limit. Minimum span value should be at least 1.5 times of the emission limit. It may go upto 2.5 times in some cases without compromising the data accuracy

Standard Condition:
A temperature of 298 K and an atmospheric pressure of 760 mm of Hg are referred as Standard condition for gaseous emission. The final results are to be normalized / corrected to standard conditions in all cases

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

Upstream:
In the direction opposite of the stack gas flow (e.g. a point near where the gases enter the stack would be upstream of a point near the top / exit of the stack).

Valid Averages: The sub average period for determining half-hour average is **1-minute average.** A valid half hour average must contain at least 22 sub average data within half-hour period (75%). This is applicable for all CEMS except Opacity.

A valid 1-minute average must contain valid data readings representing any 45 seconds over the previous 1-minute period.

Opacity Monitors normally average out 6 minute data and takes 10 data points to make hourly data. In this case atleast 50 minutes data in an hour is minimum requirement to qualify validation test.

Valid Data: Any representative data average that meets the validation criteria.

1.0 Introduction

With a view to bring transparency and industrial self regulation, CPCB the apex regulator have introduced modern and robust online monitoring of effluent and emission in all types of polluting industries in the country. Central Pollution Control Board (vide its letter No. B-29016/04/06PCI-1/5401 dated 05.02.2014) issued directions under section 18(1) b of the Water and Air Acts to the State Pollution Control Boards and Pollution Control Committees for directing the 17 categories of highly polluting industries, Common Effluent Treatment Plants (CETPs) and STPs, Common Bio-Medical Waste Incinerator and Common Hazardous Waste Incinerator for installation of online effluent quality and emission monitoring systems to help tracking the discharges of pollutants from these units in a self-regulated manner. However, this document shall be exclusively applicable for all types of industrial emissions.

2.0 Purpose

CEMS provide data on the emissions of pollutants and are physically located at plants and / or facilities that require accurate real time measurement of emissions and transmission of data to the regulators and in-house utilization of the data in optimizing and controlling the process. It is mentioned that the CPCB had issued general aspects of online water quality monitoring and CEMS installation and data connectivity with CPCB server, however; with a view to fulfill the purpose and systematic management of CEMS which describes selection, installation, operation, Calibration, Data generation etc., this document was felt necessary

This guideline document is prepared to assist both industries and regulators in successful implementation of CEMS through self-regulation. This document provides information on CEMS equipment and the pollutants that are monitored on real time basis and to develop a system to satisfy the data quality objectives to implement more transparent mechanism of environmental pollution control. All the matters addressed in this document are general in nature and the recommendations given herein should not be construed as providing specific directions for any particular Continuous Emission Monitoring System (CEMS). Each installation is site specific. No particular brands of equipment are being endorsed. The information in this paper is intended solely as a guideline and does not represent final mandate issued by CPCB. CPCB or MoEF may choose to issue more detailed, technical guideline in future. This document may be reviewed and modified periodically as warranted by modifications / revisions under Acts governing air emission time to time.

3.0 Scope & Applicability

The scope and applicability of this document is restricted to description of CEM as a system for monitoring, data storage and transfer etc. and applicable for establishing more transparent compliance monitoring mechanism for air emission. This guidance document explains:

a) The industrial sectors (activities) that are subjected to the CEMS requirements under the Acts;
b) A general description of the types of CEMS (Technology, peripherals, applicability, limitations) etc; exclusively for air emission parameters
c) A general description of what the requirements are;
d) Types of CEMS tests;
e) Quality Control and Quality Assurance; and
e) Reporting requirement.

This guideline is applicable to any industrial premise / facility as under 17 categories of Industries and others as specified by CPCB in order to install, operate and maintain a CEMS for the purpose of continuously determining and reporting compliance with applicable emission limits under consent to operate given by respective SPCBs or any other conditions given by MoEF & CC.

4.0 About CEMS

The term CEMS refers to the instrumentation and software required to measure emissions from a stationary source on a practically continuous (real time) basis. Unlike for carbon dioxide emissions or energy consumption, input-based methods of measurement are not reliable for particulate and gaseous emission, since it is a complex function of combustion conditions and abatement technology and their dynamic status of operational intricacies. Emission measurement and monitoring by CEMS has been in practice across the globe since the 1960s. CEMS refers to an unmanned instrumental packaged system of flue gas sampling, sample transfer & conditioning and analytical infrastructure integrated with an in-built data acquisition, handling and data transfer system. Depending upon the regulatory requirement the system may go from simple to complex; multiple combination of various technology based individual instrumentation involving the measurement of various gases, particulates and physical characteristics of emission. CEMS provides a continuous record of air emission, which helps in keeping track to the performance of control equipment, process optimization and vigilance to the compliance with emission of regulatory emission limit values.

4.1 Benefits of CEMS

Continuous measurement of emissions confers a number of benefits relative to manual source sampling:

i) Real time information:

Emissions may vary quite widely in real time as a function of fuel type & quality, operating processes and the operational status of Air Pollution Control Devices (APCDs), Therefore, CEMS readings provide a more accurate record of emissions on real time basis.

ii) Transparency and Openness:

The use of CEM technologies provide high quality on-going information on emissions from each source so equipped to the industries, regulators and potentially the public. Therefore, regulation based on this data is also transparent and clear, industries can predict and be aware of the costs of compliance and plan accordingly.

iii) Process optimization and ownership on regulatory compliance:

CEMS data enables the occupier to keep vigil on the process control, optimize the resource utilization, and on the other hand satisfy the regulator with validated data to maintain the records of their credentials towards the national commitment.

iv) Self Regulation

It has become a need and necessity to regulate and minimize inspection of industries on routine basis. For strengthening the monitoring and compliance through self-regulatory mechanism, online emission monitoring systems need to be installed and operated by the developers and the industries on, 'Polluter Pays Principle'.

v) A steps towards Emission Trading

CEMS is also the prerequisite to participate in Emission Trading. It is being practiced worldwide through which an industry can cap, trade their permits, earn revenue, and ultimately ensure better air quality, which may be the ultimate mechanism developed and practiced in India too in near future.

4.2 General Concept of Continuous Emission Monitoring System (CEMS)

The system comprising of different units / peripherals installed to sample, transport, condition, analyse, calibrate, data acquisition, record and transmit the emission data uninterruptedly to regulator on a real time basis without any editing/tampering is collectively called a Continuous Emission Monitoring System (CEMS)

The CEM system shall comprise of the following:

a) Instrumentation(s) and program(s) that will sample & analyze and quantify the concentration of the specified pollutants in the gas stream.
b) Instrumentation(s) and/or program(s) that will determine the flow rate of the gas stream.
c) Instrumentation(s) and program(s) that will record and process the information produced and yield electronic and printed reports showing the emission rate of the specified pollutant with the time resolution.
d) The system shall have a Quality Assurance programs and Quality Control procedures to ensure that all measurements are done as per defined Data Quality Objectives and adequate verification and validation protocol is inbuilt in the system.

5.0 Sampling Techniques

There is a wide range of instruments and systems available for continuous emission monitoring, using a variety of technologies. Based on the sampling techniques, transfer of sample the technical classification can be described in the following chart (Figure 1).

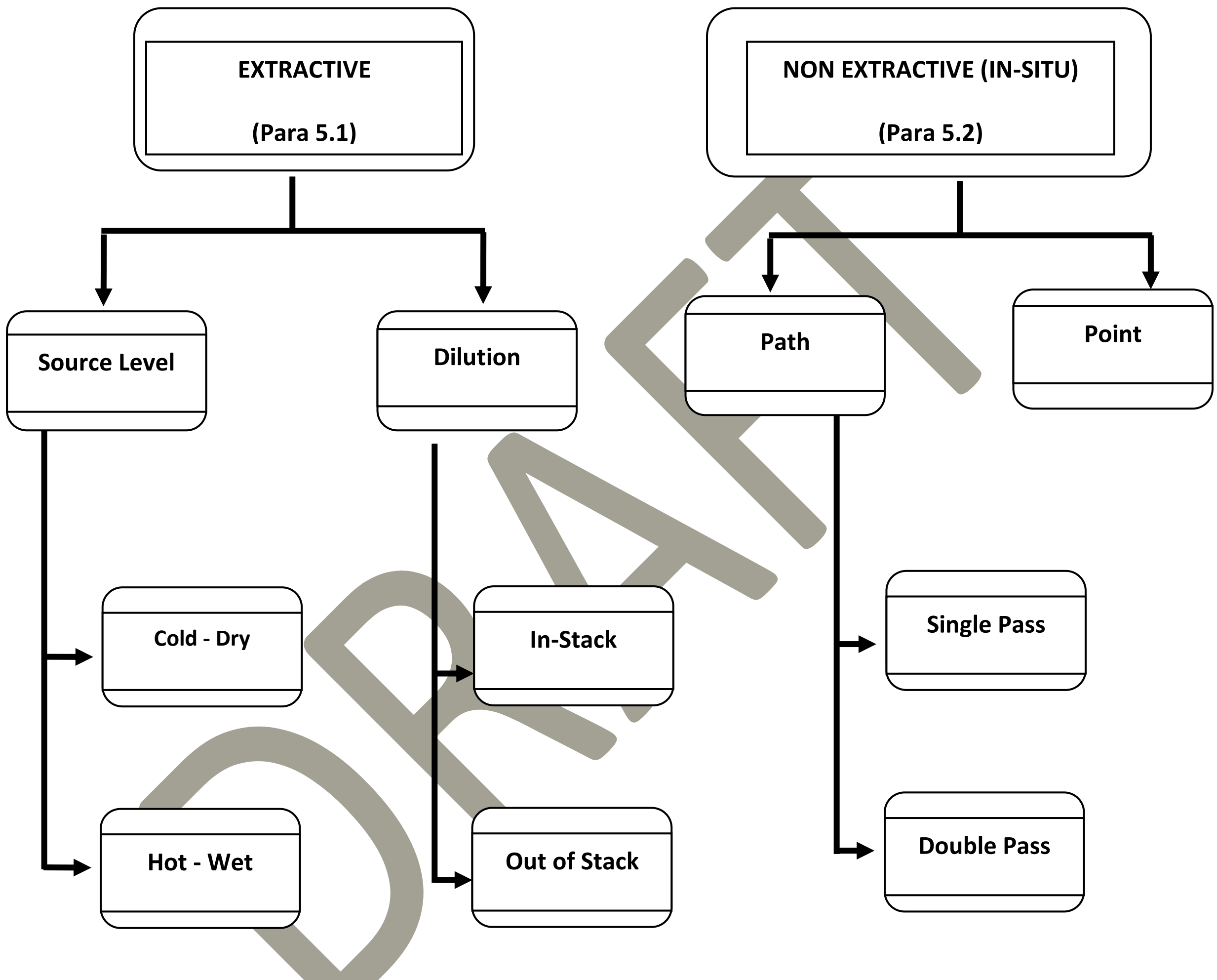


Figure 1: Basic Type of CEMS after Jahnke and Peeler,

5.1. Extractive Type CEMS

It involves mechanism of sample extraction and transfers it to the analytical instrument with or without conditioning depending upon the characteristics of flue gas, method and field condition. The typical types are detailed as following:

i) Source Level Non-Dilution Extractive Systems

This technique typically involves extracting the sample gas from the stack using a sample probe, through cold or heated sample line, gas conditioning equipment and a sample pump. The gas sample is not diluted, so the analyzers used in this case should have a higher working ranges (i.e. 0 – 5000 ppm). The non-dilution extractive system may be of two types, i.e; “hot wet” and “cold dry” process.

In **“Hot Wet Process”**, the gas is transported via a heated sample line under vacuum to the analyzer(s). The Analysers are capable to operate at high temperature and water in vapour phase. Here the results are required to be corrected for moisture.

In **“Cold Dry Process”**, the sample is allowed to condense using an electronic, electrical, or contact physical technology and the condensate is removed before sending the sample to analyser. The Samples are transported hot above the dew point and then cooled to remove moisture or dried through selective permeable membrane system like **Nafion Drying**. Here the analysis are done at almost dry basis hence, the results are not required to be corrected for moisture.

Typical Cold Dry non-dilution extractive systems have four common subsystems:

a. Non diluting extraction probe
b. Flue Gas CEM system interface,
c. sample transport line preferably heated above dew point to prevent any inline condensation
d. moisture removal (cold process) and
e. analyzers

ii) Dilution Extractive system

Dilution-extractive systems dilute the sample gas with dry contamination-free dilution gas to a level below the dew point of the diluted flue gas to eliminate condensation problems in the CEM system (in lieu of using a moisture condenser). The main difference between the two technique is that; with dilution extraction, the sample is diluted with dry zero gas, to a pre-determined factor (e.g. 20:1 to 100:1 or so) as recommended by the instrument manufacturers. The system components here are dilution probe, transfer line under positive pressure, dilution system with mixing of pollutants and diluents and finally the analyser. The moisture is not removed from the sample here, rather get diluted with contaminant free air to bring down the moisture level at analyzer’s workable range. The dilution also helps in other way to bring down the concentration to ambient level (i.e. 0 – 10,000ppb), so the similar technology and instrumentation can be used for emission measurement. Here, the concentrations reported by the analysers are required to be multiplied with dilution factor for emission value. The most unique component of a dilution-extractive system (compared to other extractive systems) is the dilution-sampling probe. There are two basic types of dilution probes; in-stack probe and out-of-stack (ex-situ) dilution probe are available in market.

a) In-Stack Dilution-Extractive Probe

Here the probe is fixed and the sample gets diluted inside the stack. The in-stack probe design is equipped with coarse and fine filters for removing particulate matter from the stack gas prior to sample dilution, flow is regulated through a quartz or glass critical orifice, and an air-driven aspirator and venturi is used for dilution of sample gas.

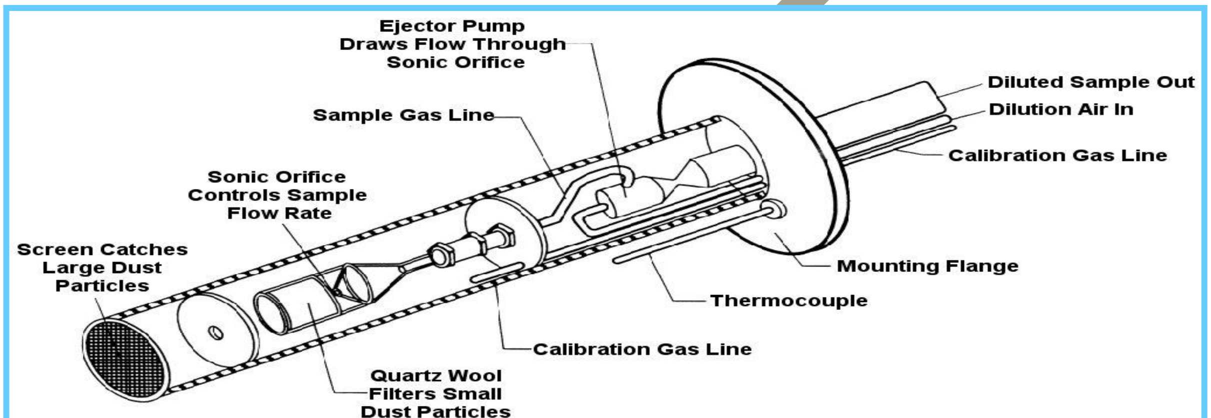


Figure 2: Typical In-stack Dilution probe

b) Out-Of-Stack Dilution-Extractive Probes.

The out-of-stack (ex-situ) dilution probe uses the same basic dilution-extractive sampling technology with the following differences. This system is designed to constantly heat the sampling assembly, to prevent condensation problem and all critical parts are mounted out of the stack for quick access and easy maintenance.

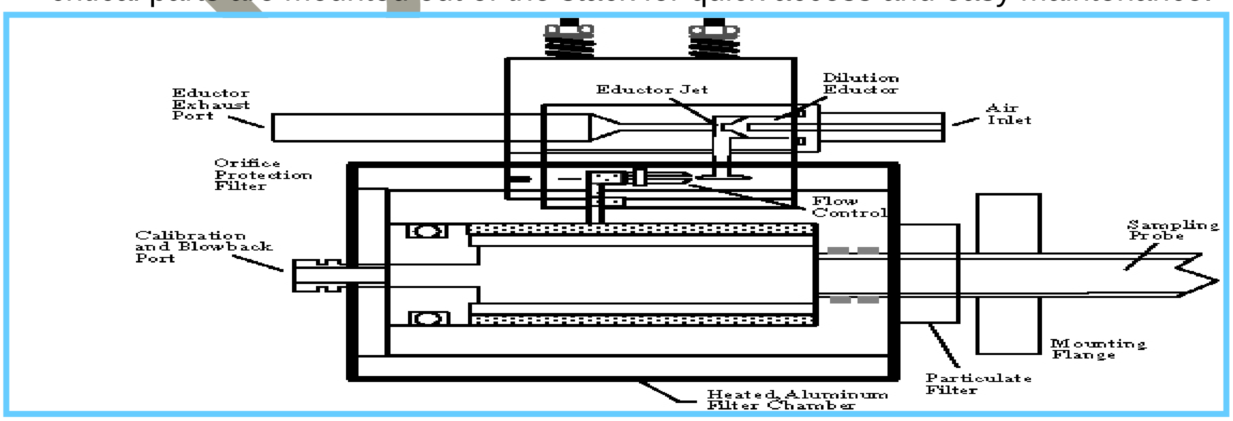


Figure 3: Typical Out-stack Dilution probe

For extractive CEMS (mainly gaseous) following components with robust technical specification are required to be installed.

i) Interface in extractive CEMS

CEM interface is the peripherals in between sampling point to the analyzer having inbuilt software and hardware control to facilitate unattended operation of the system. The interface components may vary according to the selected CEM type and pollutant of interest. Generally, it consists of following in case of an extractive CEM system:

ii) Sampling Probe and Filter

The CEM system interface typically consists of a corrosion resistive rigid probe, positioned at a representative location. A coarse filter made of sintered stainless steel or porous ceramic materials is used to filter out particulate matter greater than 10 to 50 μm size. Earlier the coarse filter used to be located at the probe inlet; however, some current designs have the filter positioned out of the stack for ease of maintenance.

iii) Sample Transport System

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

iv) Moisture Removal System

The third component, is the moisture removal system, which provides a clean, dry sample to the analyzers. Two moisture removal methods are primarily used; condensation and condensation/permeation.

a) Condensation Systems

Condensation systems rapidly cool the sample, thereby condensing sample moisture. The condensed moisture is trapped and periodically removed from the condenser assembly. To avoid absorption of the target gases by the condensed liquid, precautions are required in designing condensers and traps that minimize contact between the condensate and the cooled sample gas. There are two basic techniques generally used to prevent the trapped condensate from contacting the target gases. The first and most common approach uses a standard compressor-type refrigeration unit, and the other is the thermoelectric plate chiller, a solid-state unit with no moving parts.

b) Condensation by selective Permeation Systems

Now a day's, nafion (copolymerized Teflon membrane) dryer technology is also getting popularity which remove moisture automatically through selective permeation in transfer line without chilling or condensation.

v) Dilution Air-Cleanup System

Dilution-extractive systems require a constant source of contamination free dilution air. The air supply should be dry (29° to 40°C) and delivered at 6.3 ± 1 kilogram/centimeter^2 pressure. Additionally, the dilution air should be free of oils, particulates, CO_2, NO_X, and SO_2. The air-cleanup system is the critical component of the dilution-extractive system. A coalescing filter first filters compressed air either from the plant's process air supply or from a dedicated air compressor for particulates, then liquid and oils condensate. Oil removal is necessary to prevent the contamination of silica gel or other drying agents in the heatless air-dryer. A heatless dryer can dry the air to approximately 73°C performs additional drying of the dilution air. The CO_2 extractor utilizes two columns with different adsorbent materials to absorb any CO_2 in the dilution air. Some air cleaning systems may add a CO to CO_2 converter before the CO_2 extractor if the analyzers respond to interferences from CO. Addition of a charcoal filter trap to remove any hydrocarbons present in the dilution air is a healthy practice. An additional desiccant dryer to provide additional moisture removal is also required in some cases. A submicron filter removes any particulates that may be released from the upstream desiccant traps required to be added in the system.

a) Gas Sample Dilution Ratios

Dilution ratios typically range from 20:1 to 300:1. The dilution ratio most widely used is 100:1. The sample gas flow rates from the various dilution probes range from 50 to 300 ml/min. Dilution ratio depends on two criteria:

(1) the analyzer span range must correspond to the diluted sample gas concentration

(2) the ratio must be selected to ensure that no condensation occurs in the sample line at the lowest possible ambient temperature.

5.2. Non- Extractive (In-Situ) CEM System

a) Point CEM

These are closely coupled instrument and probe, where the analyzer is directly connected to the probe and is installed in-situ at the point of measurement. The instruments consist of sampling; analysis and detection, all are placed at the plane of measurement. No sample transport is required. The data are always required to be corrected for moisture.

b) Path (Cross Duct) CEM

In Cross-duct or Path CEM system basically an energy source (IR or UV) is projected across the stack from one side to the other. Specified target gases absorb some of this energy at specific wavelengths resulting in an altered energy state of the gas molecule. In single path, the energy is transmitted from one side to the other making one pass through the stack. In a double path, the energy is reflected from a mirror on the opposite side, doubling back on itself.

6.0 Particulate Continuous Emission Monitoring Systems (PM-CEMS)

The history of smoke measurement started with “RINGELMANN Scale”, where the darkness in smoke was measured visually by matching filters. The technologies available for PM – CEMS are detailed in following paragraphs. These are mostly of in-situ type. The extractive PM-CEMS are costly complicated and challenging option. The changes in optical properties of a light beam after interaction with particulate laden flue gas are measured in this technique.

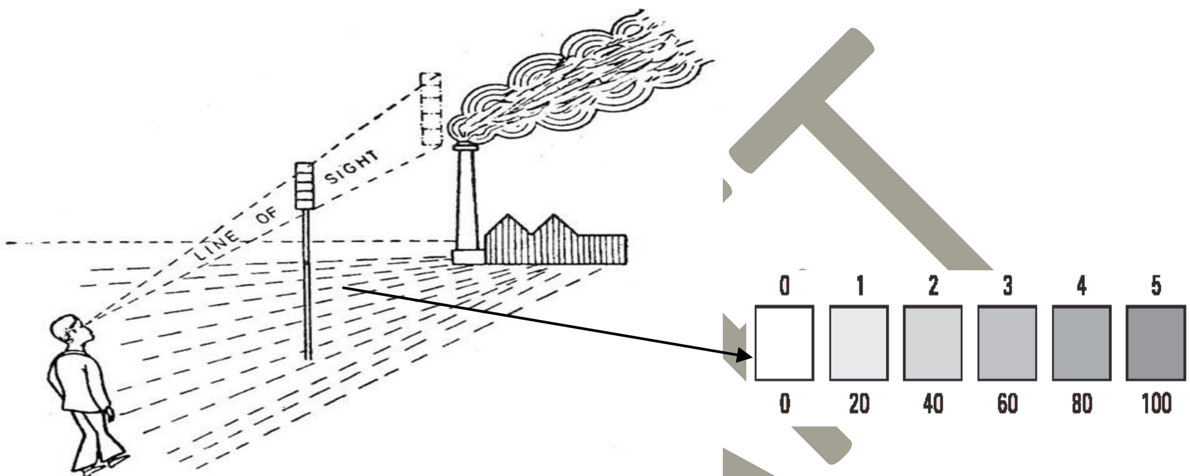


Figure 4: Smoke Density Measurement - “RINGELMANN Scale”

Afterwards, first sampling type instrument was evolved to measure smoke density in “**Bacharach scale”** by which shoot number was measured. The samples are withdrawn by a pump and PM gets deposited at centre of a disc filter. The deposited darkness of shoot are compared with a reference scale.

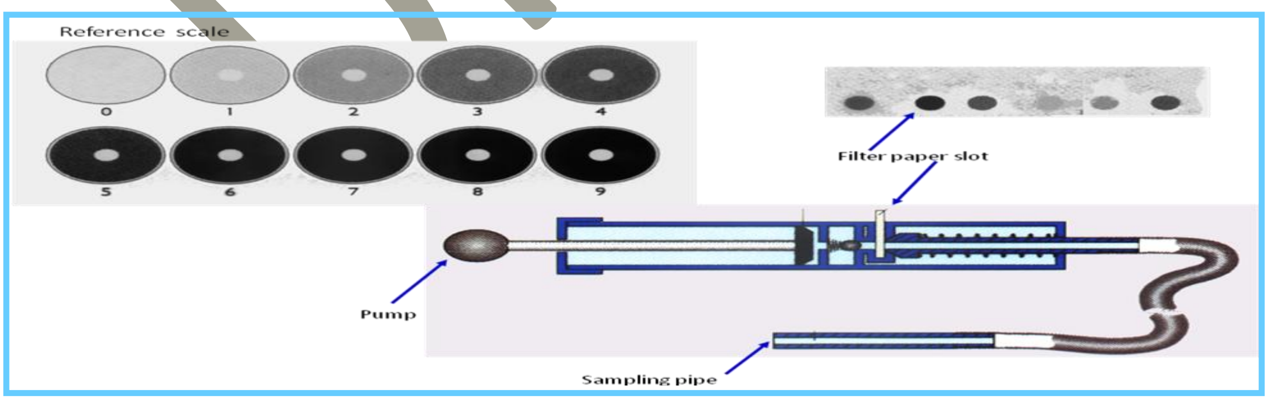


Figure 5: Bacharach scale – Shoot number measurement

The interaction of particle on light affects the properties of illumination in different ways like absorption, reflection, refraction, diffraction / scattering, scintillation etc. Advance instrumentation of optic based PM monitoring system use respective properties to correlated particle concentrations.

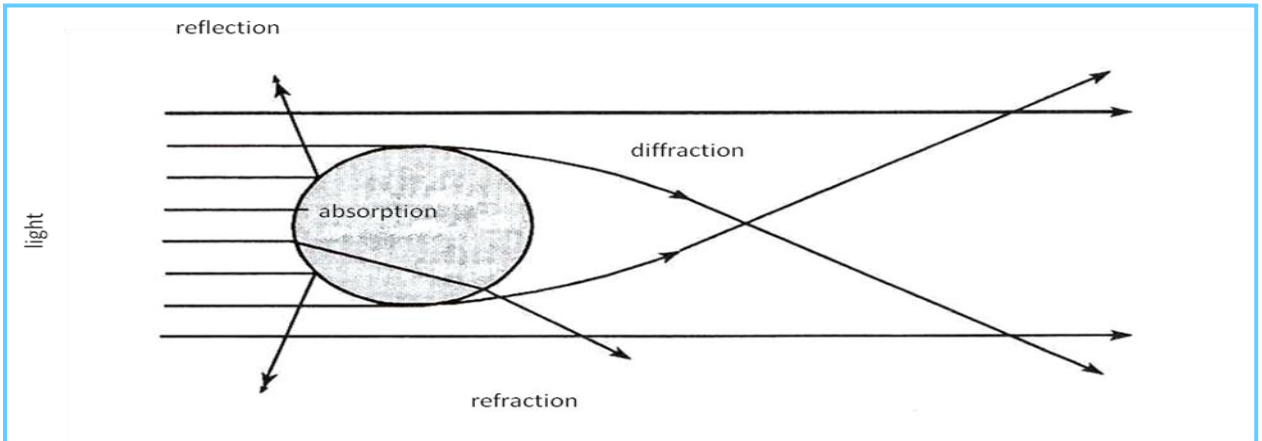


Figure 6: different properties of light after interaction with PM in flue

6.1 Transmissometry:

The oldest technology being used in continuous source monitoring for dust emission is absorption based, i.e. Opacity Monitor. The principle on which Opacity monitor works is "Transmissometry". It is the measurement of Transmittance through a defined path. The light absorbed and transmitted by or through the particles inside the exhaust duct can be expressed as:

Transmittance (T) = Ir / Io

Where, Ir is the energy received and Io is the Energy emitted

Opacity is reciprocal of Transmittance and expressed as

Opacity = 1 – (Ir / Io)

More specifically, if a beam of light with frequency (ν) travels through a medium with opacity κ_ν and mass density (ρ), presumed to be constant for both for a defined light source and PM characteristics , then the intensity will be reduced with distance (x) according to the formula;

$$I(x) = I_0 e^{-\kappa_\nu \rho x}$$

Where,

- x is the distance the light has traveled through the medium
- $I(x)$ is the intensity of residual light intensity at distance x

- I_0 is the initial intensity of light, at $x = 0$

For a given medium at a given frequency, the opacity has a numerical value that may range between 0 and infinity, with units of (length) ^{2}/ (mass).

Therefore, Opacity may be correlated with particulate concentration by understanding of Extinction and Lambert-Beers law.

As the light is attenuated by the particles

Extinction = $\log_e 1/T = e^{knal}$

When, k – the extinction efficiency; n – particle concentration in measuring site, a – mean projected area of particle and l – path length at measurement site

Now, If the physical and chemical nature of the particles are constant, 'k' is constant, 'a' and 'l' are constant to a specific duct or stack; so only variable 'n' is then directly proportional to the Extinction.

The basic operational principle of these instruments is that a collimated beam of visible light is directed through a gas stream toward receiving optics. The receiving optics measure the decrease in light intensity, and the instrument electronics convert the signal to an instrument output. In single pass opacity CEMS the light crosses the flue stream once and transmittance is detected at other side. For better resolution and higher accuracy, a dual-pass transmissometer and a modulating light source are used. The dual-pass transmissometer (with a reflector mirror on the opposite side of the stack from the light source) allows all of the instrument electronics to be incorporated into one unit. A high frequency modulation of the light source limits the possibility of interference because the instrument only reads the loss of light while the light source is on. When an LED light source is used, electronic modulation of the light (instead of chopping) is possible. Incorporating the light source and detector into one instrument also allows direct measurement of the loss of light by comparison of the source intensity and the loss of light at the same time. This helps prevent inaccurate readings due to the degradation of the light source intensity (a common problem in basic transmissometers).

A transmissometer used as a PM CEMS should use a red or near infrared light source. Some manufacturers have started using a green LED to monitor both opacity and PM concentration simultaneously. This theoretical particulate concentration generated from instrumental signal has to be standardised against Isokinetic Particulate monitoring using Reference method (USEPA Method 5 or USEPA Method 17) to generate a 'DUST FACTOR' for conversion of Extinction data to PM concentration.

There are two popular systems of Opacity monitor;

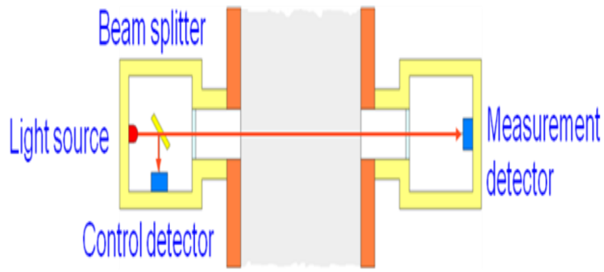


Figure 7: Opacity Monitor (Single pass)

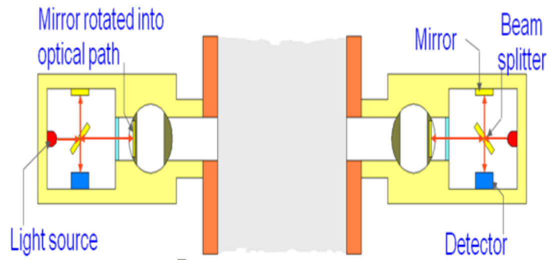


Figure 8: Opacity Monitor (Double pass)

These two systems have following advantages and disadvantages

Table 1: The advantages and disadvantages of two techniques

Single Pass	Double Pass
Simple Low cost Technique	More costly but better data quality
Difficult to keep the windows clean	High efficiency air purges needed to keep the windows clean
Cannot differentiate between gas born particles and window contamination	Protected mirrors check individual contamination on both transceivers
Cannot detect misalignment errors	Alternate, bi-directional measurement provides automatic misalignment check
Difficult to ensure linearity	Linearity – not influenced by back scatter effects
Prone to be contaminated during idle condition	Rotary valves protect transceivers during purge air or power failure

6.2 Light Scattering

A popular type PM-CEMS technique is light scattering. This technology is used in both non extractive and extractive methods depending upon the flue gas condition and other physical factors. Principally the light scattering is occurred due to reflection and refraction of the light by the particle. The amount of light scattered is based on the concentration of particles and the properties of the particles in the light's path (e.g., the size, shape, and color of the particles). If the wavelength of the incident light is much larger than the radius of the particle, "Rayleigh" scattering occurs. Rayleigh scattering causes the blue color of the sky because visible sunlight is scattered by very small particles and gases in the upper atmosphere. If the wavelength of the incident light is about the same size as the radius of the particle, a type of scattering called "Mie" scattering will occur. Mie scattering causes the haze seen on a hot summer day and the reduction of visibility by car headlights in a fog.

These two properties of light scattering are utilized using proper optics eliminating the interferences in PM CEMS by light scattering method.

A light scatter type instrument measures the amount of light scattered in a particular direction (i.e., forward, side, or backward) and outputs a signal proportional to the amount of scattering material (e.g., particulate matter) in the sample stream. The PM concentration is derived by correlating the output of the instrument to manual gravimetric measurements. In a scatter light instrument, a collimated beam of visible or near infrared (IR) light is emitted into a gas stream. The light is scattered by particles in the light path (i.e., Mie scattering), and the receiving optics focus an area of that light onto a detector that generates a current proportional to the intensity of light it receives. The angle of the source to the receiving optics and the characteristics of the optics determine the volume of space from which the scattered light is measured.

Some components included in these instruments to minimize the effect of interference and degradation of the light source are: (1) the use of a pulsed light and (2) parallel measurement of the light source intensity.

The use of the pulsed light source limits the possibility that light from some other source (e.g., ambient Stray light) will be measured, because a reference of the source intensity is measured along with each scattered light measurement.

Types of instrument vary depending upon their ability to measure forward scattering or back scattering properties of the particle. This difference is due to the design of optics preferred by different companies. Light scattering principle is applicable both for in-situ measurement (for Dry Stack) and extractive out of stack measurement for wet stack. Forward scattering type instruments are probe time and have lesser representative sampling path, hence may not be suitable for higher particle concentration. It has also some maintenance issues.

Figure 9: In–situ forward light scattering

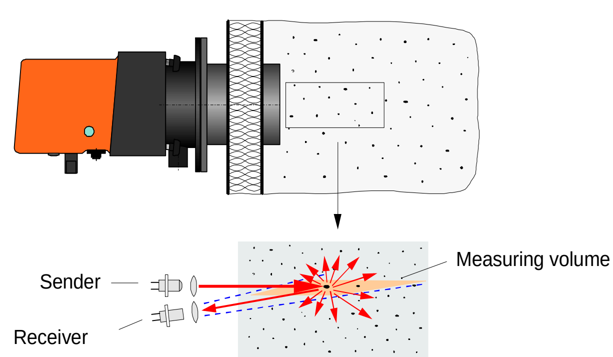


Figure 10: In–situ backward light scattering

6.3 Scatter-light Extractive PM - CEMS

Principle is same as earlier, but the gas is extracted isokinetically and heated to vaporise the water droplets

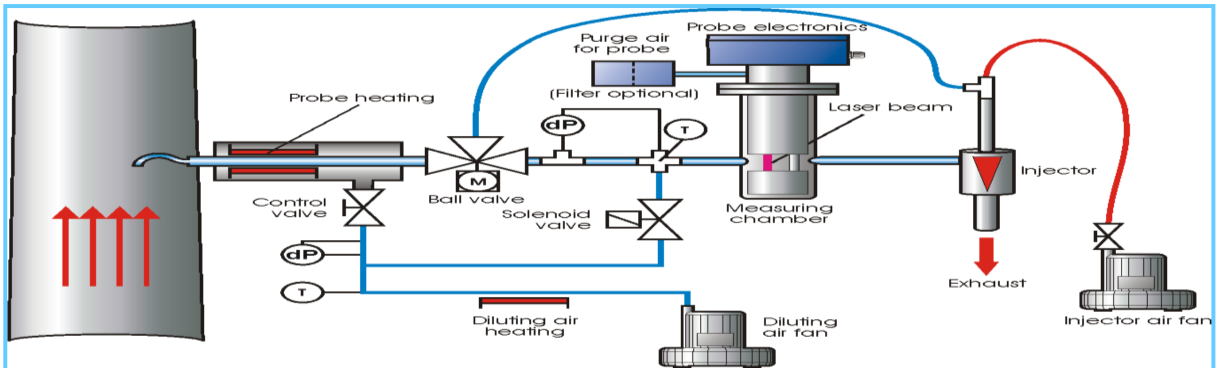


Figure 11: Extractive (Out of Stack) light scattering

Both these techniques have their own limitations. The advantages and disadvantages are presented below.

Table 2: The advantages and disadvantages light Scattering

Advantages	Disadvantages
Low price	Measures secondary particulate as PM
Easy to install	properties of flue gas Adversely affected by Particle size, density, shape change
Low maintenance as there is no moving parts in in-situ scattering system	IR light gives better response than visible light
Sensitive to low PM concentration	Measures liquid drops as PM;
Effective after Bag Filter or multi-stage APC	Dry scattering system can't be used after wet scrubber
Wet scattering is suitable for emission monitoring after a scrubber	Cost of installation and maintenance is high.

6.4 Optical Scintillation

Optical scintillation, like light extinction, utilizes a light source and a remote receiver that measures the amount of received light. The difference is that the scintillation monitor uses a wide beam of light, no focusing lenses, and the receiver measures the modulation of the light frequency due to the movement of particles through the light beam and not the extinction of light. The principles at work here are that the particles in a gas stream will momentarily interrupt the light beam and cause a variation in the amplitude of the light received (scintillation). The greater the particle concentration in the gas stream the greater the variation in the amplitude of the light signal received. The scintillation monitor must be calibrated to manual gravimentic measurements at the specific source on which it is installed.

Little advance against opacity as it reduces zero and upscale drift with modulated light to eliminate effects of stray or ambient light. The transmitter and receiver are located on opposite sides of the duct; therefore, this instrument also measures across-stack PM concentration. The instrument response increases with PM concentration and can be correlated by comparison to manual gravimetric data.

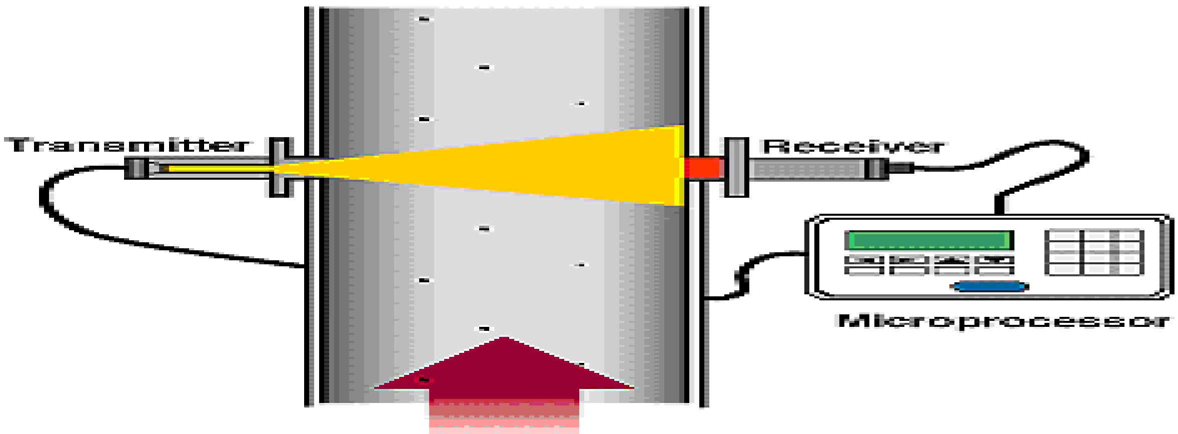


Figure 12: Optical Scintillation Technique

Table 3: The advantages and disadvantages Optical Scintillation

Advantages	Disadvantages
Low price	Measures secondary particles as PM
Easy to install	properties of PM Adversely affected by Particle size, density, shape change
Low maintenance	The cleaning of receiver in a dirty stack is an issue
Sensitivity to little high concentration	Not Sensitive to low PM concentration
Perform better in dry stack Moisture	Measures liquid drops as PM;

6.5 Probe Electrification Technique

Probe electrification takes advantage of the fact that all particles have a charge. Electrostatic charges from the friction of particles contacting a probe will electrify the probe (i.e., a small current is produced in the probe). This is called triboelectricity.

A triboelectric particulate monitoring device measures the direct current (DC) produced by the charge transfer when particles strike the probe. The DC is measured by an electrically isolated sensor probe that is connected to amplification electronics. Multiple particle strikes create a small flow of current through the instrument; current is proportional to the momentum (mass times velocity squared) of the particles. Amplification electronics convert the current to an instrument output signal.

Monitors that rely on inducing a current in the probe, rather than particle contact with the probe, work similarly except an alternating current (AC) is measured. Because the signal produced by these monitors may be affected by several factors, the instrument output must be correlated to manual gravimetric measurements. Some of the primary factors that may affect the relationship between particle mass and the monitored signal are particle velocity for triboelectric devices, particle characteristics (e.g., composition and size), and particle charge. Probe electrification does not work well in wet gas streams with water droplets or when the particles are subject to a varying electrical charge. The AC component of the induced current is being used to minimize the effect of velocity on the measurement. Charged particles present in flue when impact on a sensor & generate tribo-flow signal (current & voltage) which is may be correlated proportionally with particle concentration in emission. Actually the charged particle transfer the charges when collide with the tribo-electric probe in both the cases.

This particular technique works like a sensor than analyzer; hence kept out of emission compliance monitoring. This is good for monitoring APCD operation like bag leak detection.

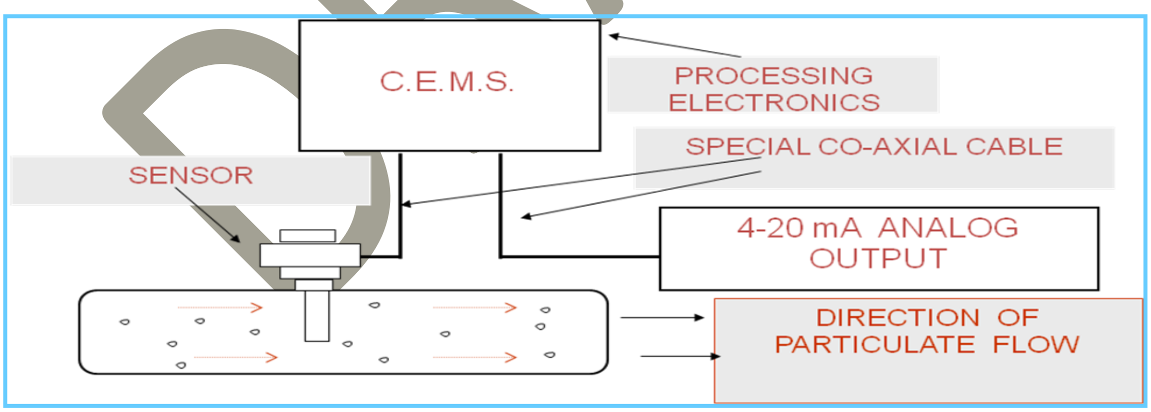


Figure 13: Probe Electrification (Triboelectric) CEMS

Table 4: The advantages and disadvantages Probe Electrification Technique

Advantages	Disadvantages
Low price	Particle charge affect adversely
Easy to install	Particle sizes and velocity affect adversely
Sensitive to low PM concentration	Length of the probe restrict the application in wider flue path
Very effective as Bag Leak Detector (BDL)	Not suitable for emission after ESP
Moisture interference can be removed by using piezo-electric shield on probe.	Measures liquid drops as PM
Suitable for reporting either concentration of mass emission depending on the technology selected.	AC tribo electric system works better in a stable flow condition. DC tribo needs additional flow measuring device
Suitable for Stack less than 5 m diameter.	Better suitable in a stack within 2 m diameter

6.6 Extractive Particulate Monitoring (Beta attenuation Technique)

The principle behind beta attenuation particulate sampling instruments (beta gauge) is that energy is absorbed from beta particles as they pass through PM collected on a filter media. The attenuation due to only the PM is measurable if a baseline beta count through just the filter can be established prior to sampling. The difference between the baseline beta count and the beta count after sampling is directly proportional to the mass of PM in the sample. The two main components of a beta attenuation measuring system are the beta source and the detector. The selection of beta source depends on:

- It has an energy level high enough for the beta particles to pass through the collection media (i.e., the filter tape) and the particulate,
- It has enough source material so that a high count rate is present, it is stable over long periods of time, and
- It does not present a danger to the health of personnel that meet the instrument.

The source of choice has been Carbon-14 because; it has a safe yet high enough energy level, it has a half-life of 5,568 years, and it is relatively abundant. Many different types of detectors can quantify beta particle counts, but the ones most widely used are the Geiger Mueller counter or a photodiode detector.

The sampling line and detector lies in the same horizontal plane at separated perpendicularly parallel geometry. A motor ensure two-way movement of filter roll. Firstly the clean filter comes in the path of detector, the instrument measures a clean

area of the filter media for a fixed period to determine the baseline (e.g., 1 - 2 minutes).
Then it advances that area of the filter to a sampling line for another set period (e.g., 8 to 9 minutes) and finally returns that area of the filter to the detector for the same period used to establish the baseline reading.
The difference in the beta count can be directly correlated to particulate mass through calibration of the instrument using a filter media containing a known mass of a particulate-like material.

This system is exclusively extractive (out stack method) with or without dilution. The main constrain of this CEMS is that it should have the capability to withdraw the sample from stack gas stream isokinetically to have proper representation. It may not generate signal continuously because sampling and analysis time has an automatic time interval.

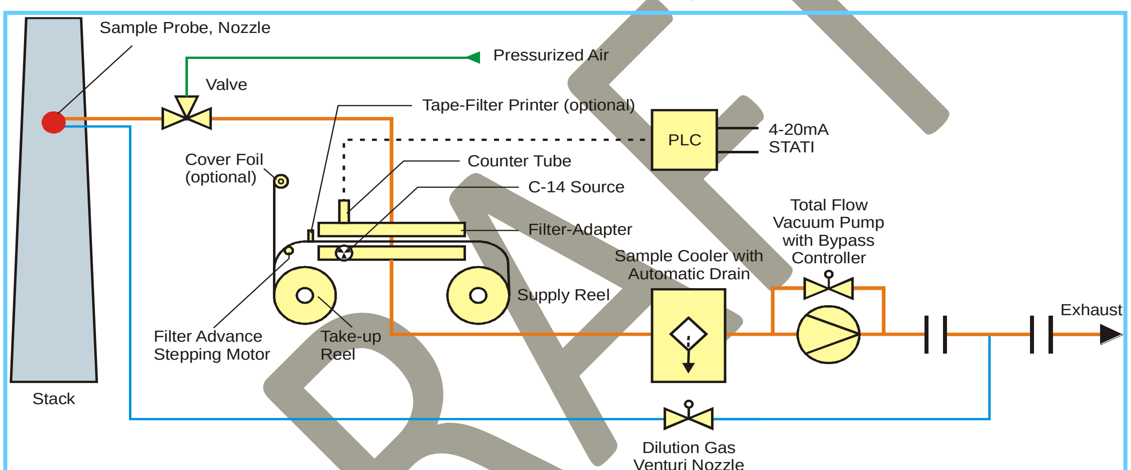


Figure 14: Extractive PM – CEMS – Beta Attenuation Technique

Table 5: The advantages and disadvantages Beta Attenuation Technique

Advantages	Disadvantages
Direct measure of PM concentration	More difficult to install
Not affected by particle characteristic changes	Expensive
Designed to work in wet stack applications	Higher recurring cost of ownership
May be used for monitoring of PM, PM_{10}, PM2.5 and even $PM_{1.0}$, using suitable size selective inlet	Iso-kinetic Sample extraction is challenging
Suitable for any types of stack	Transport of sample upto the analyser requires expertise & suitable infrastructure.
Have better correlation with Reference gravimetric method compared to other methods as the system itself is isokinetic	Use radioactive source. Require trained manpower and careful handling.

6.7 The Matrix for selection of PM CEMS

Looking into the advantages and disadvantages and limitation in field application of PM CEMS of different technologies Table 6 may be used for selection of specific CEMS for respective sources.

Table 6: PM CEMS Selection Matrix

Selection Criteria	**Types of Particulate CEMS**				
	Tribo-Flow	**Opacity**	**Light Scattering**	**Light Scintillation**	**BAM**
Duct < 1m	√	**X**	√	**X**	√
Duct 1 – 4 m	**X**	√	√	√	√
Duct > 4 m	**X**	√	**X**	√	√
Temperature of Flue gas > 500 ºC	**X**	√	√	√	√
Temperature below dew point (Water droplet)	**X**	**X**	**X**	**X**	√
Larger Particles > 20 µm	√	√	**X**	√	√
Low to Medium PM concentration	**X**	**X**	√	**X**	√
High PM concentration	√	√	**X**	√	√
Any PM CEM System must install Flow (Velocity) measurement device, Temperature probe, moisture measurement device and direct measurement facilities for diluents gases (O_2 and or CO_2. The data must be corrected to dry and normalized condition with respect to temperature and pressure (mg/NM^3)					

7.0 Gaseous Continuous Emission Monitors

The following subsections provide a brief overview of the SO_2, NOx, CO_2, and O_2 monitors that were most widely used for process as well as emission monitoring.

Table 7: Properties for ideal emission analyzer

SN	Analytical	SN	Operational
1	Fast Response	1	Low capital cost
2	Linear output	2	Low maintenance cost
3	Stable Baseline	3	>99% uptime
4	Reproducible	4	Self diagnostic
5	Wide Dynamic range	5	Meets changing requirement
6	Accurate	6	Reliable
7	Robust	7	Compliant to regulatory requirement

7.1 SO2 Monitors

SO_2 monitoring technologies are well established and several of these monitors now incorporate a microprocessor, enabling the operator to check certain monitor operating parameters, perform calibrations automatically, and perform numerous diagnostic functions. A brief overview of these technologies is given.

7.1.1 UV Fluorescence Monitors

Fluorescence SO_2 analyzers, both pulsed and continuous ultraviolet (UV) light source type, were originally manufactured for ambient air monitoring. Ambient air SO_2 concentrations are in the parts per billion (ppb) ranges, and these units operate well at that low concentration. As the fluorescence technology was proven in low concentration ranges may be well-matched for dilution probe applications. Majority of the US application have chosen this technology for CEM in a source with dilution-extractive systems for SO_2.

Principle: SO_2 molecules excited by UV radiation exhibit fluorescent property, energy emitted due to transformation of exited SO_2 to ground state emits energy, which is proportional to the molecules present in exposed medium.

The first reaction step is :

$SO_2 + h\upsilon 1\ (UV) \rightarrow SO_2^*$

Then in the second step, the excited SO2* molecule returns to the original ground state, emitting an energy Hυ1 according to the reaction:

$SO_2^* \rightarrow SO_2 + h\upsilon 1$ (UV)

The intensity of the fluorescent radiation is proportional to the number of SO_2 molecules in the detection volume and is therefore proportional to the concentration of SO_2.

7.1.2 UV Spectrophotometric Monitors

Several manufacturers offer UV and two offers second-derivative spectroscopic UV SO_2 monitors for in-situ and extractive applications. UV type SO_2 monitors have proven to be reliable instruments, and as with many other monitoring systems, electronic components (e.g., for optical contamination and lamp current compensation) have been improved over the past few years. The UV spectroscopic type SO_2 monitors are suitable for use in either extractive or in-situ CEM systems. UV light absorbs various chemicals as listed below

Table 8: Typical UV Absorbing species

Sulphur dioxide (SO_2)	**Mercaptans**
Hydrogen Sulfide (H_2S)	Aromatic Hydrocarbons
Nitric Oxide (NO)	Organic Sulfides
Nitrogen Dioxide (NO_2)	Organic di sulfides
Ammonia (NH_3)	Ketones (= CO)
Carbonyl Sulfide (COS)	Aldehydes (- CHO)
Carbon di sulfide (CS_2)	Chlorine (Cl_2)

It is not always necessary that the UV photometric analyzer is suitable for all the types of compounds. The applicability always depends upon the range of measurement, interferences and coexistence of compounds in same matrix and many other factors. However, this principle is good for SO_2 and reduced sulphur compounds (H2S, COS, CS_2 etc.)

7.1.2 IR based SO_2 Monitor

Considering the concentration level expected in emission IR based instruments are suitable for CEMS. Infrared methods may be based on IR, NDIR, FTIR absorption spectroscopy.

7.2 NO_X Monitors

Typically, Chemiluminscence, UV photometry, or infrared (IR) monitors are used for monitoring NOx. The selection of type of monitors depends on NO_X concentration in flue, interference from other constituents of flue gas and cost affordability.

7.2.1Chemiluminscence Monitors

Like UV photometry based SO2 analysers ambient air NO_X concentrations are in the parts per billion (ppb) ranges, based units operate well at that low concentration. As the UV fluorescence technology Chemiluminscence based analysers in low concentration ranges may be well-matched for dilution probe applications. Majority of the US application have chosen this technology for CEM in a source with dilution-extractive systems for NO_X. Ammonia in particular interferes and creates a potential problem in determination of NO_X. The selective catalytic converters installed convert NO_2 to NO without converting ammonia to NO. Essentially all Chemiluminscence monitors incorporate a high-vacuum sample chamber to minimize quenching (absorption of the fluorescent light by other molecules).

7.2.2 UV Spectrophotometric Monitors

Several vendors offer UV photometric and second-derivative spectroscopic analyzers for monitoring NOx. Any Spectrometric analyzers require sample filtering to remove particulate matter and sample conditioning or heated sample cells to maintain the sample gas temperature above the dew point. Various design modifications and improvements to the electronic components (e.g., isolating the electronic and optic components from the sample cell) have been implemented which has been proved to produce better result.

7.2.3 IR based NO_X Monitor

Considering the concentration level expected in emission IR based instruments are suitable for NO_X in CEMS. Infrared methods may be based on IR, NDIR, FTIR absorption spectroscopy.

7.3 Fourier Transform Infrared (FTIR) Spectroscopic multiple gas monitor

FTIR measuring system is designed for continuous emission monitoring measurements (CEM). Typical Fourier Transform Infrared (FTIR) spectroscopic based application is H_2O, CO_2, CO, N_2O, NO, NO_2, SO_2, HCl, HF, NH_3, CH_4, C_2H_6, C_3H_8 and C_2H_4 monitoring from waste incinerator or large combustion plants. Measured components and calibration ranges can be changed according to application. This application is useful for wet gas stream to measure trace concentrations of pollutants in wet, corrosive gas streams. All parts of the CEMS are heated up to 180 ºC. It can be used for undiluted gases and the sample gases do not need to be dried before. FTIR is not suitable for O_2 monitoring; however, the system may be coupled with optional the ZrO2 oxygen analyzer and/or with a FID based total organic carbon analyzer. 16 gases can be monitored simultaneously with Standard configuration of FTIR multi-gas analyser. This modular combination may be upgraded to even up to 50 gases. **The major disadvantage of the system is cost.**

Benefits

a. Highly exact and reliable monitoring of emission components in flue gases
b. Simultaneous multi-component analysis of 16 standard gas components: CO, CO, HCl, HF, H_2O, NH_3, NO, NO_2, N_2O, SO_2, CH_4, C_2H_4, C_2H_6, C_3H_8, C_6H_{14} and HCOH
c. Additionally (calculated by use of FTIR-measurement): NO_X and total organic carbon (TOC)
d. Expandable with up to two additional analyzers i.e., oxygen measurement and FID based measurement of total carbon
e. Proven, suitability-tested technologies

7.4 Differential Optical Absorption Spectroscopy (DOAS) based multiple Gas Monitor

Like FTIR DOAS also can perform multiple gas analysis. The IR option may be better suited for source monitoring. Absorption of light at different wavelength proportional to the concentrations is basic principle behind it. Gases like CO, CO_2, SO_2, NO_2, NH_3, VOC, HCl, HF etc. can be measured by this technique. Main issue with DOAS is path length. Accuracy and sensitivity of measurement at smaller path length may be a limitation for this technique.

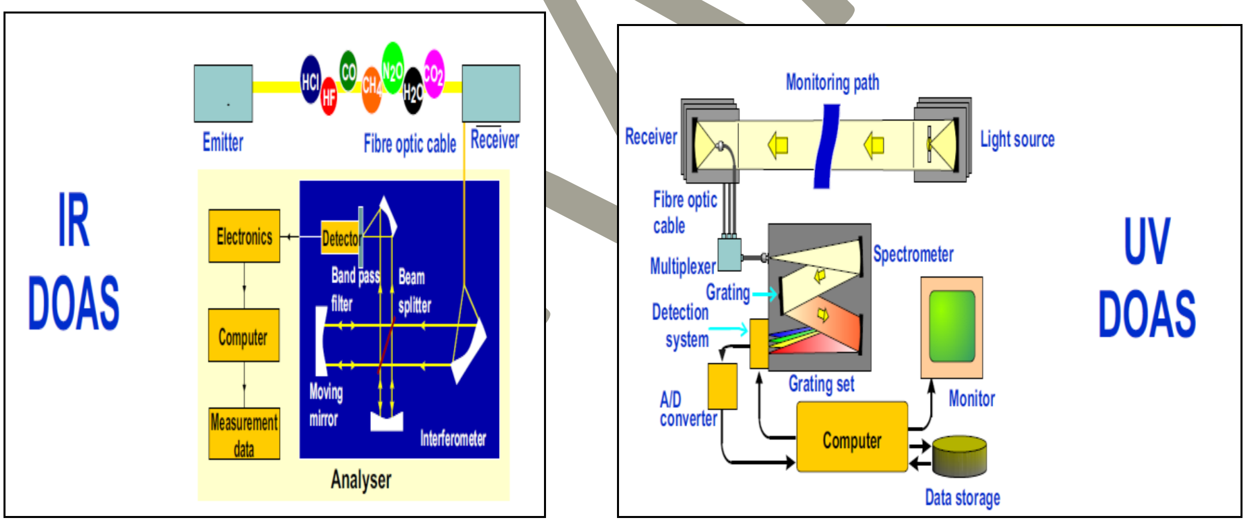


Figure 15: DOAS – CEMS

7.5 Tunable Diode Laser Absorption Spectroscopy (TDLAS)

Tunable diode laser absorption spectroscopy (TDLAS) is a technique for measuring the concentration of certain species such as methane, water vapor and many more like Ammonia, HCl, HF etc. in a gaseous mixture using tunable diode lasers and laser absorption spectrometry. Apart from concentration of gases, it is also possible to determine the temperature, pressure, velocity and mass flux of the gas under observation. TDLAS is by far the most common laser based absorption technique for quantitative assessments of species in gas phase. The basic principle behind the TDLAS technique is simple. The focus here is on a single absorption line in the absorption spectrum of a particular species of interest. To start with the wavelength of a diode laser is tuned over a particular absorption line of interest and the intensity of the transmitted radiation is measured. The transmitted intensity can be related to the concentration of the species present by the Beer-Lambert law, which states that when a radiation of wave number passes through an absorbing medium, the intensity variation along the path of the beam is measured. This application is also a cross duct gaseous measurement technology.

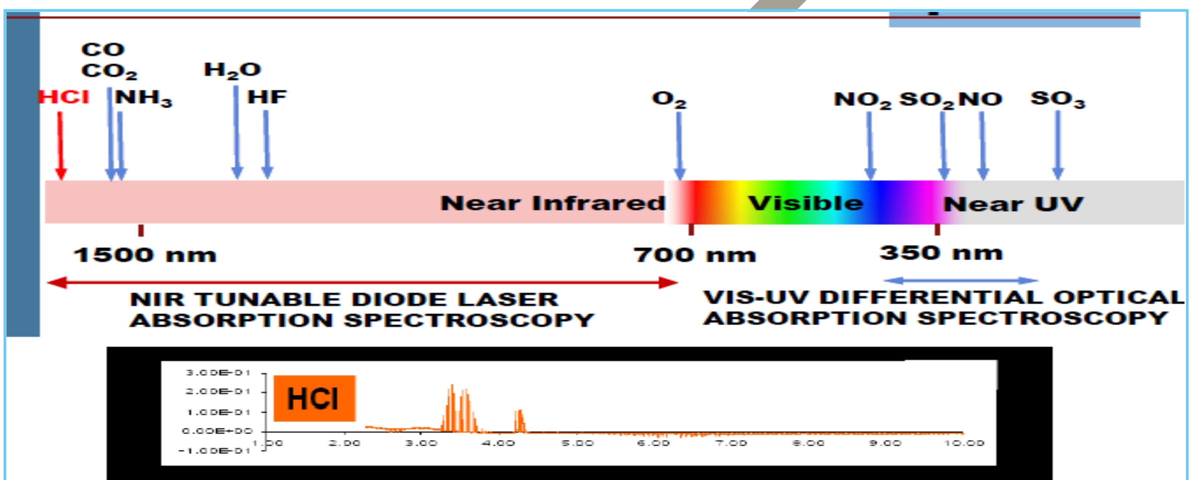


Figure 16: TDLAS – CEMS

7.6 CO_2 Monitors

Essentially all CO_2 monitors use IR-based technologies. Either non-dispersive infrared (NDIR) or gas filter correlation (GFC) technology is used. Earlier CO_2 monitors were generally considered to be less reliable and less accurate (for the concentration ranges typically observed in flue gas) than O_2 monitors. When using a dilution-extractive CEM system, however, the relative differences, advantages, and limitations between CO_2 and O_2 monitors are not an issue. A CO_2 monitor must be used to determine diluents concentrations for a dilution-extractive CEM system.

7.7 O_2 Monitors

Approximately 75% of the O_2 monitors are paramagnetic monitors and the remaining are primarily electro catalytic oxygen analyzers. These monitoring technologies have been used for many years and provide reliable for O_2.

7.8 Total Organic Carbon or Total Hydrocarbon Analyzer

Extractive Emission monitoring using FID is the best recommended method for Total Organic Carbon or Total Hydrocarbon. The analyser is calibrated with Propane/Methane hence the value reported are in equivalent to calibration gas used. However; the concentrations may be converted to Carbon mass concentration depending upon the number of Carbon present in calibration gas. The performance verification can be done also against calibrated portable FID based HC analyser.

Table 9: Overview on Technical Selection for Gaseous CEMS

Technique	Type	Parameter(s) Measured	Comments
Chemiluminscence	Extractive	NO, NO_X, NO_2*	* NO_2 calculated (NO_X – NO)
UV Fluorescence	Extractive	SO_2, H_2S*, TRS* (Total Reduced Sulphur)	* Cannot be measured simultaneously with SO_2
IR Gas Filter Correlation (GFC)	Extractive	CO, CO_2, NO_X, SO_2 and N_2O	Multiple gases maximum upto 5 can be accommodated
Fourier Transformed Infra Red (FTIR)	Extractive / Path	CO, CO_2, SO_2, NO_X, NH_3, Moisture (H_2O), HCl, HF etc.	Multiple gases preferably more than 5 may be cost effective
Differential Optical Absorption Spectroscopy (DOAS)	Path	CO, CO_2, SO_2, NO_2, NH_3, VOC, HCl, HF etc.	Multiple gases preferably more than 5, but has maintenance issues
Flame Ionization Detector	Extractive	Total HC	Requires H_2 gas for flame and carrier
Tunable Diode Laser	Path	CO, CO_2, NH_3, Moisture (H_2O), HCl, HF, CH_4 etc.	Cost effective but not suitable for SO_2 and NO_X
Zirconium Oxide Cell	In-situ	O_2	Widely used, maximum temperature tolerance is 500ºC
Paramagnetic	Extractive	O_2	Stable and accurate
Photo-acoustic Spectroscopy	Extractive	CO, CO_2, SO_2, NO, NO_2, NH_3, Moisture (H_2O), HCl, HF etc.	Can measure any Gas that absorb IR

Notes: (a) Any CEM System must have Flow (Velocity) measurement device and direct measurement facilities for O_2 and CO_2 installed (b)Any dilution extractive system must have CO_2 measurement facility at source and measuring point to prove the correctness of the selected dilution ratio.

7.9 Flue Gas Flow / Velocity Monitoring Techniques

Most commercially available flue gas flow monitors operate using one of five principles for measuring velocity and volumetric flow: ultrasonic pulse detection, differential pressure, thermal detection (convective cooling), audible acoustic detection and optical scintillation. The five varieties of flow monitors are stack or duct mounted and operates as a component (including a microcomputer, pressure transmitters, and temperature transmitters) of a system. Other types of flow monitoring systems are available:

7.9.1 Ultrasonic Flow Monitors

The volumetric flow rate of stack gas is measured by transmitting ultrasonic pulses across the stack in both directions. The tone pulses are accelerated or retarded due to the gas velocity in the stack. The time required traversing the distance of the stack traveling with and against the flow is a function of the sound velocity and the effluent velocity. Stack flow can be calculated based on the difference in the times required to traverse the stack in both directions. The ultrasonic pulses must traverse the stack or duct at a minimum angle of 10 degrees; however, traverses between angles of 40 and 70 degrees tend to provide the best results, as long as the traverse path length is not so long that the ultrasonic pulses become difficult to detect.

7.9.2 Differential Pressure Flow Monitors

The S-type Pitot tube is designed as par the design of Stausscheibe or reverse type Pitot. The probe is constructed of two in-line tubes. The sampling point of the probe consists of two opposing open faces perpendicular to the traverse axis. A side view of the probe resembles two stacked tubes with the ends tapered away from one another and the openings planed parallel to the horizontal axis. The Fechheimer Pitot probe consists of flow sensors mounted on two multipoint averaging manifolds. The probe design consists of two manifolds (tubes) welded together with a truss plate. The truss maintains a distance between the manifolds in a plane perpendicular to the flow and the stack wall. One manifold averages multiple points of impact pressure, and the other averages multiple points of wake pressure. The impact and wake pressure averages are registered by the flow transmitter. This technology is used in numerous gas flow monitoring applications other than flue gas.

Other types of noncontact flow monitors are also available in market.

7.9.3 Thermal Flow Monitors

Thermal flow monitors measure the electric power required to maintain a constant temperature of approximately 24 to 38ºC above the exhaust gas temperature in a flow sensor.

The monitors are available for both single-point and multipoint analysis, and non-sensing components of the systems can be constructed from various corrosion-resistant metals.

7.9.4 Infrared correlation

Light based noncontact devices are also suitable for velocity measurement in flue gas.

Table 10: Flow meter selection matrix

Parameters	**Types of Flow (Velocity meter)**				
	Impact Differential Pressure (Pitot Tube)		**Thermal anemometer**[1]	**Bi-directional ultrasonic**	**Infrared correlation**
Irregular Flow	Single point	Multiport			
Max Flue Gas Temperature	X	√	√ [2]	√ [2]	√
Wet stack	Up to 550°C	Up to 550°C	200 – 300°C (model specific)	450° C - 850 °C (model specific)	Up to 1000°C
Low speed	X	X	X	√	√
High Speed	X	√	√	√	√
Calibration	Factory / Site	Factory / Site	Factory / Site [3]	Factory / Site	Factory / Site

[1] Pressure Transmitter (PT) and Temperature Transmitter (TT) are not installed with a Thermal Anemometer as it directly measures Mass Flow which is usually the required quantity. However, for the purpose of ETS in Type 2 CEMS configuration, Volumetric Flow is required and hence PT and TT are necessary to calculate density and convert mass flow calculated by the anemometer to volumetric flow.

[2] Can be accounted for by using multiple probes/sensors

[3] Calibration depends on physical properties (thermal conductivity, specific heat) of the gas whose flow is to be measured. Thus variation in properties of stack gas from factory calibrated values can result in inaccurate measurement.

8.0 Basic Requirements and Steps for Implantation of CEMS in India

Industries identified to install CEMS for respective parameters have to follow the steps detailed below:

8.1 Parameters to be monitored

Industry specific emission parameters required to be monitored by CEMS are presented in **Annexure – I**

8.2 Emission Standard Limit Values

Emission standards for stationary sources are as prescribed in the Air (1981) Act and Environmental Protection (1986) and its subsequent revisions. These regulations and subsequent revisions specify their limit values. The emission limits prescribed to the industries / facilities being directed to install CEMS for respective parameters are given in **Annexure - II**

8.3 The Role of Different Parties in a Monitoring Regime

The monitoring regime proposed is based upon CEMS but not limited to the instrumentation itself; rather, it encompasses a complete institutional and technical system for ensuring high-quality emission data.

For successful implementation of the programme, major responsibilities have been entrusted to the industries and SPCBs, with a view to guide the technical issues involved including monitoring and reporting requirements outlined in this document. The industry may employ CEMS vendors to install, calibrate and help maintain a monitoring system suitable for its characteristics as an emissions source. The industry alone remains accountable for ensuring the performance of CEMS, documenting that performance through calibration, and sending quality data to the SPCBs concerned.

The SPCBs would oversee the monitoring regime, record and validate emissions data from CEMS and further use it. The SPCBs may intervene in the monitoring of a particular industry for high quality data. They may also coordinate the supporting roles of third parties such as accredited labs, CEMS vendors and CEMS working groups in respective industries. The involvement and activity web of various stakeholders in implementation process is depicted in three steps.

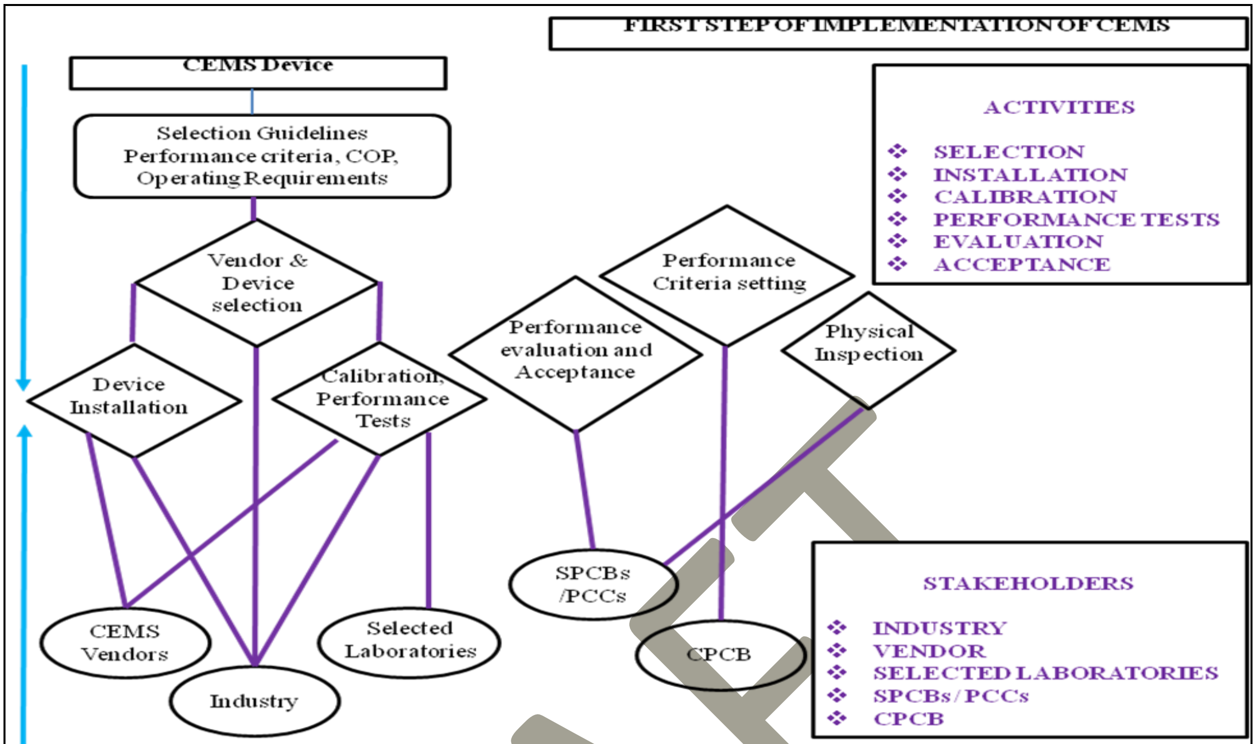


Figure 17: Stakeholder's role in selection to acceptance of CEMS in India

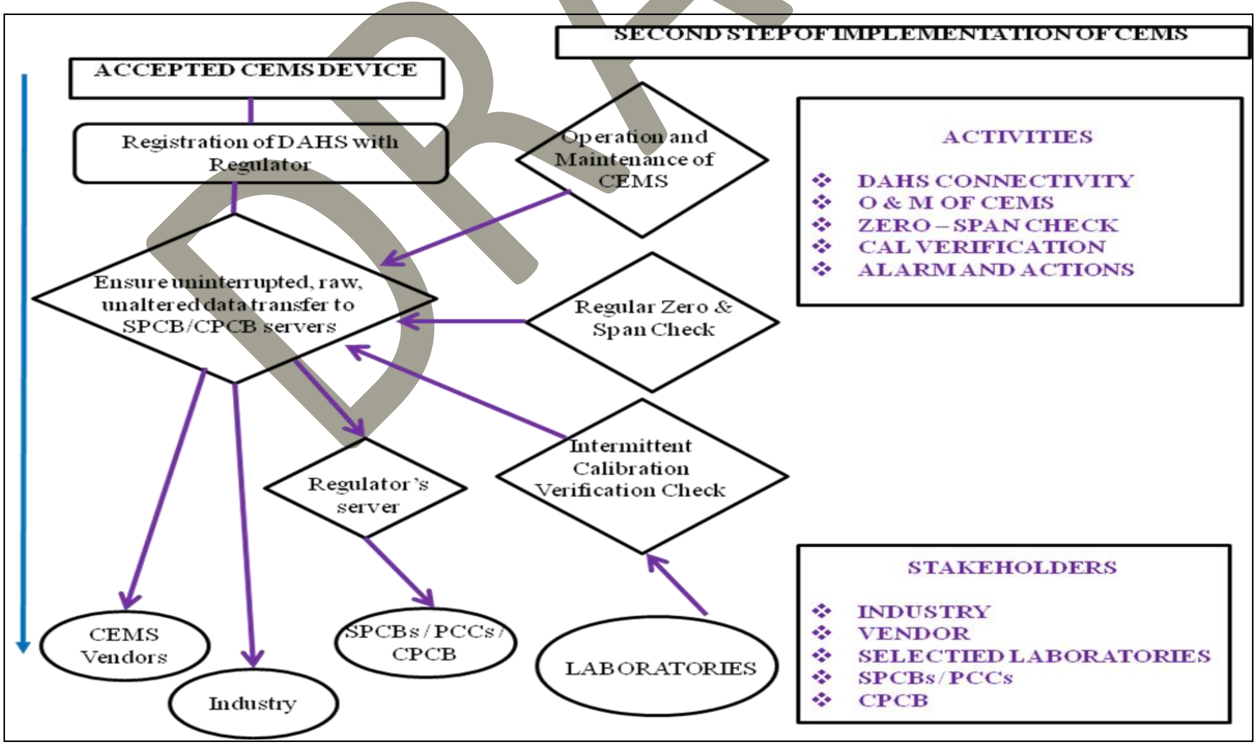


Figure 18: Stakeholder's role in acceptance to data transfer of CEMS in India

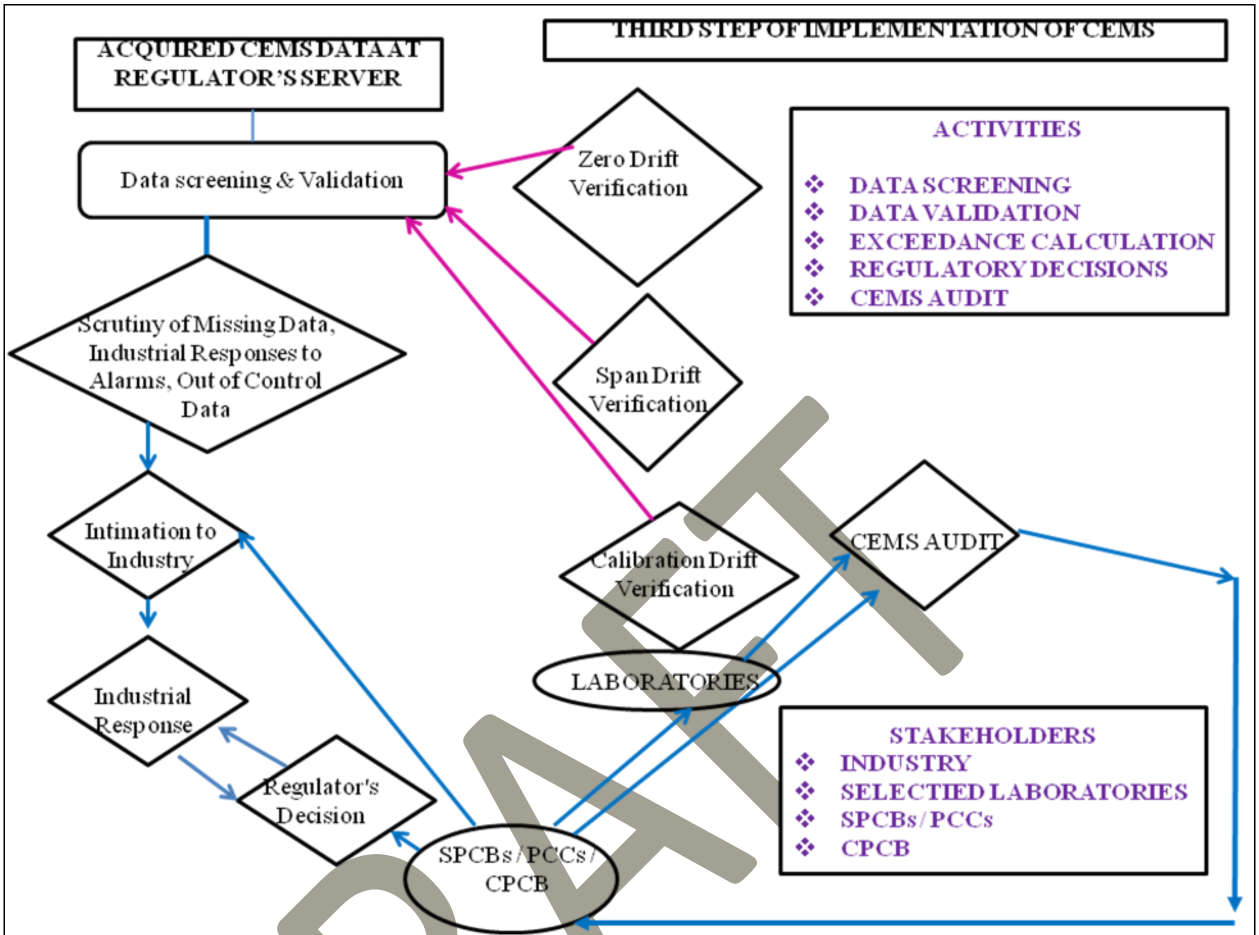


Figure 19: Stakeholder's role in Data to regulation through CEMS in India

8.4 Selection of CEMS

CEMS selection shall be the sole responsibility of the operator. The selected CEMS needs to fulfill the criteria of selection of device in light of their suitability for respective flue matrix for respective parameters, ruggedness, data accuracy, precision & robustness, desired facility of data acquisition, handling and transfer to respective terminals including regulator for smooth and tamper free data management. The CEMS selected shall preferably have COP (Certificate of Product) of MCerts, TŰV or any other equivalent international agency. Indigenous CEMS without COP needs to satisfy the performance requirement at par with internationally certified products equivalent to QAL 2 standard or EPA performance standard criteria as detailed for respective parameters.

The performance demonstration shall extend over a fortnight to one month period. The entire expenditure for conducting performance demonstration shall be borne by the manufacturer of the system / instrumentation. The performance demonstration is case specific and can never be granted as acceptable for even similar stack at same industries.

For selection of CEMS Table 6 (PM CEMS), Table 9 (Gaseous CEMS) and Table 10 (Flow / Velocity Monitor) of this guideline may be referred.

8.5 Installation Requirement of CEMS

The analysers/ instruments/ sensors have to be installed as per the specified sampling criteria, so as to have representative sampling of the emissions.

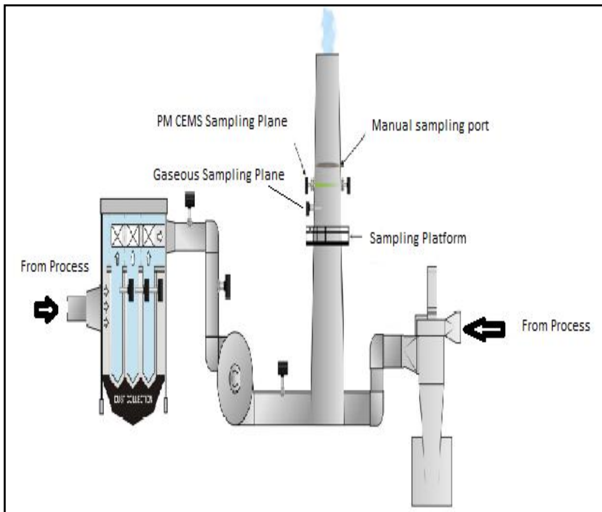
a) To ensure laminar flow the Particulate Matter monitoring systems (CEMS) shall be installed at a distance atleast at 8 times the stack diameter downstream and 2 times stack diameter upstream from any flow disturbance. PM CEMS, Flow/Velocity monitor, Moisture probe and Temperature probe installation shall strictly follow this guideline.
b) Ideally, both particulate and gaseous CEMS installation required to fulfill the criteria ensuring laminar flow. However, in extreme cases, the location at a distance atleast at 2 times the stack diameter downstream and 1/2 times stack diameter upstream from any flow disturbance for Gaseous CEMS is allowed as referred in 40 CFR Part 75 of USEPA.
c) Cross duct CEMS devices shall be installed 500 mm below the porthole designated for manual sampling ensuring no disturbance created by the probe when simultaneous data are collected during calibration. Probe type CEMS shall be installed at 500 mm below the porthole designated for manual sampling too but at 90º to the reference sampling port
d) All measurement ports into the stack shall be as per CEMS system requirement.
e) Particulate CEMS devices (Cross Duct) or probe shall be installed in horizontal plane;
f) Probe / sampling device for gaseous CEMS shall be installed protruding downwards with suction system facing the direction of flow of flue gases.
g) The construction of chimney shall adhere to CPCB publication, “Emission Regulation Part III” (COINDS/20/1984-85) unless otherwise specified by CPCB or SPCB/ PCC.
h) Safety, serviceability, clear approach etc. shall be taken into consideration while selecting the location.
i) The sampling position of CEMS has to be approved by respective SPCBs / PCCs or CPCB. Any deviations from the guidelines in an extremely exceptional case have to be flagged and communicated and endorsed to the respective SPCBs/PCCs by the occupier.

All measurements shall be carried out on a suitable CEMS and peripheral installed within an appropriate working environment as specified by the manufacturer.

The working platform used to access the CEMS shall readily allow calibration and parallel measurements to be performed using an SRM. The sampling ports for measurements with the SRM shall be placed as close as possible, but not more than three times the equivalent diameter up- or down-stream of the location of the CEMS, in exceptional cases without compromising with well mixed and laminar flow criteria in order to achieve comparable measurements between CEMS and SRM.

It is necessary to have good access to the CEMS to enable inspections to take place and to minimize the time taken to implement the quality assurance procedures of this standard. A clean, well-ventilated and well-lit working space around the CEMS is required to enable the staff to perform this work effectively. Suitable protection is required for the personnel and the equipment, if the working platform is exposed to the weather.

The schematic location for ideal installation of CEMS in a circular stack is presented in Figure 17.



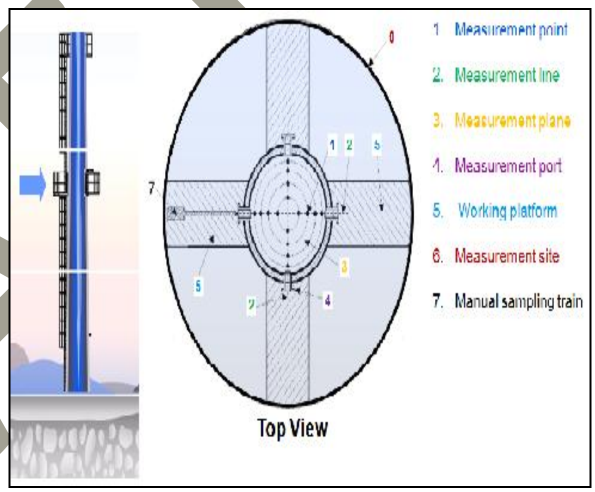


Figure 20: Schematic presentation of Position of CEMS installation in stack	Figure 21: Top view cross section of CEMS installation plane in stack

8.6 Analytical Range selection of CEMS

The instrument selected for CEM shall have a certified determination range. The certified range shall match the requirement without compromising with data sensitivity. In general, the procedures for operational analytical range selection are differing case to case. The highest measurable range in case of gaseous pollutants is at 1.5 times of the emission limit as a thumb rule in international practices. The analytical range is definitely a function of Emission Limit Value (ELV) and highest values obtained during trial run in a full load optimum condition of a specific source. In Indian scenario, this operational analytical range may be fixed maximum at 2.5 times of the ELV.

The range selection in PM shall be done based on the experience and emission data collected during trial run. It is always advised to fix the range at 2.5 times of the emission limit or at 125% of maximum concentration recorded by Reference sampling during calibration of CEMS, whichever is higher. This is to capture all data point during normal operation with only 25% acceptable extrapolation of calibration regression equation.

8.7 Calibration Requirement for PM CEMS

i) The Particulate Matter continuous monitoring system (PM-CEMS) shall be calibrated at different operational loads against Isokinetic sampling (triplicate samples at each load) at the time of installation. The facility shall cooperate to vary load of dust in flue either by changing production rate or tuning of APCD attached to the emission system.
ii) The results from the Particulate CEMS shall be compared on fortnightly basis i.e. second Friday of the fortnight, at fixed time (replicate sample) starting 10.00 am with standard Isokinetic sampling method. The frequency mentioned is required to be followed for at least first six month of operation from the date of endorsement of respective SPCBs after calibration. Afterwards the frequency may be relaxed if system performance is proved satisfactory by the SPCBs. This exercise is only to check the performance; no adjustment of Calibrated Dust Factor is allowed unless full-scale calibration is performed.
iii) In case, deviation of the comparison values for 02 consecutive monitoring is more than 10%, the system shall be recalibrated at variable loads against Isokinetic sampling method (replicate samples)
iv) After any major repair to the system, change of lamp, readjustment of the alignment, change in fuel quality, the system shall be recalibrated against Isokinetic sampling method. (Triplicate samples at each load)
v) The data capture rate of more than 85% shall be ensured.
vi) The intensity of lamp shall be checked fortnightly.
vii) The comparison/ verification of data/ calibration shall be done by CPCB/SPCB empanelled laboratory as per the specified frequency.

8.8 Calibration Requirement for Gaseous CEMS

(i) The instruments/analyzers for real time monitoring of gaseous emissions shall have calibration certificate with respect to their functioning, drift, linearity, detection limit, output, operating temperature and other relevant parameters before installing.
(ii) The concentration of span gas shall be equal or close to 80% value of selected range in respective cases. Inbuilt Calibration check Cuvette (cells) may help in regular calibration check.
(iii) Initially the instrument shall perform multilevel (minimum 5 levels including zero and span is desirable) calibration.
(iv) Calibration of extractive CEM shall ensure the calibration of whole system (Sampling, sample treatment and analysis)

(v) After six months of operation, the system shall be rechecked for its health and data accuracy and reliability, following multi point calibration (at least 03 span concentrations) using standard reference materials.
(vi) The data comparison and calibration verification shall be done on quarterly basis by empanelled laboratories following standard procedures and using certified reference standards.
(vii) The health of the instruments/analysers shall be assessed on daily basis at fixed time (10.00 a.m.) by checking the zero drift.
(viii) The instruments / analyzers shall be rechecked for zero and span drift every Friday at fixed time (10.00 a.m.) using standard methods and standard reference materials.
(ix) For Differential Optical Absorption Spectroscopy (DOAS), Non Dispersive Ultra Violet (NDUV)/Non Dispersive Infra Red lamp based systems; the calibration shall be revalidated once in 03 months, and after replacement of lamps.
(x) The values of ND-UV / ND-IR based system (folded beam-in-situ) will be compared with the standard methods using Standard Reference Material every Friday at fixed time (10.00 am) and Zero drift checked daily at fixed time (10.00 am).
(xi) In case the daily zero drift is more than the acceptable limit as specified in the catalogue/brochure of the instrument/analyser or specified in this guideline (whichever is higher) and persists continuously for five days, the instrument / analyser shall be recalibrated following procedure laid down at point (ii & iii) above.
(xii) In case the weekly span drift is more than the acceptable limit as specified in the catalogue brochure of the instrument/analyser or specified in this guideline (whichever is higher) and persists continuously in the succeeding week the instrument/analyser shall be recalibrated following procedure laid down in point (ii & iii) above.
(xiii) The instrument / analyzer shall be recalibrated after any major repair/replacement of parts/lamps or readjustment of the alignment using standard methods and certified reference materials.
(xiv) The instrument/analyzer system shall have provision of remote calibration, for verification of the system performance by SPCBs/PCCs whenever, felt necessary.
(xv) The intensity of the lamp shall be checked once every fortnight.
(xvi) Data capture rate of more than 85% shall be ensured.
(xvii) The comparison/ verification of data/ calibration shall be done by CPCB empanelled laboratory once in 6 months.

8.9 Registration Requirement

The occupier is required to supply information to the SPCB and CPCB by means of registration for new one and also to update the existing database. The information required during Registration are:

a) Name of Industrial premises / Facility
b) Address of Industrial premises / Facility
c) Plant operators (organizational chart)
d) Process Description – source specific information

e) Process activity – the type & quantity of fuel burned (load factor) etc.
f) Exhaust Stack / Vent ID
g) Installed Control devices
h) Stack height
j) Stack Diameter (ID)
i) Height of sampling location from ground level
k) Height of sampling location from point of last disturbance
l) CEMS type, make, model etc.
m) CEMS analyzer types.
n) List of parameters monitored
o) Date of Installation
p) Date of initial calibration

Operator shall provide detailed description of all parameters to be monitored and their expected normal & maximum values to be measured.

All industrial premises / facility that fall under the Air (1981) Act, EP (1986) Act and its revised regulations are to submit / update the database, based on individual operating consent issued by SPCBs.

8.10 Data Acquisition System (DAS)

(i) DAS (Data Acquisition System) defines the logging of digital data from the analyzers
(ii) The data shall be transferred directly from the analyzer (no in between logic) to the server at CPCB/ SPCBs or PCCs via Data Acquisition System.
(iii) Data should be in encrypted format (tamper proof)
(iv) DAS to automatically and seamlessly transfer data to Data Acquisition & Handling System (DAHS).
(v) Data dissemination to stakeholders from web server linked to DAHS.
(vi) The system shall operate on Open Application Programme Interface (API) protocol based on REST based technology.
(vii) The system shall record all the monitored values and transfer 15 min. average value to DAHS. The system shall have provision to assess the momentarily values as and when required.
(viii) Data validation protocol inbuilt with data quality codes to defined specification.
(ix) Web server to meet the needs of local PCBs, Industry and CPCB.

8.11 Criteria for acceptance of CEMS field Performance

A CEMS to be used at installations covered by CPCB direction shall have to be proven suitable for its measuring task (parameter and composition of the flue gas) by use of the procedure equivalent to international standards (EPA PS or EN QUAL Standards). It shall prove performance in accordance to the set performance characteristics during the field-testing.

The performance testing procedures involve all concerned including plant operator, vendor and testing laboratories. The Regulator has to inspect the installation and collect information as per Checklist (ANNEXURE III). The comments of the inspector on these information are essential tool to qualify the installation for further performance testing

Field-testing is a procedure for the determination of the calibration function and its variability, and a test of the variability of the measured values of the CEMS compared with the data quality objectives specified in these standards. The performance tests are performed on suitable CEMS that have been correctly installed and commissioned. A calibration function is established from the results of a number of parallel measurements performed with a Standard Reference Method (SRM). The variability of the measured values obtained with the CEMS is then evaluated against the required criteria to satisfy the Data Quality Objective.

Table 11: Performance Specification for SO_2, NO_X and CO

S.No.	Specification	Tolerance ranges/values
01	Zero Drift 24 hr.	≤ ± 2 % of Span
02	Span Drift 24 hr.	≤ ± 4 % of Span
03	Analyzer's Linearity	≤ ± 2 % of Span from calibration curve
04	Performance Accuracy	≤ ± 10 % of compared Reference measurement

Table 12: Performance Specification for O_2, and CO_2

S.No.	Specification	Tolerance ranges/values
01	Zero Drift 24 hr.	≤ ± 0.5 % of O_2
02	Span Drift 24 hr.	≤ ± 0.5 % of O_2
03	Analyzer's Linearity	≤ ± 0.5 % of O_2
04	Performance Accuracy	≤ ± 10 % of compared Reference measurement or within 1% of O_2

Table 13: Performance Specification for PM CEMS

S.No.	Specification	Tolerance ranges/values
01	Zero Drift between two servicing intervals	≤ ± 2 % of Full Scale range
02	Reference point Drift between two servicing intervals	≤ ± 2 % of Reference value range
03	Analyzer's Linearity	The difference between the actual value and the reference value must not exceed ±2 percent of full scale (for a 5 point check).
04	Performance Accuracy	≤ ± 10 % of compared Reference measurement

The performance test procedures are repeated periodically, after a major change of plant operation, after a failure of the CEMS or as demanded by regulators.

9.0 Quality Assurance / Quality Control

A Quality Assurance Plan (QAP) must be written, implemented, maintained and followed. It must include and describe a complete program of activities to be implemented that will ensure that the data generated by the CEMS is complete, accurate, precise, traceable and reliable. The QAP must satisfy the requirements as stated in this document and any other requirements which are necessary to ensure accuracy, precision, traceability and reliability of the data and information.

a) *Operational checks* are those procedures that are performed on a routine basis, generally daily, to determine whether the system is functioning properly. These procedures include daily zero and calibration checks and visual checks of system operating indicators and so on

i. Daily zero & span checks shall be made using procedures recommended by the manufacturer.
ii. Daily records must be kept, however; adjustments shall be made only in the cases when drift is greater than 10% of the calibration gas value, the activity shall be recorded and linearity shall be crosschecked.
iii. For extractive systems, the calibration gases are to be introduced upstream of all filters and sample conditioning system as close to the tip of the probe as possible.
iv. For opacity monitors daily drift is limited to +/-2% opacity
v. For PM's the daily drift is limited to +/-3% of reference value
vi. For flow monitors the daily drift is limited to +/-3% of span

b) *Routine maintenance* is performed at regular intervals.

I. Tasks to be performed at least monthly are: replacing filters, replacing bearings on motors, cleaning pumps, etc.
II. Tasks to be performed at least quarterly are: leak checks, linearity check on instruments, etc.

c) Regular performance checks of system operation include zero and span checks, purging, data capture rate, alarms, comparison of data with history, outlier identification, checking of average and report generation.

10.0 CEM System Test

The initial test for gas and opacity/dust monitors, the performance specification test or certification test, have two major criteria that CEM systems must meet: 1) calibration drift and 2) relative accuracy,

a) ***Calibration drifts*** "The difference in the CEM system output readings from the established reference value after a stated period (usually one week) of operation." The calibration test is conducted by introducing calibration gases into the CEM system, to examine the system's ability to hold its calibration over a period of time.

b) ***Relative accuracy*** "The absolute mean difference between the gas concentration or emission rate determined by the CEM system and the value determined by the reference methods plus the 2.5% error confidence coefficient ($CC = t_{0.975}\ (SD/\sqrt{n})$) of a series of tests for gases and 10 % error confidence coefficient of a series of tests for PM, divided by the mean of the reference method tests." That is,

$$RA\ (\%) = \frac{|d| + |CC|}{RM} \times 100$$

Where, |d| = the mean difference between the reference method result and the CEM result

|CC| = the confidence coefficient

RM = the average of the reference method values obtained in the test series

The principal sampling strategy for the relative accuracy test is to take CEM readings and reference method samples at the same time.

11. Record Keeping

All industrial premises / facility subject to CEMS requirements must maintain a file for:

a) All pertinent information, manufacturer literature, phone logs, meeting notes;
b) Operations and maintenance records;
c) Emission measurements, system performance specification test data and field accuracy tests, calibration checks;
d) Excess emission reports, instrument logbooks, downtime, adjustments and maintenance.
e) For unusual values reported by CEMS the reason for it with documented evidences must be recorded.
f) The history of zero/span adjustments and calibration must be kept available for inspection.

These records must be retained and made available to SPCB/PCC/CPCB for inspection upon request.

12. Reports

a) CEMS Performance Test Report:
This test is to be conducted by the person responsible for the installation. A copy of the test results to be furnished to the SPCB/PCC/CPCB upon completion. The test report

has to be self explanatory, unambiguous, properly calculated and reproduced with unit of expression as required by the regulators. The basic calculation for reporting is given in ANNEXURE IV.

b) Report of Excesses emission:

(i) Any Exceedence of values over the prescribed standards or norms shall be considered as violation.
(ii) Instantaneous elevated data i.e. spikes with duration less than one minute shall be dealt separately and not considered for data averaging.
(iii) Continuous Exceedence of values upto 10% over the standards/norms for more than half an hour shall require preventive action from the industry.
(iv) Frequent Exceedence of the values i.e. more than 5% of the total data capture in a day of the prescribed standards/norms shall invite action from SPCBs/PCCs
(v) Any Exceedence of the monitored values as against the standards shall invite SMS & email to the industry from SPCBs/PCCs, requiring immediate feedback on the corrective action initiated/taken.
(vi) In case the emission/ discharge quality exceeds continuously the prescribed norms by 10% over the standards and for duration of one hour or more, the industry shall inform the SPCBs/PCCs of the action initiated to control the emission/discharges and the effectiveness of the measures taken. In case the industry fails to control the emissions/discharges within the norms it shall move towards closure of its operation following the laid down standard operating practices.
(vii) For any second failure of the industry to keep the emissions/discharges within 10% of the norms for period exceeding one hour the industry shall immediately move towards closure of its operation under intimation to SPCBs/PCCs.
(viii) The values recorded during calibration or during preventive maintenance shall not be considered for Exceedence and assessing the data capture rate.
(ix) Plant start-up or batch process starting emissions shall not be considered for averaging for the initial, 30 minutes period in case of batch processes or small furnaces/ boilers not operating continuously.
(x) Plant shut down period shall be excluded while calculating data capture rate.

c) Daily Monitoring Data Transfer Reports

In addition to the continuous transmission of real-time data generated by CEMS a 24 hourly summary template has to be forwarded to the regulator positively by next day. The daily data format is prescribed as Annexure V.

d) Monthly Monitoring Report is required to be submitted in prescribed format as Annexure VI. The monthly report to the authority shall include:

i. All daily mean value emission data, related to the daily operating time derived from the half-hourly mean values for gases & Total PM.
ii. The date and time identifying each period the system was inoperative, and the nature of repairs. Information to include in CEM instrument downtime summary

1. Duration of downtime
2. Reasons for the downtime

iii. A summary of the excesses/ Excess Emission Report.
1. Date of excess emission
2. Start and end time excess emission
3. Magnitude of excess emissions
4. Reason or cause for the excess emissions
5. Corrective actions taken or measures taken to minimize emissions

iv. Zero / span calibration records.
v. A record of any on-stack maintenance of CEMS monitors / probes.

e) Quarterly Monitoring Report shall include the following besides the monthly task (the prescribed format is given as Annexure VII)
i. Leak check on sample system
ii. Instrument linearity check results
iii. Relative Accuracy Test report

Note: Monthly reports must be received by the SPCB/PCC/CPCB within 15 calendar days after the end of the month and quarterly reports must be received by SPCB/CPCB within 7 days of each calendar quarter.

f) Annual Report: All the monthly and quarterly tasks plus Third party audit report in presence of Regulator

13.0 Further Readings

S.No.	References
1.0	**CPCB's CEMS related Documents** i) Direction for installation of CEMS and CWQMS in 17 Cat. Industries, CETP, HWI, BMWI ii) Draft Notification on CEMS and CWQMS iii) Minutes of Meeting with Industries on Online Monitoring iv) List of Parameters for CEMS and CWQMS v) First hand information on list of suppliers vi) CPCB/e-PUBLICATION/2013-14 on "Specifications and Guidelines for Continuous Emissions Monitoring Systems (CEMS) for PM Measurement With Special Reference to Emission Trading Programs"
2.0	**USEPA Documents related to CEMS** a) Continuous Monitoring Manual b) 40 CFR Part 75: CEMS Field Audit Manual c) USEPA CEMS Performance Specification i) PS – 2 : Performance Specification for SO_2 and NO_X ii) PS – 3 : Performance Specification for O_2 and CO_2 iii) PS – 4 : Performance Specification for CO iv) PS – 4A: Performance Specification and Test Procedure for CO v) PS – 4B: Performance Specification and Test Procedure for CO and O_2 vi) PS – 6: Performance Specification and Test Procedure for Emission Rate vii) PS – 8A: Performance Specification and Test Procedure for Hydrocarbon (TOC) viii) PS – 11: Performance Specification and Test Procedure for PM CEMS ix) PS – 15: Performance Specification for Extractive FTIR CEMS x) PS – 18: Performance Specification for HCl – CEMS d) Quality Assurance (QA) Documents i) Procedure 1: QA Requirement for Gaseous CEMS ii) Procedure 2: QA Requirement for PM CEMS iii) Procedure 5: QA Requirement for Total Gaseous Mercury (TGM) CEMS and Sorbent Trap e) 40 CFR part 180 f) COMS (Continuous Opacity Monitoring System)
3.0	EN Documents i) EN 15267 – Part 1: Certification of AMS (CEMS) ii) EN 15267 – Part 2: Certification of AMS (CEMS) iii) EN 15267 – Part 3: Certification of AMS (CEMS) iv) EN 14181 – Quality Assurance of AMS (CEMS) v) EN 14884 – Test Method AMS (CEMS) for TGM
4.0	UK Documents a) RM:QG-06: Calibration of PM CEMS (Low Concentration) b) Mcerts : BS EN 13284: PM CEMS
5.0	Standard Operating Procedure for Compliance Monitoring using CEMS – Abu Dhabi

Parameters for online monitoring as per Guidelines

Annexure-1

Sl No	Category	Effluent Parameters	Emission Parameters
1.	Aluminium	pH, BOD, COD, TSS, Flow	PM, Fluoride
2.	Cement	-	PM,NOx,SO_2
3.	Distillery	pH, BOD,COD,TSS, Flow	PM
4.	Dye and dye intermediate	pH, BOD,COD, TSS, Cr, Flow	-
5.	Chlor Alkali	pH, TSS, Flow	Cl_2,HCl
6.	Fertilizers	pH, flow, Ammonical Nitrogen, Fluoride	PM, Fluoride, Ammonia
7.	Iron & steel	pH, Phenol, cyanide, flow	PM,SO_2
8.	Oil refinery	pH, BOD,COD,TSS, flow	PM,CO,NOx,SO_2
9.	Petrochemical	pH, BOD,COD,TSS, flow	PM,CO,NOx,SO_2,
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
13.	Pulp & 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
17.	Copper	pH, TSS, flow	PM SO_2
18.	Textile(GPI)	pH, COD, TSS, flow	-
19.	Diary(GPI)	pH, BOD,COD,TSS, flow	
20.	Slaughter House	pH, BOD,COD,TSS, flow	

ANNEXURE II

Parameter specific Emission Standards for industries need to install CEMS

<table>
<tr><th>SN</th><th>Industries / Facilities</th><th>Units of Operation</th><th>Parameters prescribed</th><th colspan="2">Emission Limits</th><th>Options available for CEMS</th></tr>
<tr><td rowspan="5">01</td><td rowspan="5">Aluminum</td><td>Raw Material Handling</td><td>PM</td><td colspan="2">PM 150 mg/NM^3</td><td rowspan="5">In situ PM CEMS (Preferably optical)

NDIR for CO

FTIR for CO and F

DOAS for all (but Path length may be an issue)</td></tr>
<tr><td>Calcinations</td><td>PM,
CO</td><td colspan="2">PM 250 mg/NM^3
CO 1% (Max)</td></tr>
<tr><td>Green Anode Shop</td><td>PM</td><td colspan="2">PM 150 mg/NM^3</td></tr>
<tr><td>Anode Bake Oven</td><td>PM
Total F</td><td colspan="2">PM 50 mg/NM^3,
0.3 Kg/MT of Al</td></tr>
<tr><td>Pot room</td><td>PM,
Total F</td><td colspan="2">PM 150 mg/NM^3
Total F$^-$ 2.8 Kg/MT (Soderberg Tech.)
0.8 kg/t (Pre-baked Technology)</td></tr>
<tr><td rowspan="5">02</td><td rowspan="4">Cement</td><td rowspan="2">Rotary Kiln with Co-Processing</td><td rowspan="2">PM
NO_X
SO_2</td><td>Commissioned on or before 25.08.2014</td><td>Commissioned on or after 25.08.2014</td><td rowspan="4">Preferably Cross Duct PM CEMS

NDIR for CO

IR GFC, FTIR, DOAS for multi-gas analysis (NOX, SO2, HCl, HF)

FID for HC (TOC)

Hot wet extractive gaseous CEMS Preferable)</td></tr>
<tr><td>30 mg/NM^3
800 mg/NM^3
100 mg/NM^3</td><td>30 mg/NM^3
600 mg/NM^3
100 mg/NM^3</td></tr>
<tr><td rowspan="2">Vertical Shaft Kiln with Co-processing</td><td rowspan="2">PM

NO_X
SO_2</td><td>Commissioned on or before 25.08.2014</td><td>Commissioned on or after 25.08.2014</td></tr>
<tr><td>50 mg/NM^3

500 mg/NM^3
200 mg/NM^3</td><td>75 mg/NM^3 (Critically Polluted /Urban area)
150 mg/NM^3 (other Areas)
500 mg/NM^3
200 mg/NM^3</td></tr>
<tr><td></td><td>Rotary Kiln without Co-Processing</td><td>PM
NO_X

SO_2</td><td colspan="2">30 mg/NM^3
600 mg/NM^3
800 mg/NM^3 (with ILC)
1000 mg/NM^3 (for mixed stream ILC and SLC
100 / 700 / 1000 mg/NM^3 (Depending on Sulphur in Limestone)</td><td>Preferably Cross Duct PM CEMS

IR GFC, FTIR, DOAS for multi-gas analysis (NO_X, SO_2, HCl, HF)</td></tr>
<tr><td>03</td><td>Distillery</td><td>Boiler Stack</td><td>PM</td><td colspan="2">150 mg/NM^3</td><td>In-situ PM CEMS</td></tr>
<tr><td>04</td><td>Chlor-Alkali</td><td>(Hypo tower)
(HCl Plant)</td><td>Cl_2
Cl_2, HCl</td><td colspan="2">Cl_2 – 15 mg/NM^3
*HCl vapour and Mists – 35 mg/NM^3</td><td>FTIR, TDLAS</td></tr>
</table>

SN	Industries / Facilities	Units of Operation	Parameters prescribed	Emission Limits		Options available for CEMS
05	Fertilizers	Phosphate Urea (Old plants)before 01.01.1982 Urea (New plants)after 01.01.1982	PM, Fluoride PM, Ammonia PM, Ammonia	PM – 150 mg/NM^3 Total Fluoride – 25 mg/NM^3 150 mg/NM^3 2 Kg/MT of product 50 mg/NM^3 0.5 Kg/MT of product		In-situ or Cross Duct PM CEMS FTIR, TDLAS, for gases (Hot Dry Extractive is preferable)
06	Iron & Steel	Coke Oven Plant New Batteries at GF sites Rebuild Batteries Existing Batteries	PM SO_2 NO_X	50 mg/NM^3 800 mg/NM^3 500 mg/NM^3		In-situ or Cross Duct PM CEMS preferably optical based technology **NDIR, IR GFC, FTIR, DOAS for multi-gas analysis** (CO, NOX, SO2, HCl, HF)
		Sintering Plant	PM	150 mg/NM^3		
		Blast Furnace		Existing Units	New Units	
			PM SO_2 NO_X CO	50 mg/NM^3 250 mg/NM^3 150 mg/NM^3 1% (Max)	30 mg/NM^3 200 mg/NM^3 150 mg/NM^3 1% (Max)	
07	Oil refinery	Furnace, Boiler and captive power plant Gas based	PM SO_2 NO_X CO	Before 2008 10 mg/NM^3 50 mg/NM^3 350 mg/NM^3 150	After 2008 5 mg/NM^3 50 mg/NM^3 250 mg/NM^3 100	In-situ or Cross Duct PM CEMS preferably optical based technology Gaseous anlysers preferably be dilution extractive due to safety issues **NDIR** (CO)**, IR GFC** NOX, SO2)
		Furnace, Boiler and captive power plant Liquid Fuel based	PM SO_2 NO_X CO	Before 2008 100 mg/NM^3 1700 mg/NM^3 450 mg/NM^3 200 mg/NM^3	After 2008 50 mg/NM^3 850 mg/NM^3 350 mg/NM^3 150 mg/NM^3	In-situ or Cross Duct PM CEMS preferably optical based technology Gaseous anlysers preferably be dilution extractive **NDIR** (CO)**, IR GFC** NOX, SO2
		Sulphur Recovery Unit (SRU)	H_2S NO_X CO	Existing SRU 15 mg/NM^3 350 mg/NM^3 150 mg/NM^3	New SRU 10 mg/NM^3 250 mg/NM^3 150 mg/NM^3	UV Fluorescence for H_2S, SO_2 **NDIR** (CO)

08	Petrochemical	Furnace, Boiler Heater Vaporizer Liquid Fuel based	PM, SO_2 NOX CO	Existing Plant 100 mg/NM^3 450 mg/NM^3 1700 mg/NM^3 200 mg/NM^3	New / Expansion 50 350 850 150	In-situ or Cross Duct PM CEMS preferably optical based technology Gaseous anlysers preferably be dilution extractive due to safety issues **NDIR** (CO)**, IR GFC** (NOX, SO2)
		Furnace, Boiler Heater Vaporizer Gas based	PM, SO_2 NOX CO	Existing Plant 10 mg/NM^3 50 mg/NM^3 350 mg/NM^3 150 mg/NM^3	New / Expansion 5 mg/NM^3 50 mg/NM^3 250 mg/NM^3 100 mg/NM^3	In-situ or Cross Duct PM CEMS preferably optical based technology Gaseous anlysers preferably be dilution extractive due to safety issues **NDIR** (CO)**, IR GFC** (NO_X, SO_2)
09	Power Plant	TPP Installed before 31st December 2003	PM NO_X SO_2 Hg	Less than 500 MW 100 mg/NM^3 600 mg/NM^3 600 mg/NM^3 0.03 mg/NM^3	More than 500 MW 100 mg/NM^3 600 mg/NM^3 200 mg/NM^3 0.03 mg/NM^3	Cross Duct PM CEMS **IR GFC** (NO_X, SO_2) FTIR, DOAS for Multigas analysis
		TPP Installed before 1st January 2004 upto 31st December 2016	PM NOX SO_2	Less than 500 MW 50 mg/NM^3 300 mg/NM^3 600 mg/NM^3	More than 500 MW 100 mg/NM^3 600 mg/NM^3 200 mg/NM^3	
		TPP Installed before 1st January 2017 onward	PM NOX SO_2 Hg	30 mg/NM^3 100 mg/NM^3 100 mg/NM^3 0.03 mg/NM^3		

SN	Industries / Facilities	Units of Operation	Parameters prescribed	Emission Limits		Options available for CEMS
10	Zinc	 Smelter SRU	 PM SO_2	Old units 100 mg/NM^3 1370 (Upto 300 T) 1250 (above 300 T)	New Units 75 mg/NM^3 1250 (Upto 300 T) 950 (above 300 T)	In-situ PM CEMS UV Fluorescence / IR for SO_2
11	Copper	 Smelter SRU	 PM SO_2	Old units 100 mg/NM^3 1370 (Upto 300 T) 1250 (above 300 T)	New Units 75 mg/NM^3 1250 (Upto 300 T) 950 (above 300 T)	In-situ PM CEMS UV Fluorescence / IR for SO_2
12	Biomedical Incinerator	Incinerator Stack	PM NO_X HCl CO & CO_2 Temp. P.C.C Temp. S.C.C.	150 mg/NM^3 450 mg/NM^3 50 mg/NM^3 Combustion Efficiency > 99% 850 ± 50 ºC 1050 ± 50 ºC		In-situ PM CEMS NDIR for CO Ideally system should be Hot wet Extractive Type
13	Common Hazardous Waste Incinerator	Incinerator Stack	PM HCl SO_2 CO NO_X HF O_2 TOC	50 mg/NM^3 50 mg/NM^3 200 mg/NM^3 100 (30 min); 50 (24 hourly) mg/NM^3 400 mg/NM^3 4 mg/NM^3 ≤ 11% 20 mg/NM^3		Ideally system must be Hot wet Extractive Type In-situ Optical based PM CEMS FTIR Type Multigas analysis is best suitable FID based instrument for TOC Paramagnetic or Zirconum cell Type Oxygen sensor.

Notes: * Mist not possible by CEMS

- *Flue gas velocity, Temperature, moisture, CO_2 and O_2 measurement are compulsory for all installation. Installation using dilution techniques must have CO_2 measurement facilities at stack and at the instrument end.*
- *All the data has to be corrected to mass/volume at STP (760 mm Hg Pressure and 298 K temperature).*

ANNEXURE III

Check list for Inspection and Certification of Installation of CEMS

A. General Information

SN	Particulars	Information
1	Name of the Company	
2	Address	
3	Type (Category)	
4	Contact Person	
5	E. Mail	
6	Phone Numbers	

B. Information on Source Emission

SN	Particulars	Information
1	Application Description	
2	Size or Production Capacity	
3	Average Running Load	
4	Number of Emission points of process stacks for which Emission Limits are Prescribed	
5	Number of Emission points of process stacks installed CEMS	
6	Air Pollution Control Devices (APCDs) of individual emission points	
7	Parameters covered under CEMS for individual stack	
8	Type of CEMS installed (In-situ or Extractive)	
9	Technology adopted for individual parameters	
10	Parameter wise Make and Model of individual CEMS installed	

SN	Particulars	Information
11	The Sample conditioning system if Extractive CEMS are Used	
12	Distance between probe and analyser in case of extractive CEMS	
13	Whether Flue gas Temperature, Moisture, Velocity and diluents (O_2 and or CO_2) monitoring systems are installed; if Yes detail thereof;	
14	Location of DAHS	
15	Shelter or Analyser Location	
16	Availability of Calibration Gas cylinders attached to systems with concentrations and validity	

C. Flue Gas Stream Constituents at Sample Probe Location

SN	Constituents	Expected Concentration		Ranges	
				Minimum	Maximum
1	SO2		ppm		
2	NOX		ppm		
3	CO		ppm		
4	H2S		ppm		
5	NH3		ppm		
6	HCl		ppm		
7	HF		ppm		
8	Hydrocarbon		ppm		
9	O2		%		
10	CO2		%		
11	Opacity / PM		% / mg/NM^3		

D. Flue Gas Conditions at Sample Probe Location

Condition	Expected Range	Observed Range	
Flue gas Temperature (ºC)		Minimum	Maximum
Flue gas static pressure (mm H_2O)			
Flue gas velocity (m/Sec)			
Particulate (mg/NM^3)			
Moisture (%)			
Water Droplets (Yes or No)			
Fuel Used			
Quantity of Fuel Burnt			

Note: The values recorded should be in order of historical data

E. Ambient Environment at CEMS Enclosure Location

Check Points	**Observation**	
Elevation from sea level (m)		
Temperature (ºC)	Minimum	Maximum
Relative Humidity (%)	Minimum	Maximum
Availability of UPS Yes / No		

F. Physical Arrangement at Probe Location

Check Points	**Observation**
Measurement location (Stack or Duct)	
Shape at Measurement Location (Circular or Rectangular)	
Height of the CEM from Ground Level (m)	
Distance of CEM downstream from last disturbance (m)	
Distance of CEM upstream from last disturbance (m)	
Inside Dimension at CEM location	
Wall thickness at CEM location	
Outside Dimension at CEM location	
Material of Construction of Stack or Duct	
Height of the manual Isokinetic sampling port (m)	
Distance between CEM and Isokinetic sampling port (m)	

G. Operational Aspects

Check Points	**Observation**
Calibration and Operation of Particulate CEMS	
Comment on CEMS Selection	
Comment on CEMS Installation Criteria	
Date of First Calibration	
Calibration at different Load Condition performed or not	
Present Dust Factor	
Actual Range of Measurement set in CEMS	
Number of calibration performed so far	
% Variations in selected Dust Factor with justification	
Reported unit of measurement	
Whether suitable corrections for Moisture, Temperature, Diluents (CO_2, O_2) are incorporated online in reports or not	
Records of servicing and maintenance is available or not	
Data Capture Rate	

Check Points	Observation
Verify if there is any change in scaling in data logging and transfer	
At least last one month data	
Verify if there is any sealing at upper end at below the selected range	
Verify if there is sudden fall or rise of data without justification	
Calibration and Operation of Gaseous CEMS	
Comment on CEMS Selection	
Comment on CEMS Installation Criteria	
Comment on Sample Transfer line and conditioning in case of Extractive CEMS	
Date of First Calibration (Multipoint with establishment within selected range)	
Actual Range of Measurement set in CEMS	
Zero Drift (Daily, Weekly and Monthly)	
Span Drift (Daily, Weekly and Monthly)	
Span Gas Concentration (it should be at 80% of Range)	
Reported unit of measurement	
Whether suitable corrections for Moisture, Temperature, Diluents (CO_2, O_2) are incorporated online in reports or not	
Records of servicing and maintenance is available or not	
Data Capture Rate	
Verify if there is any change in scaling in data logging and transfer	
At least last one month data	
Verify if there is any sealing at upper end at below the selected range	
Verify if there is sudden fall or rise of data without justification	

ANNEXURE IV

Formulae for Data Reporting

SN	Parameters	Units of Expression	Standard values	Algorithm	Remarks
01	Barometric Pressure (P_{bar})	mm of Hg			
02	Standard Pressure (P_{std})	mm of Hg	760		
03	Actual Pressure (P_{actual})	mm Hg			
04	Stack Temperature (T_S)	Kelvin		x º C + 273.15	
05	Temperature at Analyser (T_m)	Kelvin		x º C + 273.15	
06	Standard Temperature (T_{std})	Kelvin	298	25 º C + 273.15 = 298	
07	Moisture (M)	%			
08	Moisture Fraction (Mw)	Ratio		(M) /100	
09	Wet m^3 to Wet Nm^3	Wet Nm^3		x m^3 * {(P_{actual})/ (P_{std})}{™/ (T_{std})	
10	Wet Nm^3 to Dry Nm^3	Dry Nm^3		x m^3 * {(P_{actual})/ (P_{std})}*{™/ (T_{std})}*{1 / (1 – Mw)}	
11	Conversion of ppmw of any gas to mg/Nm^3	mg/Nm^3		(x ppm) * (molecular weight) / 24.45	All the instantaneous values required to be corrected in CEMS
12	Conversion of ppmv of any gas to mg/Nm^3	mg/Nm^3		{(x ppmv)}*{(12.187)}*{(MW)} / {(273.15 + 25 °C)}	This is not applicable for CEMS as Pressure correction is not applied
13	CO_2 Correction		12 %	{x mg/Nm^3} * {(12 / Measured CO_2)} ***<u>Correction not needed wherever CO_2 is > 12%</u>***	All the instantaneous values required to be corrected in CEMS wherever applied

SN	Parameters	Units of Expression	Standard values	Algorithm	Remarks
14	O_2 Correction		11%	Cr = {x mg/Nm^3 * (20.9 - 11)} /{ (20.9 - Measured O_2)} ***<u>Correction not needed wherever O_2 is < 11%</u>***	All the instantaneous values required to be corrected in CEMS wherever applied
15	O_2 Correction		3 %	Cr = {x mg/Nm^3 * (20.9 - 3)} /{ (20.9 - Measured O_2)} ***<u>Correction not needed wherever O_2 is < 3%</u>***	Applicable for gas and liquid fuel in Petrochemical industries
16	Combustion Efficiency			{(%CO2)*100} / {(% CO2 + %CO)}	Applicable for Biomedical Waste Incinerator

ANNEXURE V

Continuous (Real time) Source emission Daily Monitoring Report Format

A) Source Information:

1.	Reporting Period	From:	To:
2.	Name of the Industry with ID (If any)		
3.	Plant Name		
4.	Stack ID		
5.	APCD		
6.	Operation Time (Hours)		

B) Information on CEMS

Parameter	Make	Instrument ID	Type	Span	Location

C) Information on CEMS Operation Summary

Parameter	Down time		Reasons	Corrective Actions
	From	To		

Notes: Excluding Zero and Span Checks. Report Downtime as % of source operation time

D) Data Averages

Parameter (P)	Units	Hourly Average Emission																								
		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

24 hourly Data:	**PM**	**SO_2**	**NO_X**	**CO_2**	**O_2**	**HCl**	**F**	**Others**
Min								
Max								
Average								

Report Prepared by:

(Signature)

Report Approved by:

(Signature)

ANNEXURE VI

Continuous (Real time) Source emission Monthly Monitoring Report Format

Pollutant	Inst ID	Stack ID	Data Capture Rate	Average monthly emission	Downtime	Reasons of Downtime	Excess Emission events	Magnitude of Excess Emission	Zero – Span Calibration Drift	Maintenance / Repair of CEMS
			(%)	Units as applicable	% of source operation		(hrs.)	% from Standard limit	%	

Report Prepared by:

(Signature)

Report Approved by:

(Signature)

ANNEXURE VII

Continuous (Real time) Source emission Quarterly Monitoring Report Format

Parameter	Instrument ID	Location	Data Capture Rate	Downtime	Zero – Span Calibration Drift	Out of Control Periods in terms of Drift	Corrective Actions	Leak Check Results	Linearity Check	Accuracy Test Report
			(%)	% of source operation	%					

Report Prepared by:

(Signature)

Report Approved by:

(Signature)