

Guidelines for Continuous Emission Monitoring Systems



CENTRAL POLLUTION CONTROL BOARD
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Note: Efforts have been made to include all available monitoring technologies/instrumentation in the document. In case any high end technology/ instrumentation is not covered or is introduced subsequently the details be forwarded to CPCB, so that the same can be incorporated while reviewing this document subsequently.

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1.0 BACKGROUND

In order to track release of pollutants through air emissions and effluent discharge from industries with high pollution potential, 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 (such as Pulp & Paper, Distillery, Sugar, Tanneries, Power Plants, Iron & Steel, Cement, Oil Refineries, Fertilizer, Chloral Alkali Plants, Dye & Dye Intermediate Units, Pesticides, Zinc, Copper, Aluminum, Petrochemicals and Pharma Sector, etc.), Common Effluent Treatment Plants (CETP), Sewage Treatment Plants (STPs), Common Bio Medical Waste and Common Hazardous Waste Incinerators; for installation of online effluent quality and emission monitoring systems. The directions envisage:

- a) Installation of online emission quality monitoring system in 17 categories of highly polluting industries and in Common Hazardous waste and Biomedical waste incinerators for measurement of the parameters, Particulate Matter, NH₃ (Ammonia), SO₂ (Sulphur Dioxide), NO_x (Oxides of Nitrogen) and other sector specific parameters, not later than by March 31, 2015 and transmission of online data so generated simultaneously to SPCB/PCC and CPCB as well. The deadline was later extended to June 31, 2015.
- b) Installation of surveillance system with industrial grade IP (Internet Protocol) cameras having PAN, Tilt, Zoom (PTZ) with leased line real time connection for data streaming and transmission of the same in case of industries claiming Zero Liquid Discharge (ZLD); and
- c) Ensure regular maintenance and operation of the online system with tamper proof mechanism having facilities for online calibration (onsite/offsite; Remote).

In addition to above, G.S.R. 96(E) January 29, 2018 Notified by MoEF&CC under Environment (Protection) Act, 1986 mandates installation of CEMS with the Boilers used in the Industries namely Sugar, Cotton Textile, Composite Woolen Mills, Synthetic Rubber, Pulp & Paper, Distilleries, Leather Industries, Calcium Carbide, Carbon Black, Natural

Rubber, Asbestos, Caustic Soda, Small Boilers, Aluminium Plants, Tanneries, Inorganic Chemicals & other such industries using boilers.

Parameters required to be monitored in the stack emissions using Continuous Emission Monitoring system, are industry specific and are specified below: -

- a) PM (Particulate Matter)
- b) HF (as Total Fluoride)
- c) NH₃ (as Ammonia)
- d) SO₂ (Sulphur Dioxide)
- e) NO_x (Oxides of Nitrogen as NO₂)
- f) Cl₂ (Chlorine)
- g) HCl (Hydrochloric acid) and HF (Hydro Fluoric Acid)
- h) TOC (Total Organic Carbon) / THC (Total Hydro Carbon) / VOC (Volatile Organic Carbon)- C_nH_m
- i) Hg (Gaseous mercury)
- j) Process parameters (Mandatory) to be monitored at each stack at sampling point/plane:
 - 1 Temperature
 - 2 Flow (applicable wherever load based standards prescribed and DC Tribo system installed for monitoring of PM)
- k) Diluents gas CO₂ or O₂ as prescribed in the emission standards of respective processes /industries
- l) Carbon Monoxide as prescribed in the emission standards of respective processes /industries i.e. Incinerators, etc.;
- m) The emission values should be corrected for Moisture Content (For In-situ and Hot extractive analyzer real time moisture monitoring values of inbuilt measurements can be used). Moisture content value recorded during manual monitoring conducted by empaneled labs, at the time of verification/calibration can be considered for correction.
- n) For normalization of emission values absolute pressure is also required to be monitored in the sampling plane. Value recorded during manual monitoring can be used for normalization.
- o) Real time moisture monitoring is incinerator stack.

2.0 NEED FOR CEMS

Industries such as Power, Cement, Iron & Steel, Chlor-alkali, Pharmaceuticals, Fertilizers, Refineries, Pesticides, Distilleries, Sugar, Pulp & Paper, Textile, Tanneries, and other categories of industries release large quantum of pollutants through air emissions and effluent discharge.

In order to regulate such emissions and discharges to safe limits, SPCBs and PCCs have prescribed standards for various pollutants emitted/ discharged by the industries as notified under the Environment(Protection) Act, 1986. Compliance monitoring needs strengthening to ensure that industries and facilities comply with emission standards.

With rapid industrialization, it is becoming a need and necessity to regulate compliance by industries with minimal inspection of industries. Therefore, efforts need to be made to bring discipline in the industries to exercise self-monitoring so as impart confidence on their compliance to notified standards; one such mechanism is to implement online emission and effluent monitoring systems and transfer reliable data on compliance to regulatory authorities (SPCBs/PCCs / CPCB, other government agencies). Online emission and effluent monitoring systems need to be installed and operated by the developers and the industries on 'Polluter Pays Principle'.

Verification, validation and accuracy check of the values indicated by the online devices needs to be done. For proper interpretation of data, measures need to be taken at the level of SPCBs/PCCs. For regulatory and for purpose of actions to be taken against non-complying industries/facilities, the existing method of sampling, analysis and related procedures under the existing statutes need to be continued, till further direction.

Various technologies are available for monitoring the particulate matter and gaseous emission from the stacks of industries and effluent discharge from industries and facilities for the parameters specified in the directions issued by CPCB/SPCB or notified under E(P) Act, 1986. However, this guideline document aimed to help industries and regulatory agencies in implementation of online emission monitoring system through proper selection, operation and

data transfer in a transparent self-regulatory mechanism.

3.0 CONTINUOUS EMISSION MONITORING SYSTEM (CEMS)

In recent years Online Emission Monitoring Technology has received attention and interest in context of providing accurate and continuous information on particulate matter/ gaseous emission from stacks. There are already commercially available systems for monitoring parameters such as PM, HCl, HF, NH₃, SO₂, CO, O₂, CO₂, NO_x, VOC, etc.

3.1 Objectives of Continuous Emission Monitoring Systems

The Continuous Emission Monitoring (CEM) System comprises of all the equipment necessary to determine the concentration of gaseous emission and/or particulate matter and/or emission rate using analytical measurements and a computer program to provide results in units of the applicable emission limits or standards. The data generated is gathered either through analog outputs to a recording system or send directly to a DAS (Data Acquisition System) for storage and onward transmission.

Data Acquisition System includes special modules for data validation and further transmission to Central servers located at SPCB/ CPCB through a cloud server compatible to specific types of analyzers. It is important to have properly engineered CEM systems.

i) Compliance with legislation

For any given process, limits have been imposed on the quantum of emissions that an industry is permitted to release to the atmosphere for a particular parameter/ pollutant. These limits are expressed as: -

- Maximum concentration in ppm or mg/Nm³ (as specified in standards)
- Maximum mass emission (Kg/Tonne or Kg/unit production)

For calculating maximum mass emissions i.e, Kg/Tonne or Kg/unit production, values of flow and concentration are required.

CEMS data shall be used as tool to monitor performance of pollution control systems as well as to generate alarms on exceedances with respect to notified standards (for manual measurement). CEMS data will be used for regulatory purposes once CEMS based standards are notified by Government of India. However, at present CEMS data would

help regulatory bodies in close surveillance on industries based on alarm system.

ii) Validity/ Availability of Measured Data

Quality assurance procedures shall be used to validate the quality of data produced by the CEMS required for comparing compliance with notified standards (for manual measurement). Reference methods will be defined to substantiate the accuracy and precision of the CEMS.

Performance Specifications will be used for evaluating the acceptability of the CEMS at the time of or soon after installation and whenever specified in the Indian regulations. The CEMS has to include continuous quality check for Zero and for scale(Span) point, preferably without human intervention, to ensure continuous data validity and credibility.

Zero check on Gaseous CEMS must be achieved, by using zero air supply using high grade instrument air (free from moisture, component of gases under measurement and gases having interference) or an inert gas like N₂, done automatically and periodically. The Instrument supplier is responsible for verification of zero gas / instrument air being used in the industry. A certificate to this effect has to be provided by the instrument supplier to the industry at the time of installation.

Use of Certified Zero & Span Test Gas Cylinders or Gas filled “Calibration Cuvette / Cells”, Certified by leading global Agencies like TUV/ MCERT are also acceptable for CEMS in India. Cuvette/ Cells known to have long term stability compared to cylinders can also be used for calibration. Ambient air not being a certified gas is not recommended for calibration.

iii) Basic Requirement

The major prerequisites of efficient Continuous Emission Monitoring System are:

- a) It should be capable of operating unattended over prolonged period of time.
- b) It should produce analytically valid results with precision/ repeatability
- c) The analyzer should be robust and rugged, for optimal operation under extreme environmental conditions, while maintaining its calibrated status.

- d) The analyzer should have inbuilt zero check capability or external capability with a condition that no human intervention should be required to carryout daily check at defined time.
- e) It should have data validation facility with features to transmit raw and validated data to central server at SPCB/CPCB. The data validation will be done after approval of SPCB/PCC or after 07 days of submission of request for validation to SPCB/PCC wherever is earlier.
- f) It should have Remote system access from central server for provisional log file access. The facility shall be incorporated in the system within 06 months of the issue of these 1st Revised Guidelines.
- g) It should have provision for simultaneous Multi-server data transmission from each station without intermediate PC or plant server.
- h) It should have provision to send system alarm to central server in case any changes are made in configuration or calibration. The facility shall be incorporated in the system within 06 months of the issue of these 1st Revised Guidelines.
- i) It should have provision to record all operational information in log file.
- j) There should be provision for independent analysis, validation, calibration & data transmission for each parameter.
- k) The instrument must have provision of a system memory (non-volatile) to record data for atleast one year of continuous operation. Existing instruments not having adequate system memory shall be backed up with external devices within six months. All new instruments installed shall have inbuilt provision of system memory.
- l) It should have provision of Plant level data viewing and retrieval with selection of Ethernet, Modbus & USB.
- m) Record of calibration and validation should be available on real time basis at central server from each location/parameter.
- n) Record of online diagnostic features including analyzer status should be available in database for user-friendly maintenance.
- o) It must have low operation and maintenance requirements.
- iv) The analyzer must include the following features (typical

characteristics):

- a) Continuous measurements on 24x7 basis.
- b) Direct Measurement of pollutant concentration.
- c) Expression and display of measurements in ppm, mg/m³ or volume % as specified in standards.
- d) Display of the measurement values as well as all the information required for checking/maintenance of the analyzer.
- e) Display of functional parameters.
- f) Response time < 200 seconds.
- g) Power supply compatible with utilities available on Indian industrial sites.
- h) Digital communication with distant computer for data acquisition/recording/reporting.
- i) RS232 / RS485 / Ethernet / USB communication ports.
- j) Analog Outputs for transmission to Plant's supervision center.
- k) Maximum lifetime of analyzers should be restricted to expected life period specified by the Vendors or up on the perusal of deterioration in performance of the analyzers i.e. frequent breakdowns and requirement of minimum data capture is not on it.
- l) Type approved according to Indian Certification Scheme (or by foreign accredited institutes such as TÜV, MCERTS or USEPA).

3.2 Merits of CEMS

The major advantages of CEMS over traditional laboratory based and portable field methods are:

- a) CEMS provide continuous measurement of data for long periods of time, at the monitoring site of interest, without skilled staff being required to perform the analysis.
- b) All the major steps in traditional analysis like sample collection, transportation, conditioning, calibration and analysis procedures including QC are usually automated in the sampling systems and on-line analyzers.
- c) In case of sudden disturbance in the Production Process/ Pollution Control system, the on-line analyzers provide timely information for taking immediate corrective/preventive steps compared to conventional methods.

4.0 TECHNICAL OPTIONS FOR SAMPLING OF POLLUTANTS IN CEMS

The sampling technologies are summarized in **Figure1**. Two types of systems available for monitoring of particulate and gaseous pollutant are mentioned below: -

- 1) In-Situ Systems:
 - Folded Beam/ Point
 - Cross Duct
- 2) Extractive systems:
 - Hot Extractive Systems with Heated Analyzer (Hot and Wet System)
 - Hot Extractive Systems with Sample Cooling and Cold Analyzer (Cold and Dry System)
 - Extractive dilution system (In-stack and out stack)

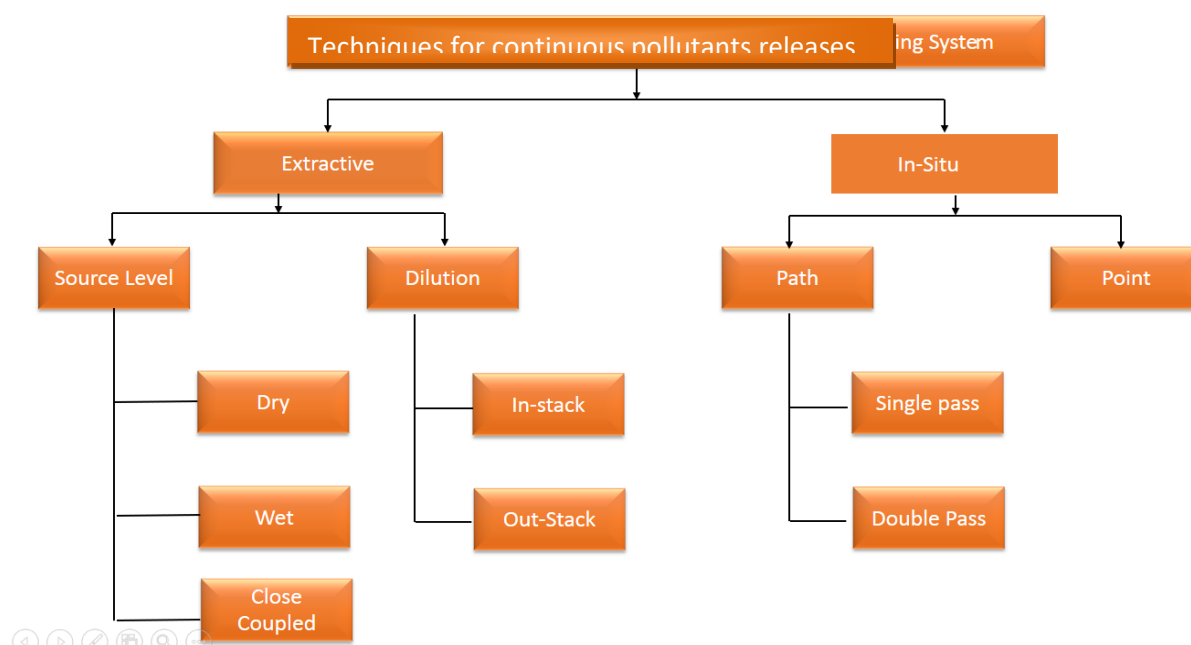


Figure 1: Techniques for Continuous Sampling of Pollutant Releases from Stacks

The sampling location has major impact on the representativeness and accuracy of sample collected. Suitable measurement sites and sections are necessary to obtain reliable and comparable emission measurement results. Appropriate measurement sections and sites have to be planned while designing a plant.

Emission measurements in flue gases require defined flow conditions in the measurement plane, i.e. an ordered and stable flow profile without vortexing and backflow so that the velocity and the mass concentration of the measured pollutant being released in the waste gases can be determined. Emission

measurements require appropriate sampling ports and working platforms. The installation of measurement ports and working platforms should be considered in the planning phase of a measurement section, refer **Figures 1.1& 1.2**. Specifications of regulations along with official requirements if any, should be considered in selection and specification of measurement site and sections.

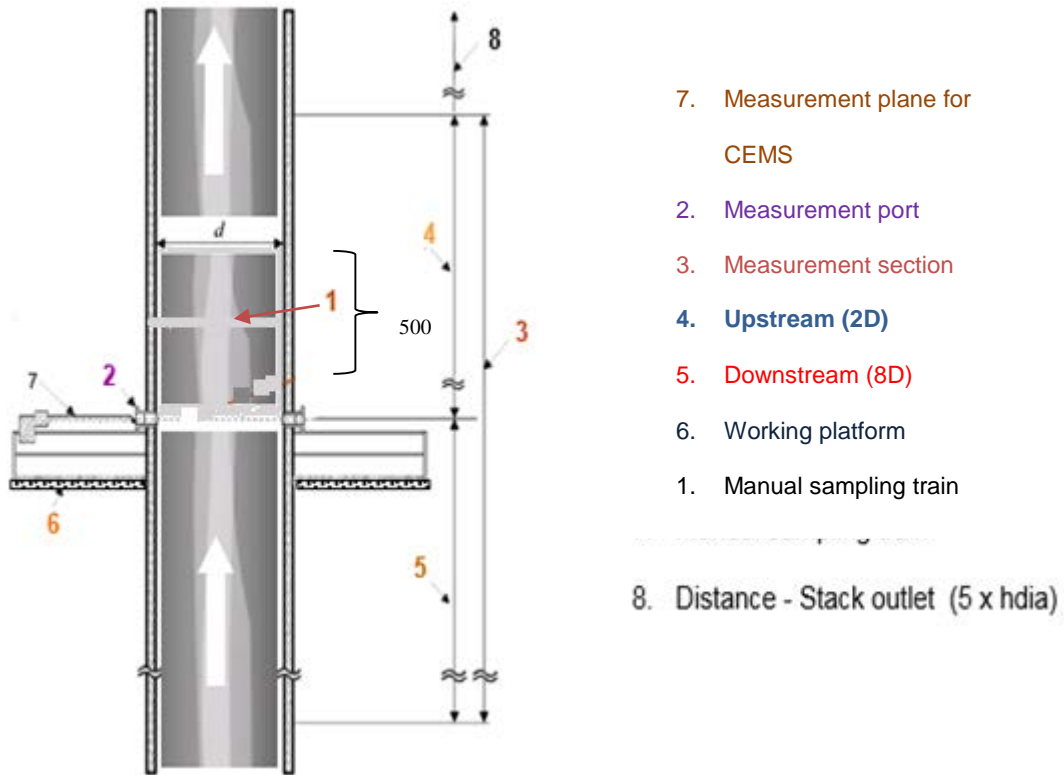


Figure 1.1: Measurement Site and Measurement Section

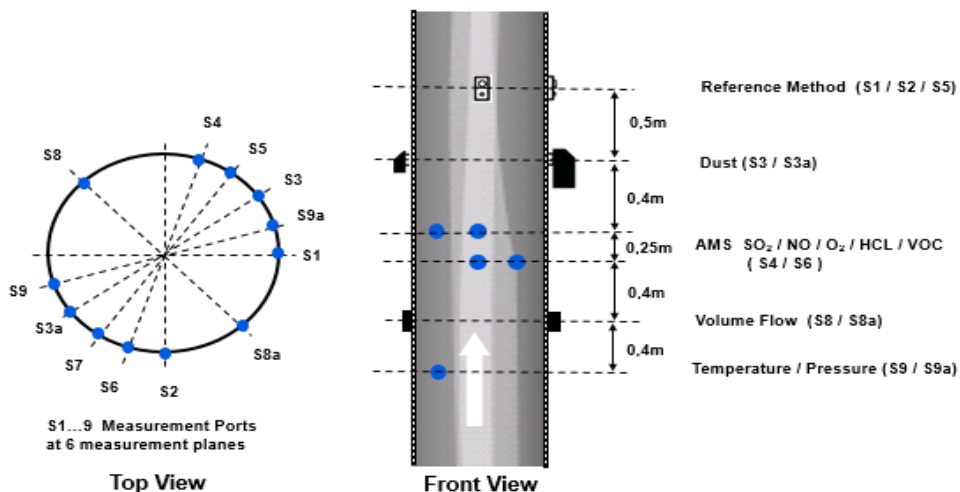


Figure 1.2 : Measurement Site and Measurement Section

The measurement site and measurement section for CEMS is based on EN 15259 criteria for selection of measuring point/ port locations and depends upon following conditions (For Details refer EN15259 Standards):

- Whether to monitor concentration alone or gas flow also;
- Whether the system requires periodic calibration using standard method or whether the CEMS can be calibrated by other means.

The influence of these factors in determining the positional requirements is shown in the decision tree in **figure 2**.

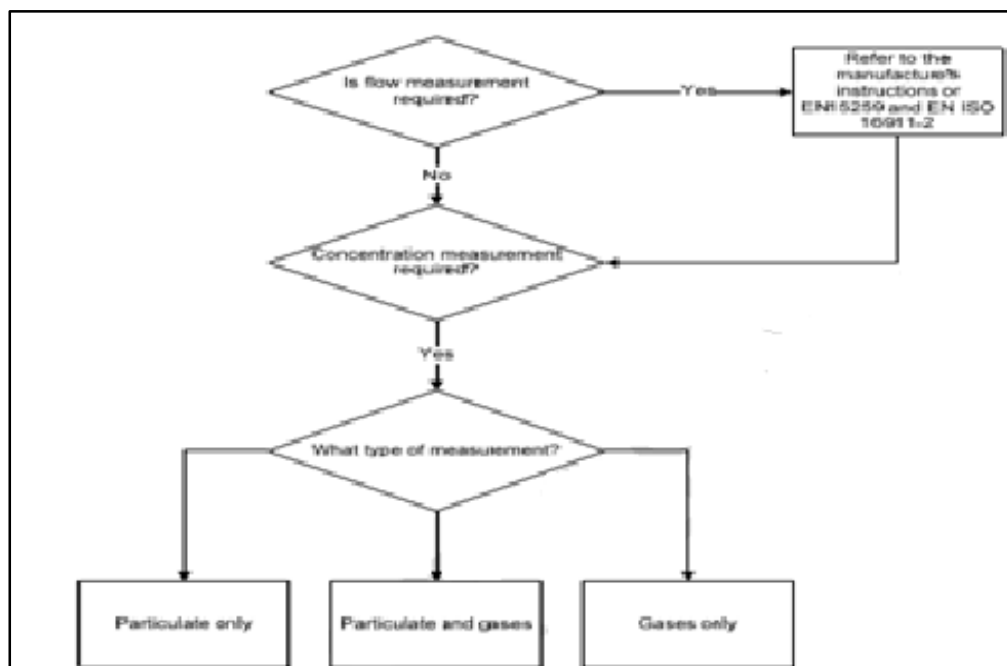


Figure 2: Selecting a sample location

4.1 Sampling Location for Particulate Matter

The analyser/ systems installed for particulate matter monitoring require calibration performed by manual isokinetic sampling carried out through either BSEN 13284-1, IS: 11255 Part 1 (Particulate Matter) or EPA method 17 or EPA method 5 or BS ISO 9096:2003. The sampling location for the analyser must be in accordance with the CPCB prescribed guidelines (Emission Regulation Part-III).

The sampling plane for PM-CEMS should be 500 mm below manual sampling plane vertically. In addition to the above, for convenience of CEMS maintenance and manual sampling from the same platform, the manual sampling port may be shifted 30-50 cm right or left at horizontal plane of CEMS port without altering their vertical position (500 mm apart). For gaseous CEMS the same plane can be shared. In case of existing stacks where provision

cannot be complied with, the industry shall inform the respective SPCBs/PCCs and proceed as advised/directed.

The sampling point or plane should be in a straight length of stack/duct (**Figure 3**) where;

- The angle of gas flow is less than 15°
- No local negative flow is present;
- The minimum velocity is higher than the detection limit (3 m/ Sec) of the method used for the flow rate measurement (for Pitot tubes, a differential pressure larger than 5 Pa);
- The ratio of the highest to lowest local gas velocities is less than 3:1.

If the above information cannot be verified e.g. on a new installation, then the above criteria is generally fulfilled by siting the ports in sections of duct with at least eight hydraulic diameters of straight duct downstream of the sampling plane and two hydraulic diameters upstream hydraulic diameters from the top of a stack.

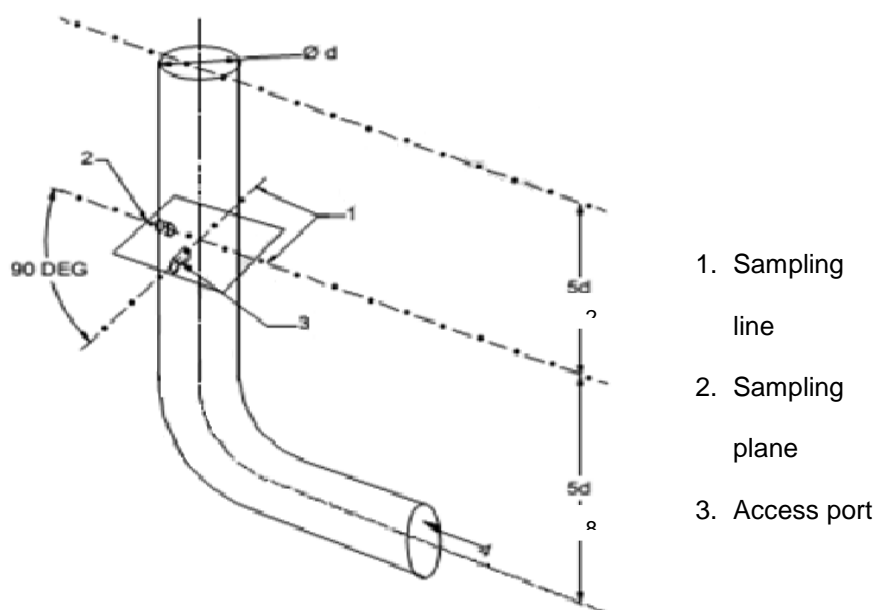


Figure 3: Sample Plane Requirement for Particulate Matter Measurement

4.1.1 Sampling location for systems with particulate matter and gas analyzers

While selecting a location for installation of analyzers in large ducts, the gas profile at the proposed sampling point must be checked for stratification. A stratification test is undertaken to confirm that the gas composition is homogenous. Typically, a surrogate gas such as oxygen or carbon dioxide is measured using a direct reading instrument in order to obtain information on the

gas profile within the duct. The stratification test must take into account variations of gas composition with time. This can be achieved by using two continuous analysers each connected to sampling probes. One probe is placed at a fixed location in the duct; the other is used to obtain samples at grid locations across the duct traverses. The two sets of data can then be compared in order to compensate for variations in concentration with time.

4.1.2 Sampling location for gas analysers

Selection of a sampling location for gas analysis alone is less difficult than for particulate measurement. A location in the duct where the gas is well mixed and therefore homogenous should be chosen.

4.1.3 Design of porthole locations for new stacks being installed after the date of issue of this 1st Revision of Guidelines is mandatory. For stacks which are already in place as on date the new design implementation must be done within a period of six months from date of issue of 1st Revision of Guidelines.

4.1.4 Stacks that are more than 15 (Fifteen) years old (from the date of 1st revision of guidelines) / stacks built with thick RCC walls / stacks with inner rubber lining / etc. where it is considered that making provisions for monitoring as per new guidelines is not possible or it may take longer period; industry is advised to communicate the reasons thereof to SPCBs/PCCs and SPCBs/PCCs to verify and certify the reasons in writing to this effect. In such cases CPCB should be intimated by the industry with records of documents scanned and sent at cems.cpcb@nic.in.

4.2 Analysis of Measurement Techniques

4.2.1 In Situ system:

In-situ is defined as in situation.

Non-extractive (in-situ) systems

In-situ type analyzers may be of two types: point in-situ type or cross stack type. These are explained below.

- Point in-situ

Point in-situ systems perform measurements at a single point in the stack, as do extractive system probes. Now a days in the in-situ systems the sensing

optics are contained in a tube fitted with holes or filters to allow flow-through of stack gases. The sampling path will be relatively short compared to the stack or duct diameter, so the sampling location must be carefully chosen to ensure that the sample is representative of the flue gas.

- Multi Point in-situ

In certain CEMS, the measurement length is extended over the length of a probe (say 0.05mt to 1.00mt) to increase resolution and provide more coverage (representative measurement). In any case 1/3rd of the stack cross section ensures better representation.

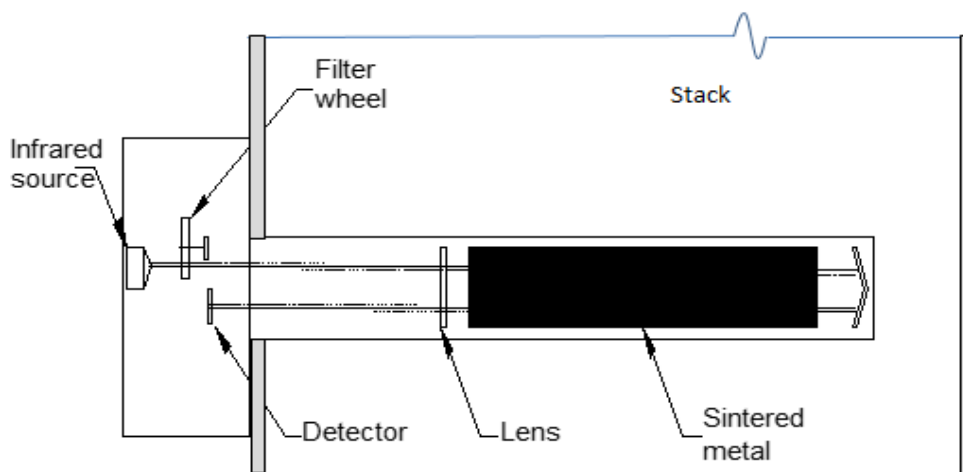
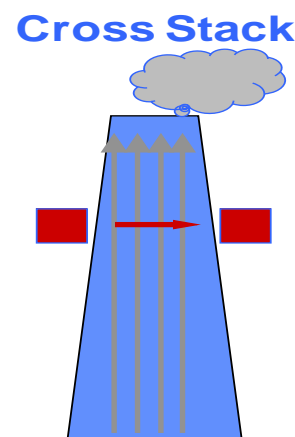


Figure 4.2.1 a: Point in-situ gas analyzer

Cross stack monitors

Cross stack monitors measure over the entire stack or duct diameter. They are based on a beam of a certain wavelength that crosses the duct and is attenuated proportionately to the concentration of the target compound. In some systems, a pipe may be used in the stack for support or calibration purposes, or to reduce the optical path lengths in very large stacks or ducts. There are two basic types of path systems: single pass and double pass where the beam is reflected back across the stack. These systems can be simpler than extractive systems, however there are additional challenges associated with making valid zero and span checks and minimizing interference from other pollutants.



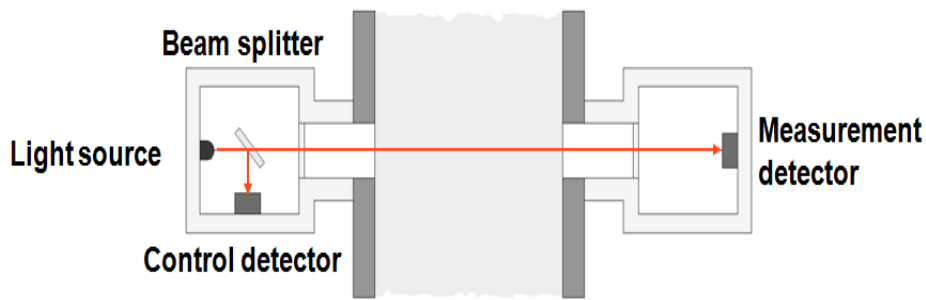


Figure4.2.1 b. Single pass transmissometer /opacity monitor

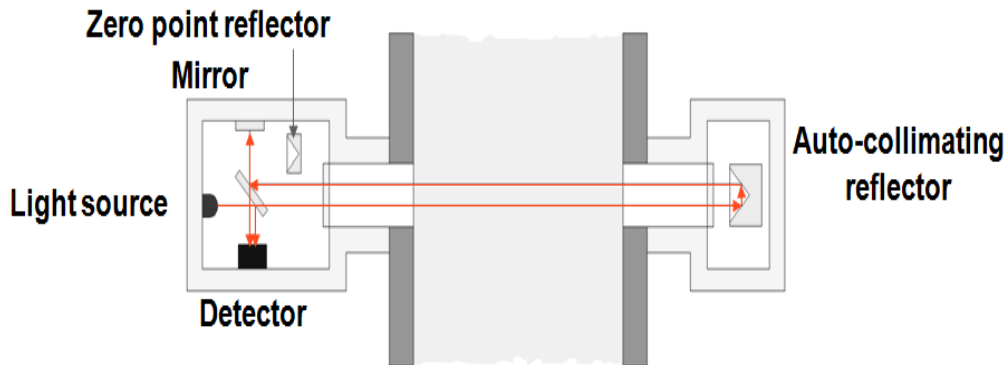


Figure4.2.1 c. Double pass transmissometer /opacity monitor

Single beam and double beam principle- Single-beam configuration is simplest where one light beam from source is passed to receiver. Dual or double-beam configurations internally split the light emitted from the source into two beams – one becomes measurement beam and another becomes reference beam. The measurement beam is projected through the optical medium of interest and is referenced to the second (reference) beam, which is totally contained within the instrument. There can be common or separate detectors for both the beam.

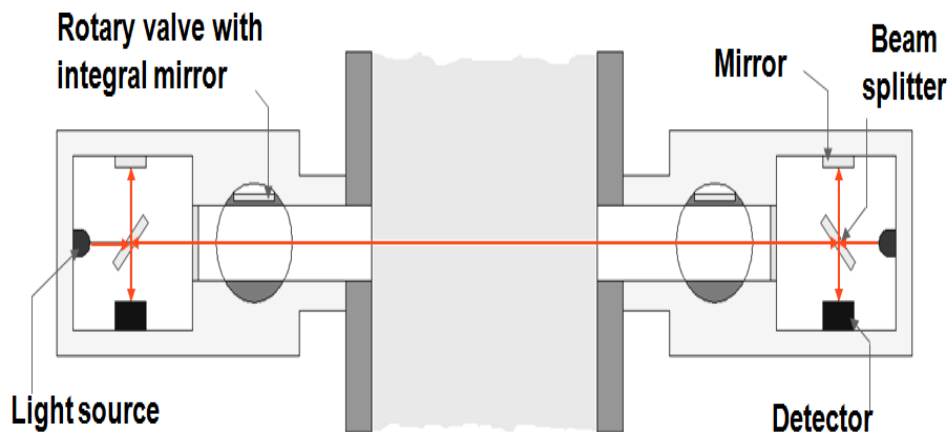


Figure4.2.1 d: Double Beam Transmissometer (Measurement)

➤ **Benefits:**

- ✓ Fast Response time
- ✓ Reasonable cost
- ✓ Process control
- ✓ No sample conditioning required.

➤ **Limitations:**

- ✓ Two flanges may be needed so an access to both side of stack is required.
- ✓ Systems are subject to stack vibration and temperature variations
- ✓ Proper alignment is required for correct measurement
- ✓ Sensitivity is limited due to the path length (critical for stacks with small diameters)
- ✓ Limited quantity of gases can be monitored
- ✓ Analyzer is subject to cross interferences especially from Water (Moisture)/ Temperature / Pressure.
- ✓ In situ systems are installed outside at top of stack so inconvenient conditions for maintenance
- ✓ No absolute method of On Line Calibration using injection of span gases along the path length.
- ✓ Complete Calibration equipment to be installed with analyser on top of stack platform.
- ✓ After readjustment the equipment has to be brought down to lab for calibration / validation checks.

4.2.2 Extractive system (Gaseous Pollutant)

Source-level extractive systems are those in which a sample of flue gases is continuously extracted from a pointmoi and conveyed to the analyzer using a sampling line. Particulate matter may be removed from the gas, and it may be cooled and dried, but in all other respects the sample is not altered by the sampling process. Three types of source-level extractive systems are marketed commercially:

- a. Hot and wet systems and Hot and Wet -Close Coupled Systems
- b. Dilution Extractive Systems
- c. Cool and dry systems with conditioning at the analyzer enclosure

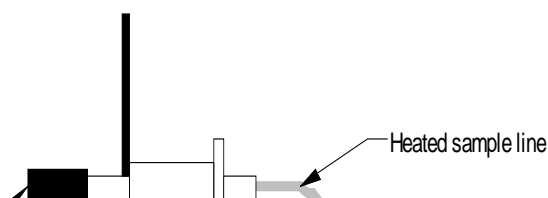


Figure 4.2.2 a: Hot and wet gas sampling system

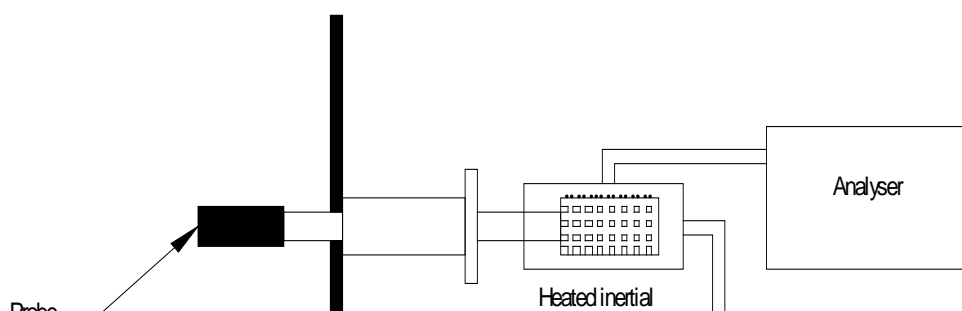


Figure 4.2.2 b: Close coupled gas analyzer

In some cases, a combination of these systems may be used, for example when there is a requirement to measure both highly reactive and less reactive pollutants concurrently.

A source-level extractive system consists of several basic components: probe, sample line, filters, moisture-removal system and pump. In some source-level systems the analyzer, for example IR analyzer, O₂ zirconia sensor or TOC Flame Ionization Detector (FID), is mounted on the stack or duct, after a short sample line. In this case, analyzer response times are very fast and apart from particulate filtering, sample conditioning is not required. These systems are known as close coupled.

➤ **Benefits:**

- ✓ Sensitivity of the system is not related to stack diameter.
- ✓ Varying stack temperature does not affect the measurements
- ✓ Can be proven using reference calibration gases.

➤ **Limitations**

- ✓ Longer response time, moisture removal, however meets the emission requirement.
- ✓ The closed coupled systems are subject to stack vibration and temperature variations requiring higher maintenance as calibration also mounted on stack, however extractive system (Hot-Wet or Dry Direct Extractive does not have this issue)

4.2.3 Dilution based extractive system

The need is to transport the sample hot, and to filter and dry relatively large volumes of flue gas. This problem can be largely avoided by using dilution systems, where gas is drawn into the probe at much lower flow rates than in a source-level system. Dilution systems are used in conjunction with ambient air level gas analyzers.

Oxygen or CO₂ must be measured separately for correction purposes (the diluted sample is 'swamped' by dilution air).

There are two types of commercially available dilution systems: **dilution probes**, where dilution of the sample gas takes place **in the stack**, and **out-stack dilution systems**, where dilution is carried out external to the stack. The out-stack dilution sampling is less sensitive to changes in stack gas temperature, pressure and density. However, heated sample line is required for out stack dilution system.

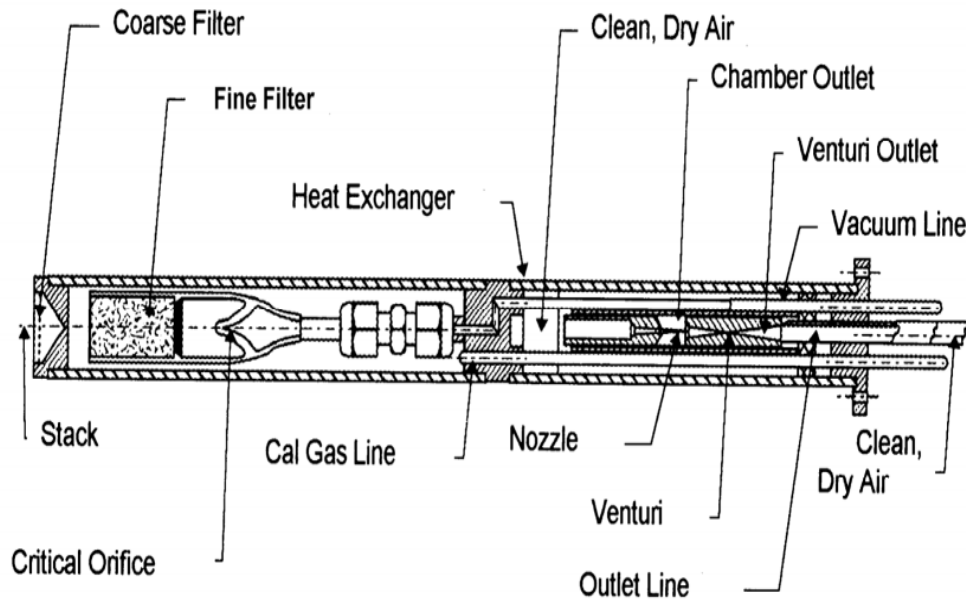


Figure 4.2.3 a: Typical in-stack dilution probe

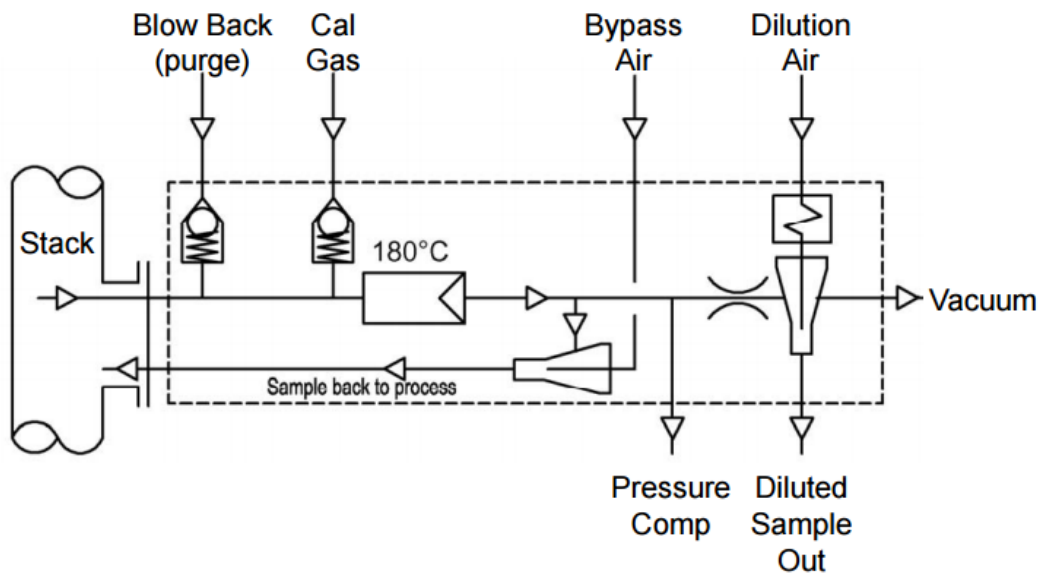


Figure 4.2.3 b: Typical out-stack dilution probe

Sample gas is extracted from the stack at a known flow rate, mixed with a known flow rate of dry air / dilutant.



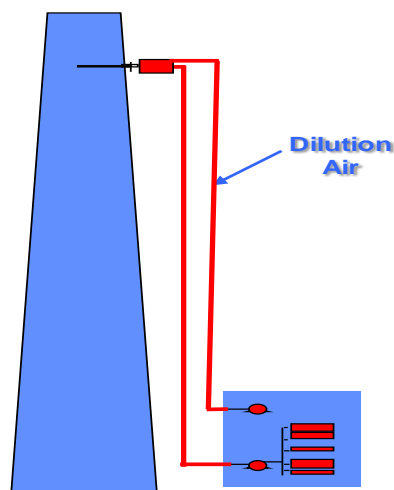
Benefits:

- ✓ It can be used to reduce moisture content so no heated sampling components are required.
- ✓ No power required at the probe so it can be used in hazardous areas.
- ✓ Low effect of stack temp variation, dust & moisture as dilution is done.

- ✓ long distance transportation of sample at positive pressure can be done

➤ **Limitations:**

- ✓ Flow rates are critical and need to be controlled to avoid varying dilution ratios.
- ✓ Balance is to be maintained with respect to Sample gas concentration vs analyzer sensitivity.
- ✓ Cannot be used for all gases including oxygen.
- ✓ Careful consideration of probe materials for high temperature and corrosive applications.
- ✓ Require periodical controlled cleaning due to presence of dust / ash \ sulfur presence, which effect the micro critical orifice leading to erroneous measurements.



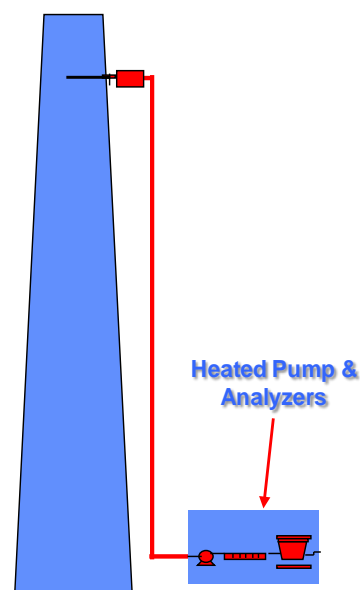
4.2.4 Hot Wet Extractive system with Heated Analyzer

Sample gas is extracted from the stack and transported to the analyzer using heated line and heated sampling components – filters, pumps etc., including the analyzer measurement cell.

The temperature of all components in contact with the sample gas is typically at 180°C to avoid condensation and loss of soluble gases.

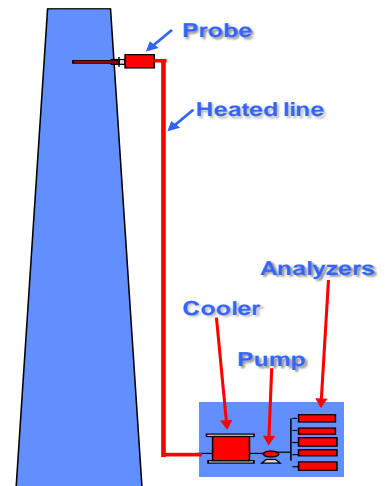
➤ **Benefits**

- ✓ Sensitivity of the system is not related to stack diameter.
- ✓ Varying stack temperature does not affect the measurements
- ✓ Use technologies like FTIR that can measure most gases including NH₃, HF, HCl, VOC, H₂O and O₂.
- ✓ Multi gases including specialty gases that are difficult to measure in other techniques.



➤ **Limitations**

- ✓ Costly heated sample lines and components.
- ✓ Heated lines not UPS protected due to power required- risk of condensation and damage.
- ✓ More time required to maintain the system and heat stressed components.
- ✓ Online continuous H₂O measurement for online correction of moisture as normalization being a
- ✓ hot wet technique.



4.2.5 Cool and Dry Systems - Hot Extractive System with Gas Cooler and Cold Analyzer

Sample gas is passed through a cooler to bring the sample gas temperature down to a low temperature and to remove water so sample is almost dry. Coolers are typically Peltier or Compressor type with outlet at about 3-4°C.

➤ **Benefits**

- ✓ Varying stack temperature does not affect the measurements
- ✓ Multi gas measurement is possible with flexibility of different principle of measurements.
- ✓ Can use analyzers operating at low/ambient temperatures so components are not heat stressed.
- ✓ These analyser are versatile as suitable for harsh environments and can be placed in a clean, dry & temperature controlled environment, so more stable system and easier to maintain
- ✓ Analyzers are running at low temperatures, so systems tend to be cheaper than heated systems and widely used concept.
- ✓ These are also available in hazardous area installation.

➤ **Limitations**

- ✓ It cannot be used on very soluble/corrosive gases.
- ✓ Soluble gases (HCl, HF, NH₃, SO₂) can be lost during the cooling resulting in lower than actual readings.
- ✓ Heated Sample gas line is required to maintain the flue gases above dew point.
- ✓ Leakage in sampling line will give erroneous results due to mixing of ambient air.

- ✓ Possibility of choking of lines in case of high dust loading.
- ✓ Risk of condensation in case of power fail
- ✓ In high dust concentration applications frequent choking occurs

4.2.6 Extractive sample drying by other method

- ✓ Extracted sample may also be dried by applying specific sample line through selective permeation. Water gets eliminated from the sample stream to the outer jackets containing dry and cold air.

4.2.7 Gas Sampling and Conditioning

The accuracy, repeatability and response time of the analysers are more dependent on the sample handling system rather than the analysers only. The reliability, accuracy, repeatability and response time of the measurement results of extractive analysers are impacted by possible failure of some of the components of sample handling system for extractive sampling.

Inline filters – used for applications where dust concentration in sample gas is on higher side, gets frequently choked and need regular maintenance which effects percentage availability of measurement. The incorporation of technology for effective, heated, automatic back flush to clean these filters from outside can enhance the measurement data availability.

Heated Probe – accommodates heated fine filter, to arrest dust particles in sample gas to protect sensitive analyzer and provide uniform heating to the sample coming out from the stack and avoid condensation or cold spots.

For effective filtering, the probe should have more filtering area with automated back purge and back flush to reduce filter cleaning frequency and increasing the uptime of measurement.

Heated Filter: the common problem with the heated filter is associated with ineffective filtering area and selection of right micron size.

Sample Gas Pumps – are running 24x7 for months need to be robust and reliable.

5.0 MEASUREMENT TECHNIQUES FOR PARTICULATE MATTER AND GASEOUS POLLUTANT

5.1 Techniques / Instrumentation for Online PM Monitoring

Particulate Matter Continuous Emission Monitoring Systems (PM CEMS) measure a parameter (e.g. scattered light) which can be correlated to dust concentration by comparison to a gravimetric sample taken under isokinetic conditions rather than the mass concentration directly. The performance and suitability of any particulate monitor is therefore application dependent. A number of techniques are used in practice which provide a practical and robust solution for most industrial applications. There are two main types of Particulate Measurement Techniques:

- A. **In-Situ Systems** (Point or Cross-duct) for application in flue gas stream with temperature above dew point ($>95\text{ }^{\circ}\text{C}$)
- B. **Extractive Systems** for applications with entrained water droplets in the gas stream

A. In-situ systems

The main cross-duct techniques used for Continuous Monitoring of Particulate Matter are: -

- a) **Light Attenuation (Transmissometry)**: In this method the amount of light absorbed by particles crossing a light beam is measured and correlated to dust concentration. In Opacity/Extinction instruments the amount of light reduction is measured directly, whereas in Ratio-metric Opacity systems the ratio of the amount of light variation (flicker) to the transmitted light is measured.

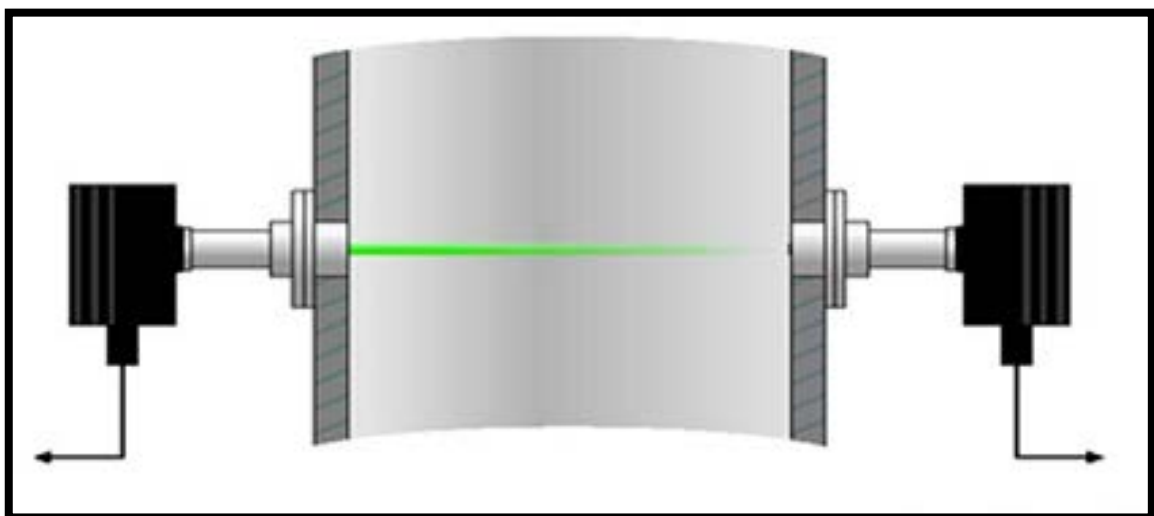


Figure 5.1: Light Attenuation

As with in-situ path systems for monitoring gaseous pollutants transmissometers may be single-pass or double-pass design. Double-pass types use a reflector on the opposite side of the stack or duct so that the light is transmitted twice through the flue gas. The single pass transmissometers have become obsolete. Some modern single-pass transmissometers are designed with two identical senders and receivers on each side of the stack to alternatively transmit and receive light in order to increase sensitivity and reduce the effects of fouling of the optical surfaces. The light sources use includes filament bulbs, light emitting diodes and lasers. Light colour green shown in figure is symbolic to understand the mechanism.

The simplest of the transmissometers will produce an opacity that can be correlated with a smoke colour scale, e.g. the Ringelmann scale. More sophisticated analysers that are equipped with on-line zero and span adjustment can be programmed to produce an output proportional to 1.0 mg/m³ based on the results of calibration measurements.

Transmissometers are usually designed for cross duct measurement with a sender and receiver on opposite sides of the stack for single pass system. For double pass both light source and receiver are placed in the same side with a reflector at opposite end to pass the light through the flue gas twice.

Point in-situ transmissometer type analysers have been developed in which the light source and detector are carried at opposite ends of a rigid tube. The tube contains a series of slots which allows the passage of PM-laden flue gas through the tube and hence between the light source and detector. This arrangement overcomes some of the problems associated with the cross duct systems with regard to alignment of sender and receiver and differential expansion caused by temperature variations, and stack vibrations.

Limitations of measurement: Transmissometry (Opacity monitors) is used extensively worldwide to monitor, "Opacity". This is particularly true in the utility and power generation industries. Adoption of opacity monitors for particulate matter monitoring in stacks is less universal due

to their inapplicability to the lower levels of particulate now found in industrial processes. Industries where Opacity monitors are still well accepted are the power, cement and steel industries due to their historical experience in satisfying opacity requirements. There are a number of Opacity instruments with TUV approvals for particulate measurement. The certification ranges for opacity monitor are dependent on path length. The measuring range of 0-1000mg/m³ is suggested for a path length of 0.5 to 15 mt. However, low range i.e. 0 to 10 mg/Nm³ can be monitored in stack with minimum 5m path length. The limitations of technologies are widely accepted.

- It cannot monitor particulate levels below 25mg/m³ per meter path-length in general, as at low concentrations the reduction in the light beam caused by the particles is indistinguishable from the zero drift of the source/detector (i.e. variation in the intensity of the receiver with no dust conditions). This limitation makes the instrument unsuitable for many well abated emission applications (e.g. after a bag filter).
- The system is sensitive to dust contamination on the lens surfaces since it is not possible to distinguish between the reduction in light caused by dust in the stack and dust on the lenses. In practice a curtain of air (provided by a blower) is injected into the transmitter and receiver heads to keep the lens surfaces clean.
- Systems without retro-reflectors (i.e. non double-pass) are sensitive to misalignment between the transmitter and receiver.
- The calibration of the instrument changes with changes in the particle properties:
 - Particle type and refractive index (mainly changes the amount of light scattering)
 - Particle colour mainly changes the amount of light absorbed
 - Particle size and shape (changes the amount of light scattering) manifests itself in requiring a number of regression curves to be calculated at differing process conditions and differing fuels used for combustion.
- Water vapour and water droplets absorb light over the light frequency range used by opacity monitors and therefore opacity instruments are

not suitable for stacks with flue gas below dew point or containing water droplets from wet collectors. This makes opacity monitors unsuitable for monitoring particulate matter emissions from coal fired power plant applications where Flue Gas Desulphurization (FGD) plant is not fitted with stack reheat (wet FGD).

- b) **Light scattering:** In this system the amount of light scattered by the particles in a specific direction is measured. Forward, side or back scatter are a function of the angle of scattered light that is measured by the detector. Light scattering techniques (especially forward scatter) are capable of measuring dust concentrations several magnitudes smaller than that measured by transmissometers.

When light is directed toward a particle, the particle may both absorb and scatter the light, deflecting it from its incident path. An opacity monitor or transmissometer measures the intensity of light that is not scattered. Other instruments have been developed to measure the scattered light. The intensity of the scattered light depends on the angle of observation, the size of the particle, its refractive index and shape, and the wavelength of the incident light. Both in-situ and extractive analysers of this type have been developed. A light beam is passed through the Particulate Matter (PM) laden flue gas. Absorption and scatter attenuate the light. Light scatter analysers measure the intensity of the scattered light at a predetermined angle to the beam direction. The amount of light scattered in any direction is dependent on the size distribution and shape of the dust particles. Variations in the intensity of the light source and sensitivity of the detector are compensated for by the use of a reference beam, in the opposite phase to the measuring beam, onto the photoelectric detector.

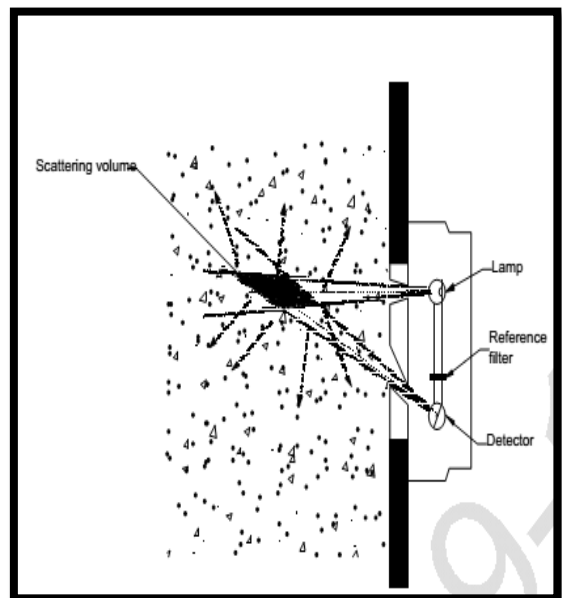
Scatter light measurement is a more sensitive measurement method for low dust loading. Opacity measurement at low loading is limited by the requirement to measure very small variations in the light received on the axis from the transmitter. Scatter light analysers measure only the scattered light and do not have to deal with the small variation in a large amount of transmitted light.

Instruments can be based on the forward scatter, side scatter or back scatter principles, and can be in-situ, point in-situ or extractive. This type

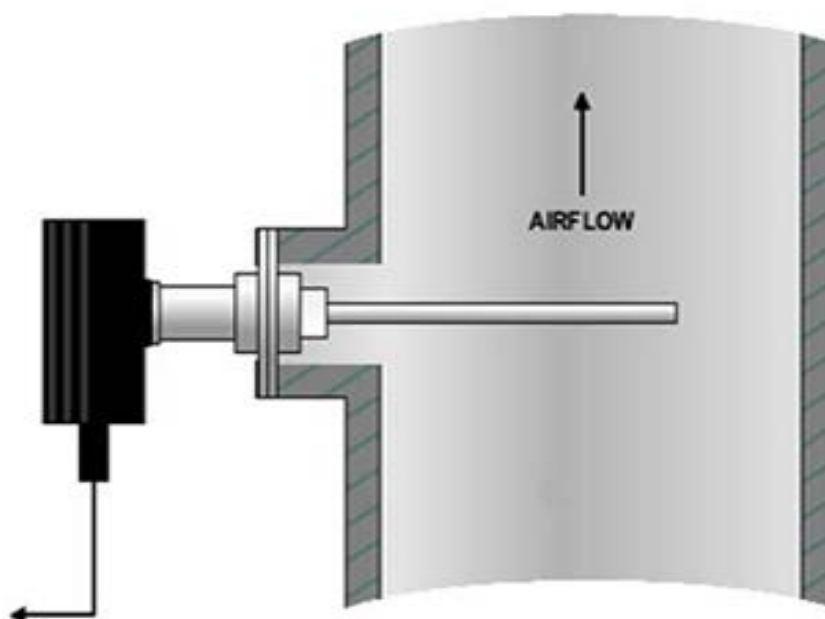
of analysers can be claimed to be more accurate for measure low PM concentrations of upto $1\text{mg}/\text{m}^3$

Limitations of technology: Side Scatter or Back Scatter instruments are used in low dust concentration applications, such as those found in Power plant, Lead Smelters and Incinerators equipped with bag house as pollution control systems. Their technical limitations are as follows:

- The calibration is affected by changes in particle size and type of particle. For example, with absorbing particles (such as black fly ash) the response of a Back Scatter device is reduced by a factor of 20% from peak response when the particle size changes from $0.8\mu\text{m}$ to $0.7\mu\text{m}$. The peak response for non-absorbing particles is three times greater than for absorbing particles.
- Back and Side Scatter devices are less sensitive than Forward Scattering devices although can still provide sensitivity of less than $1\text{mg}/\text{m}^3$.
- In-situ light scattering instruments cannot differentiate between water aerosols and solid particles



- c) **Probe Electrification (Non-Optical):** The electrical current produced by particles interacting with a grounded rod protruding across the stack/duct is measured and correlated to dust concentration. Charge induction (AC Triboelectric and Electro Dynamic) and DC Triboelectric instruments are types of probe electrification devices in which different signal and current analysis are performed. The Probe Electrification techniques are not all the same and should not be confused by each other. Electro Dynamic systems are used in Europe as Compliance devices due to their inherent reliability, repeatability and self-check capability.



Consideration should be taken when selecting Probe Electrification instruments. It should not be used after Electrostatic Precipitators as the action of the filter can affect the charge characteristics of the measured particulate causing errors in the instruments readings. In case Tribo probe is mounted above ESP, then a Faraday Shield is placed around the entire probe length and grounded to negate the charge of flue gas particles emerging from the ESP field. All three techniques are highly sensitive and are responsive at low concentrations below 1 mg/m^3 . The stack diameter may be a limiting factor in probe electrification technique. The probe length shall cover at least half diameter to make representative sampling. Sticky, moist flue gases always pose threat to the performance, as the surface of the probe gets easily coated and restrict the charge exchange resulting in poor performance. Frequent cleaning and maintenance is required.

d. 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 gravimetric 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.

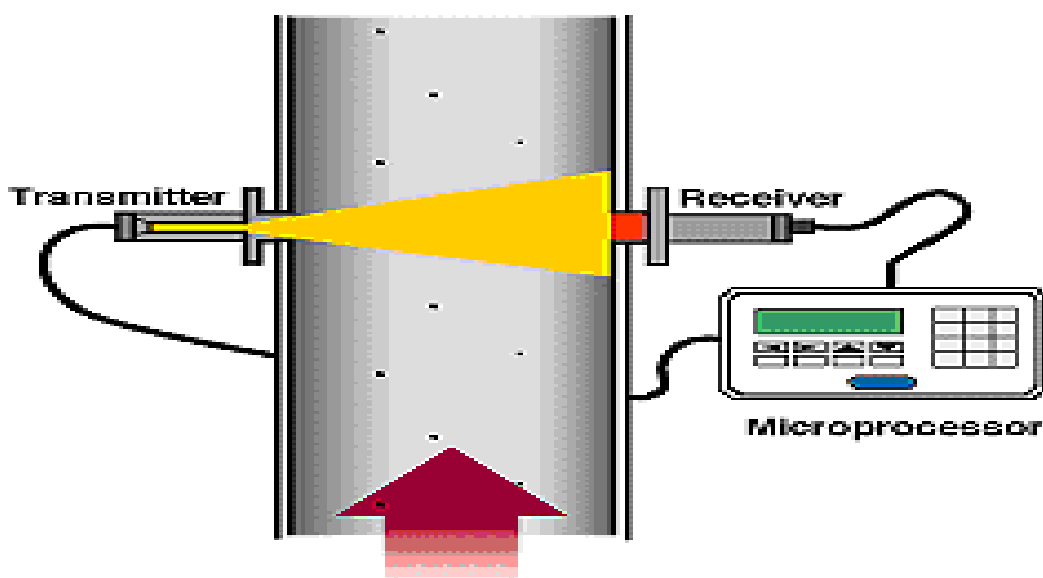


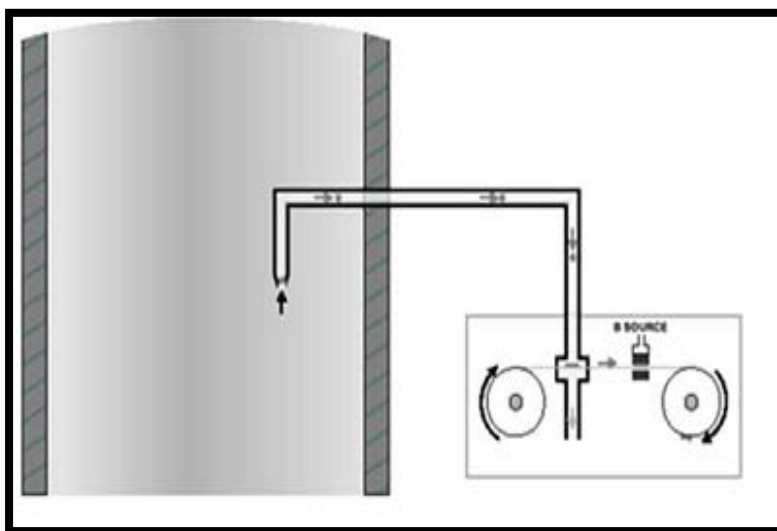
Table 1: The advantages and disadvantages Optical Scintillation

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;

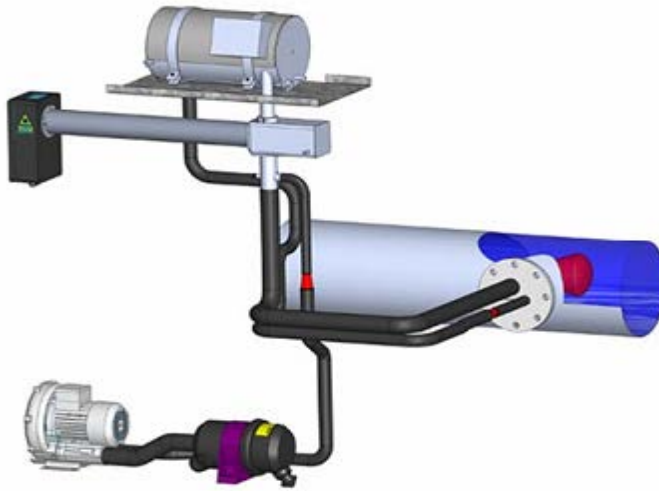
B. Extractive systems

The presence of water droplets in saturated gas streams below the dew point i.e., after wet collectors will affect the monitoring response of all in-situ technologies to an extent where calibrated results cannot be guaranteed. In these instances, extractive systems must be used. The two common methods for measuring in wet stacks are: -

- a) **Beta Attenuation:** The moving gas stream is sampled and the particulate is collected onto a filter. The filter is advanced periodically (typically every 15 minutes) into a measurement chamber, so that radioactive Beta particles can be passed through the sample and the amount of Beta particles transmitted through the sample is measured. The advantage of this technique is that the absorption of radioactivity is not significantly affected by the type of particle (although particles with different Nucleonic density have different responses).



- b) **Extractive Light Scatter:** The flue gas is extracted (recommended under isokinetic conditions) and then passed into a heater unit to evaporate any water or water vapour below dew point water before measurement in an external light scattering chamber. A Forward Light scattering technique is normally used in the chamber. Extractive systems have been designed to overcome the problematic issues of sample handling on a continuous basis. In stacks filled with wet scrubber as air pollution control device, where dust concentration is low and mass of water droplets is high compared to the dust particular extraction of sample slightly over isokinetic is deserved.



5.1.1 Requirements of an efficient on-line PM CEMS

One of the fundamental issues in obtaining good results from particulate matter measuring instruments is to ensure that the instrument fits for purpose of the intended application. This means that the instrument: -

1. Must have a stable, reliable response, which can be directly correlated to dust concentration with limited cross interference from likely changes in process or flue gas conditions. Certified products provide guidance on the application suitability of different instruments. Manufacturers should be contacted for more detailed guidance on the application suitability of a specific type of instrument. Industry is responsible for the selection of appropriate technology for measurement of emission as per CPCB guidelines.
2. Can operate over a long duration in the application without the need for frequent maintenance or cleaning. The Maintenance Interval as stated in the certificate can provide guidance on servicing issues. The maintenance and calibration schedules suggested by manufacturer should be followed strictly.
3. The system has sufficient resolution for the intended application. The systems certificates state the ranges in mg/Nm^3 for the instrument which is the lowest dust range at which the instrument will still meet the required performance standards.
4. Instrument measuring range selection: The Measuring Range should be 2.5 to 3.0 times of Prescribed Standard value. i.e. if Prescribed Standard

for PM parameter is 50 mg/Nm³ then selected Instrumental Measuring range should be in between 0-125 or 0-150mg/Nm³.

The span calibration (for gaseous parameters) should be performed at 60 to 80% of the selected instrumental measurement range.

5. The minimum detection level of the instrument should be considered in relation to the normal operating condition of the plant to ensure a meaningful stable response from the instrument at normal plant conditions which can then be calibrated.
6. The operating technology should be suitable for the type of Filtration system (pollution control system) used, the diameter of the stack or duct, the dust loading and any other additional parameters (like corrosiveness, stickiness, moisture, etc.) that may affect the operation of the PM CEMS i.e. for applications with entrained water droplets an extractive PM CEMS which conditions the wet gas stream to remove the entrained liquid must be used to obtain quantitative results.

5.2 Techniques/ Instrumentation for Online Gaseous Pollutant Monitoring

The extractive type of emission gas analyzers available are:

1. Non Dispersive Infrared (NDIR)

Many gaseous pollutants absorb light energy in one or more regions of the spectrum. Sulphur dioxide / Nitric Oxide / Carbon Monoxide and a wide range of other gases absorb infrared radiation and ultraviolet radiation. Each type of pollutant molecule absorbs light at a characteristic wavelength, and therefore it can be distinguished from other pollutant species.

Continuous emission monitors using this principle apply the Beer-Lambert Law, which states that the transmittance of light (i.e., the ratio of the intensities of the transmitted and incident light) through a medium that absorbs it is decreased exponentially.

Hetero-atomic gaseous molecules, which contain two or more dissimilar atoms in the molecule, display unique absorption characteristics in the infrared region of the spectrum. Homo-atomic molecules containing only one type of atom within the molecule do not produce characteristic vibrations when exposed to light in the infrared region; therefore, they cannot be measured by this technique.

By using this principle an instrument can be designed to measure pollutant gas concentrations. Non-dispersive photometry analysers using infrared (NDIR) have been developed for monitoring a wide range of gases.

Simple non-dispersive infrared analysers use filters or other methods to measure the absorption of light over a relatively small range of wavelengths centered at an absorption peak of the molecule of interest. In a simple NDIR analyser, infrared light is emitted from a source such as a heated coil or other type of infrared radiator. The light is transmitted through two gas cells: a reference cell and a sample cell. The reference cell contains a gas such as nitrogen or argon that does not absorb light at the wavelength used in the instrument. A sample of the gas is passed through the sample cell of the instrument. As the infrared beam passes through the sample cell, pollutant molecules will absorb some of the light. As a result, when the light emerges from the end of the sample cell it has less energy than when it entered. It will also have less energy than the light emerging from the reference cell. The energy difference is detected by a detector. The ratio of the detector signals from the two cells gives the light transmittance, which can be related to the pollutant gas concentration.

Simple non-dispersive infrared analysers are still supplied for applications where only one gaseous species is to be monitored. They are relatively low cost, reliable and robust. A limitation of analysers based on this principle is that gases that absorb light in the same spectral region as the gas of interest will cause a positive interference in the measurement.

Water vapour are strongly absorbing in the infrared region and must be removed from the sample before the gas enters the analyser. One solution to this problem is to use absorption cells arranged in series, as in the O₂ detector. The NDIR analysers combine with O₂ measurement for online continuous correction / normalization for any diluent of emission gases being measured by CEMS system.

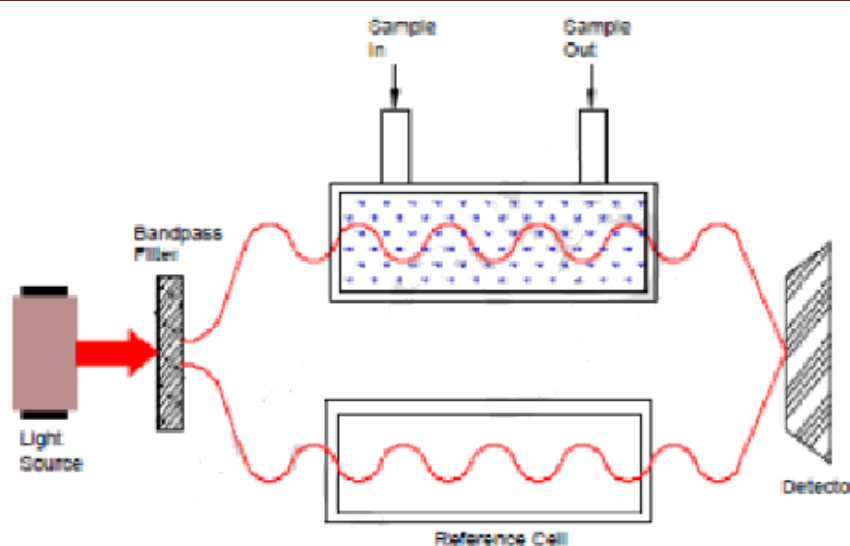


Figure 5.2 : NDIR System

2. Photoacoustic Detector

A variant of the pneumatic detector technique is the photoacoustic detector. Analysers based on this principle of operation monitor acoustic waves resulting from the absorption of chopped light by molecules in a sealed sample cell.

In a light-absorbing molecule, when vibrational-rotational energy dissipates absorbed light energy into kinetic energy, the pressure will increase in the sealed chamber in which they are confined. If the light beam is turned on and off, the pressure will alternately increase and decrease, producing a pressure pulse or acoustic signal. In practice this is achieved by placing a rotating chopper between the light source and the measurement chamber. When the chopper produces pulses between 20Hz and 20 KHz frequency, the pressure pulse can be detected by sensitive microphones.

By placing different optical filters in a carousel located between the chopper and measurement chamber, a range of organic and inorganic compounds can be measured at ppb levels. In the photoacoustic technique light absorption is measured directly, so if there is no absorbing gas in the measurement cell, no pressure pulse will be generated. If some gas is present, some sound will be generated and if more gas is present more sound will be generated.

The technique does not provide continuous analysis, as the sample must be sealed in the measurement chamber before the analysis sequence can begin. This cycle typically takes 40 seconds to complete five determinants.

3. Gas Filter Correlation (GFC) NDIR

A type of NDIR technique, which is widely used in in-situ monitors, is also applied to extractive system analysers. The gas filter correlation (GFC) technique uses a reference cell that contains a 100% concentration of the pollutant of interest, instead of the 0% concentration in the techniques discussed previously. Radiation from an infrared source passes through a filter wheel, which contains a neutral gas, such as N₂, in one cell and the gas of interest in the other cell. The light is then passed through a modulator that creates an alternating signal.

When the instrument is operating the filter wheel is continuously rotating. When light passes through the gas filter it will be attenuated. The gas filter contains enough of the target gas to remove most of the light at the wavelength where the target gas absorbs. The gases not absorbed at selected wavelengths are not removed and are passed on to the detector. The net result is reduction of light energy reaching the detector. When the light passes through the neutral cell its intensity is not reduced. If a sample of gas containing the target pollutant is introduced into the sample cell the molecules will absorb light energy at the absorption wavelength of the target gas. Because the gas filter was chosen to absorb energy at the same wavelengths, the absorption is already complete in the gas filter cell beam, and the detector will see the same signal as it did when the sample cell contained zero gas. The beam passing through the N₂ side however will carry less energy because light is absorbed by the target gas in the sample cell. The difference between the two beams is monitored, and can be related to the concentration of the gas of interest in the sample. Other gases having spectral patterns in the same regions as the target gas will not affect the measurement, as they do not correlate. Moisture has absorption and needs to be removed and adequate correction is required.

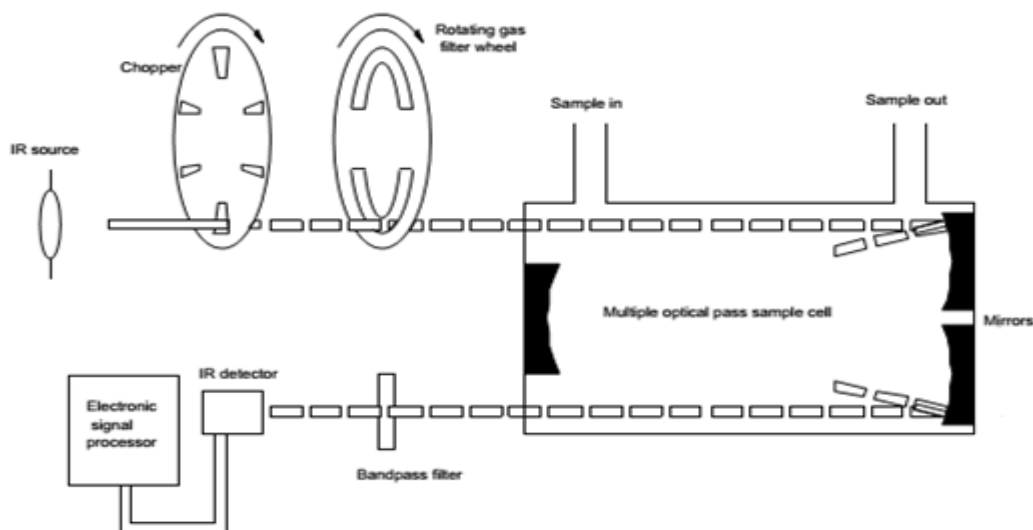


Figure 5.2.a: Gas Filter Correlation NDIR

4. Differential Optical Absorption Spectroscopy (DOAS)

Another non-dispersive method measures light absorption at different wavelengths, those at which the molecule absorbs energy and those that do not. In this system a reference wavelength is used instead of a reference cell. The system can monitor SO₂, NO₂, HCl, HF, CO, CO₂ and NH₃ in stack emissions. These parameters are however selective to UV/IR-DOAS technology. The extractive UV-DOAS system can also measure gaseous mercury when fitted with heated sample gas probe, heated gas transfer line and also heated measuring cell after conversion of total gaseous mercury into elemental mercury.

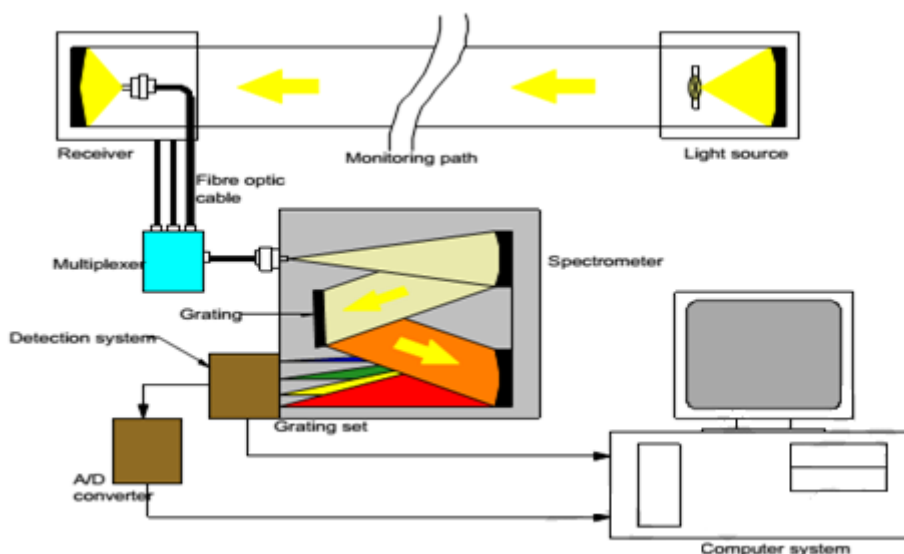


Figure 5.2.b: Differential Optical Absorption Spectroscopy

5. Fourier Transform Infrared Spectroscopy (FTIR)

Infrared-active gases, such as CO₂, CO, SO₂, NO, NO₂, HCl, HF, VOC, H₂O, can be measured simultaneously using Fourier transform IR spectroscopy (FTIR spectroscopy). Unlike in traditional spectroscopy, the absorption spectrum is not recorded by means of dispersive elements such as lattices or prisms, but using an interferometer arrangement.

Most FTIR spectrometers are based on the Michelson interferometer which has the function of a mono-chromator. The radiation hits a beam splitter which reflects 50 % of the radiation and transmits the remaining 50%. The reflected and transmitted beams hit two mirrors which are perpendicular to one another and are reflected back to the beam splitter. The beam splitter recombines the two reflected beams into one. The recombined beam is passed through a cell filled with the gas component to be measured and then focused on an IR detector.

Continuously shifting one of the mirrors opposite the beam splitter produces differences in the optical path length which the two beams have to cover on the way back to the beam splitter. This difference (path difference of the interferometer) produces interference in the recombined beam which results in the fundamental coding. The shifting makes the interference signal (local intensity distribution) variable (interferogram). This means the interferogram contains all the information about the spectrum in encrypted form. The absorption of the modulated IR radiation in the measurement cell means that the interferogram contains all the spectral information at the same time.

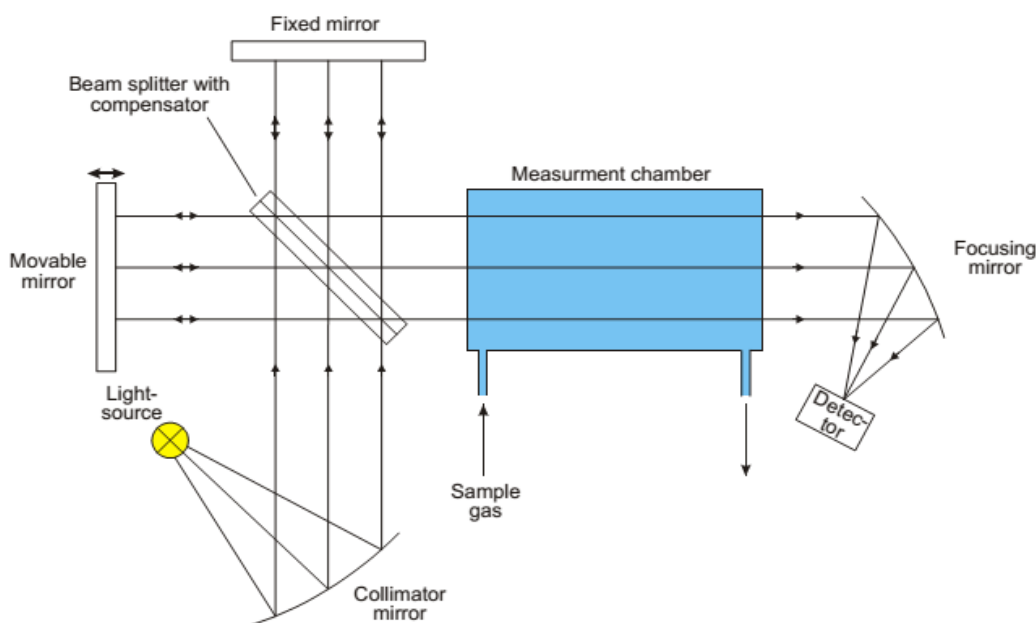
A mathematical Fourier transformation into the IR range (demodulation) is then applied to the interferogram recorded. By comparing the IR spectrum recorded to a reference spectrum, the FTIR spectrometer can quantitatively detect a number of IR-active measured objects, depending on the software version used. Once the instrument has been calibrated the calibration data are stored as a spectral library, which is stored as software. Essentially the FTIR technique provides a 'signature' of the total absorption spectrum of the sample gas over a broad spectral range. Instruments typically works in wavelength range from 2.5 to 25µm.

This FTIR is an advanced technology and works on Hot Wet Technique completely heated at 180°C and has wide applications due to multi gas

measurement over the IR spectrum of 2 to 25 μm and can measure CO , CO_2 , SO_2 , NO , NO_2 , HCl , HF , NH_3 , H_2O , VOC , etc. For monitoring of low concentration of NH_3 , HCl and HF extractive system is preferred. Additional modules of O_2 & VOC can also be integrated into the online measurement. Best suited for wet process with high moisture even as high as 50 – 60 Vol% in background eg. Waste Incineration, waste to power, process like Dry Cement, process using alternative fuels like pet coke, waste, bio mass, etc. The minimum detection limit (MDL) is in parts per billion (10^{-9} ratio at atmospheres), when resolution is 0.5 cm^{-1} and optical path is 100m (**Table 2**).

Table 2: Minimum Detection Limit of FTIR Method for different compounds

Sl. No	Compound	Frequency (cm^{-1})	MDL (PPB)	Remarks
1.	Carbon Dioxide (CO_2)	2363	0.4	MDL is 0.4 ppb if no other CO_2 is present. In air, the minimum detectable change in CO_2 would be about 50 ppb
2.	Carbon Monoxide (CO)	2200-2100	2.0	Array of lines
3.	Hydrogen Chloride (HCl)	3050-2700	1.5	Array of lines
4.	Nitric Oxide (NO)	1920-1870	4.0	Array of lines
5.	Nitrogen Dioxide (NO_2)	2210	1.0	Array of Lines
6.	Sulfur Dioxide (SO_2)	1361	2.0	Spike; water must be carefully subtracted
7.	Water (H_2O)	1700-1400	5.0	MDL is 5 ppb if no other water is present. In Humid air, the minimum detectable change in water content would be 1000 ppb.



6. Non Dispersive Ultraviolet (NDUV)

The characteristics of light in the ultraviolet (UV) region of the spectrum (shorter wavelength, higher energy) lead to molecular electronic transitions when the light is absorbed. Absorption of ultraviolet photons excites the electrons of the atoms within the molecule to a higher energy state. The excited electrons quickly lose the energy by returning to the ground state by one of four methods; dissociation, where absorption of high-energy photons can cause the electron to leave the molecule completely, causing it to fragment; re-emission, where an identical photon is re-emitted as the electron decays back to its ground state; fluorescence, where a photon is emitted at a lower frequency than the original absorption as the electron decays back to its ground state, causing the gas to appear to glow.

Analysers that are designed to operate in the UV region typically employ the differential absorption technique. Analysers designed to measure SO₂ measure UV light absorption at a wavelength in the SO₂ absorption band centered at 285nm. This is then compared to the absorption at the wavelength region of 578nm where there is no SO₂ absorption.

Differential absorption NDUV instruments have proven to be very reliable in source monitoring applications and can also measure both NO & NO₂ simultaneously without need of NOX Converter. The technique has lower interferences but cannot measure other pollutants like CO / CO₂.

7. Ultraviolet Fluorescence

Ultraviolet fluorescence analysers for SO₂ are based on the absorption of UV light at one specific wavelength by the SO₂ molecules, and its re-emission at a different wavelength. Commercially available instruments contain either a continuous or pulsed source of UV radiation. Filters are used to produce a narrow waveband around 210nm. The light (photon) emitted from the excited molecules is passed through a filter and then to a detector photomultiplier tube. The amount of light received at the specific wavelength is directly proportional to the number of SO₂ molecules and is a measure of concentration in the measurement cell, provided the sample flow rate is tightly controlled. A problem with this measurement principle is the 'quench effect' caused by the capture of the emitted radiation from the SO₂ molecules by other molecules present in the gas e.g. CO₂, O₂, N₂, etc. The quenching effect varies depending on the molecule involved and it is therefore very difficult to compensate for this effect when the matrix gas containing SO₂ has a time variable composition, e.g. a boiler flue gas. This effect has limited the use of this type of analyser for emission monitoring purposes, however it has found wide application as an ambient air analyser for SO₂ where the matrix gas, i.e. ambient air, does not vary significantly in composition.

UV fluorescence analysers can be used for emission monitoring purposes at Large Combustion Plants (LCPs) if a high ratio dilution sampling system as described earlier is used. In case of measurement of SO₂ concentrations in the stack gases, the quality of the dilution air significantly affects the measurement result. Besides inability to measure components like O₂, CO, CO₂, etc. is its limitation compared to other techniques like NDIR/NDUV with capacity for multi gas measurements.

8. Flame Photometry

Flame photometry analysers are specified in Environment Agency Technical Guidance Note M2 for the measurement of total sulphur. The technique is non-selective, and is not specific to SO₂. It is therefore rarely used for continuous monitoring, but is a popular technique for Total Sulfur measurement as an online ASTM Technique.

9. Chemiluminescence Analysers

Chemiluminescence is the emission of light energy that results from a chemical reaction. It was found in the late 1960s that the reaction of nitric oxide (NO) and ozone (O₃) produced infrared radiation from about 500 to 3000nm. It lost its status due to interferences/ Quench Effect of CO₂/Moisture and requirement of additional accessories like Ozone generators, pumps etc besides the inability to measure measurement components like SO₂, CO, CO₂, etc. compared to other techniques like NDIR/NDUV which can do multi gas measurements.

Nitrogen dioxide (NO₂) does not participate in this reaction and must be reduced to NO before it can be measured by this method. Most commercial analysers contain a converter that catalytically reduces NO₂ to NO. The NO (converted from NO₂) plus the original NO in the sample is then reacted with O₃ as described above to give a total NO + NO₂ (NO_x) reading.

Chemiluminescence monitors are well established for the monitoring of NO_x. The method is also well established for ambient air monitoring. These monitors have very low detection limits (of around 0.1 ppm) and a wide range when equipped with dilution system (up to 10,000 ppm), plus a short response time of a few seconds. This type of system has found wide acceptance in Ambient Measurement for very low concentration levels. In North America the system is used with conventional sampling systems and also with high ratio dilution samplers. For high concentration stack gases, the system is not popular in Europe as it requires dilution technique for diluting the high concentrations in Stack gas by extractive dilution system.

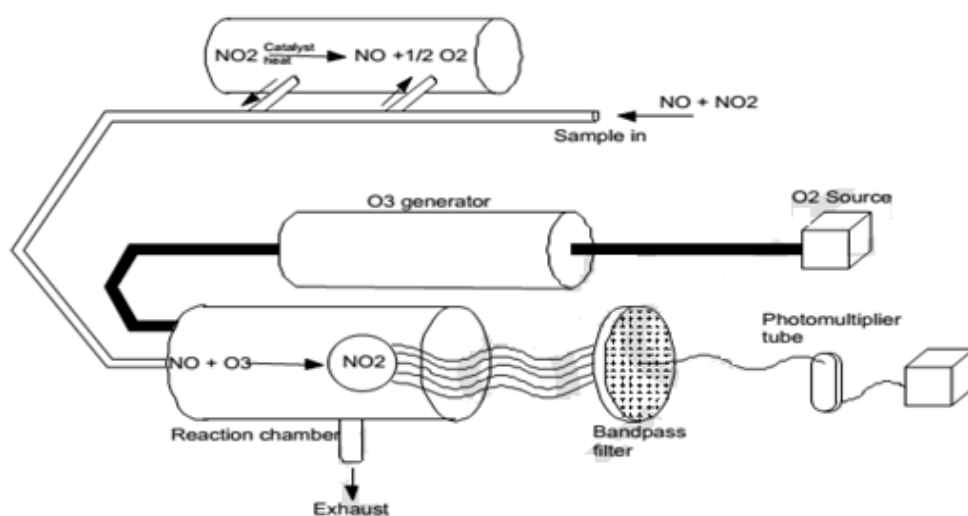


Figure 5.2.c: Chemiluminescence Analysis

10. Derivative/Laser Spectroscopy

Derivative/LASER spectroscopy involves scanning a spectral absorption peak and obtaining its second derivative or higher derivatives with respect to wavelength at the peak maxima. The derivative peak is measured, and this has the effect of increasing the detection sensitivity of the measurement. In analysers using this technique either the originating light from the light source is modulated or the light seen at the detector is modulated. This modulation produces a signal at the detector that is dependent on the shape of the absorption curve of the molecules.

Scanning over the absorption spectrum produces harmonics of the absorption line. The second harmonic of the signal is usually used to measure the concentration of the absorbing gas. The amplitude of the second harmonic is proportional to the second derivative of the intensity with respect to the wavelength.

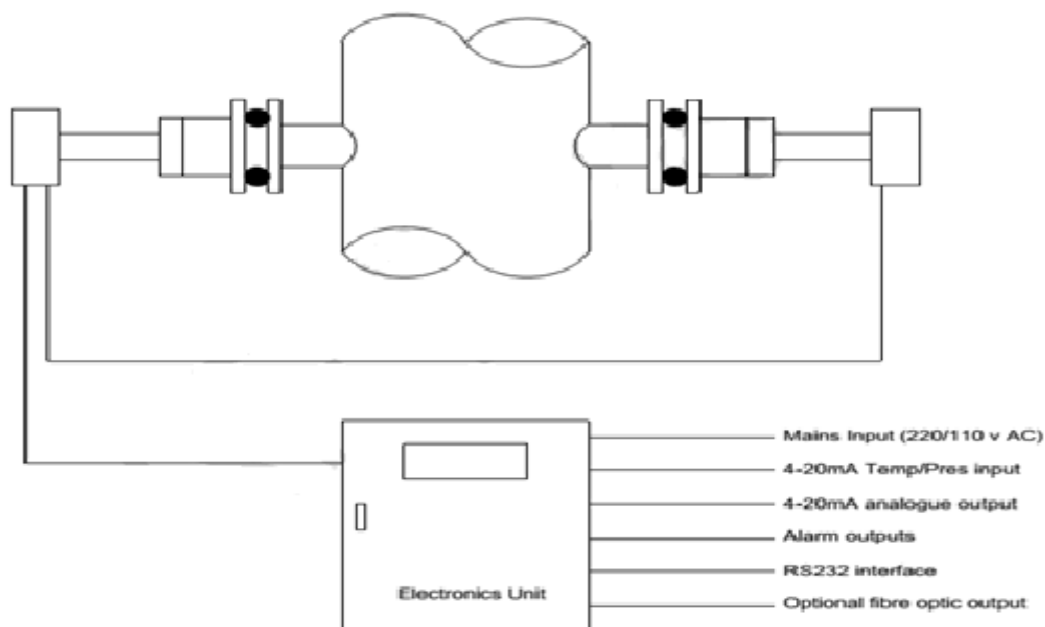
Tunable diode lasers (TDL) have been used in extractive, path in-situ, point in-situ and close-coupled monitoring designs using second derivative detection techniques. A simple diode laser system can employ the differential absorption technique, tuning the laser to different wavelengths by changing the laser temperature or its driving current.

Large interferences of gases may influence the measured concentration. This is due to line broadening effect as a result of molecular collisions. Different types of molecule may broaden the absorption line differently. Modern TDL analysers automatically compensate for this effect using digital filtering techniques.

An interesting aspect of the technique is its ability to measure oxygen concentration. As mentioned previously, homo-atomic molecules such as O₂ do not exhibit unique absorption characteristics in the infrared region of the spectrum. By using the derivative spectroscopic technique, the spin of electron is modified can be detected.

If oxygen is to be monitored using this technique, it is important to use pure nitrogen rather than air to purge the sensor 'windows', as the presence of oxygen in the purge gas will interfere with the measurement. Alternatively, it may be possible to correct the interference introduced by the purge air by calculation. In this technique the total path length, the path length containing

purge air, the path length containing flue gases and the temperature of the purge air and flue gases are measured, and the data are used to discriminate between oxygen present in the purge air and oxygen in the flue gases. Advance TDL techniques like CRDS (cavity ring down spectroscopy) or ICOS (Cavity Off-Axis Spectroscopy) are very stable at as low as ppb levels.



11. Flame Ionization Detector

The Flame Ionization Detector (FID) is the standard method for the measurement of Total Hydro Carbon (THC) / Total Organic Carbon (TOC)/ Total Volatile Organic Carbon (TVOC). The FID is capable of sensing most organic compounds and because of its relatively high sensitivity; it has become widely used in environmental applications.

In a typical FID the gas sample enters the base of a combustion chamber, where it is mixed with either hydrogen or a mixture of hydrogen or O₂10% and helium. A mixture of hydrogen and helium is used in order to reduce oxygen synergistic effects; however, more fuel gas is required with this approach resulting in shortened operating times. An alternative technique employs ceramic material to construct the burner nozzle; in this case pure hydrogen may be used for the fuel gas. The mixture is burned in a jet with oxygen.

The flame produces ions and free electrons. A current is applied between the burner and a collector plate, and the ions and free electrons increase the current flow in the circuit, which is sensed by an electrometer. The current is approximately proportional to the number of carbon atoms entering the flame; as the response of the detector is slightly different for different types of organic

compounds, the detector must be calibrated for the compounds being analysed to achieve the best accuracy.

The FID is selective and convenient to use in source sampling applications, since it does not respond significantly to other gases in the sample such as N₂, water vapour, CO, SO₂ and NO. However organic compounds that contain nitrogen, oxygen or halogen atoms may give a reduced response. The FID based system applicable for CEMS is hot- wet extractive, as a heated measurement.

12. Photo Ionisation Detector

In a photo ionisation detector (PID), a light in the UV region of the spectrum ionises organic molecules. The major components of the flue gas sample such as O₂, CO, N₂, CO₂ and water vapour are not ionised by the UV source. A typical PID analyser consists of a UV lamp and a pair of electrodes to measure the current proportional to the concentration.

Different molecules require different energies to photoionise, and the frequency of the light used in the PID may not ionise all of the organic species present in the sample.

PIDs are used in conjunction with gas chromatographs, or alone as portable analysers, where the technique can be used to produce extremely rugged and compact instruments. However, as the PID technique can be non-selective, analysers of this type are usually used as screening devices.

13. Gas Chromatography

Gas Chromatography (GC) is used to isolate the individual components of a mixture of organic and inorganic compounds from each other for subsequent identification and quantitative analysis. GC is based on the selective distribution of compounds between a stationary phase and a mobile phase (carrier gas). In the process, the moving gas phase passes over a stationary material that is selected to adsorb the organic molecules contained in the sample gas depending on polarity. The stationary phase can be either liquid or solid, and is contained in a long thin tube, commonly known as a 'column'. Columns are made from fused silica, glass or stainless steel.

In an ideal column operated under ideal conditions, each molecular species will exit the column at a different time depending upon molecular weight and

polarity. Selecting the appropriate column and operating it under the appropriate temperature with a suitable carrier gas flow rate will enable separation of the gas sample into its individual components. It should be noted that the technique is not truly continuous.

The compounds separated in a chromatographic column must be detected and quantified using appropriate detectors considering their sensitivity to the parameter being analyzed. Many types of detectors are available and the most commonly used for source monitoring applications being TCD, FID, PID, FPD, etc.

Analysers based on the principle of gas chromatography are complex and expensive. Although portable versions are available, they are not often used for the continuous measurement of organic compounds in emissions to atmosphere from LCPs and waste. Gas Chromatography techniques have been most popular technique in the Petroleum Refining/Petrochem industry for process measurements.

14. Zirconium Oxide (ZrO₂) Analyzer for Oxygen measurement

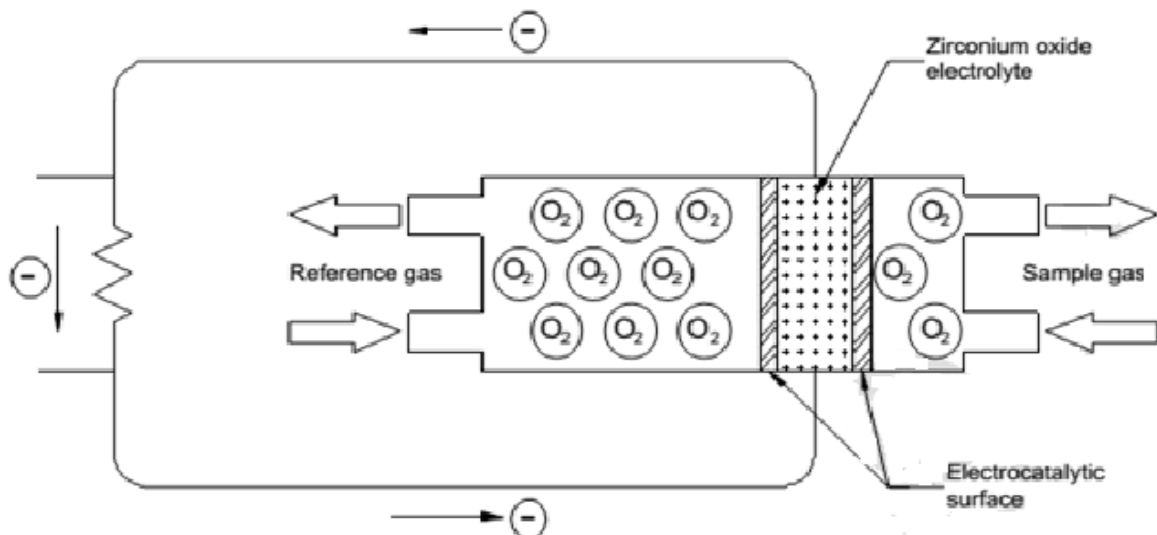
Analysers using ZrO₂ for the measurement of oxygen concentration in flue gases can either be in-situ, i.e., the measurement cell is in the stack; extractive on-stack, i.e., the cell is mounted on the stack with a sampling probe protruding into the flue gas; or extractive with the cell mounted in an analyser some distance from the stack.

In this method ceramic material, Zirconium Oxide (ZrO₂) coated with a thin layer of platinum, acts as an electrolyte to allow the transfer of oxygen from one side of the cell to the other. In the cell the oxygen concentration in the reference side is maintained at 21%. When the sample side of the cell is exposed to flue gases, the oxygen concentration in the sample side will be less than in the reference side. When ZrO₂ is heated to around 600°C, oxygen ions can migrate through the material, releasing electrons in the process. This results in the generation of an electromotive force, which is proportional to the difference in oxygen concentration between the two sides of the cell. If the reference oxygen concentration is known, the sample concentration can be calculated. The main characteristics of these analysers are:

- Very accurate and reliable measurement of O₂;

- A fast response time (for in-situ measurement) makes it ideal for process control applications;
- It is a well-understood technology with examples at most boiler plants (for combustion control);
- It has a low capital cost and low maintenance;
- The measurement is on a wet basis. The level of water vapour must be known to calculate the concentration on a dry basis.

It should be noted that the electrical output of the ZrO_2 cell is zero when both sides of the cell contain ambient air. The output of the cell increases as the oxygen content in the sample side of the cell is reduced. Thus it is normal practice to 'zero' ZrO_2 analysers at the 'air point', i.e, 21% oxygen.



15. Paramagnetic Analysers for Oxygen measurement

These extractive type analysers make use of the paramagnetic properties of oxygen for the measurement of concentration. Oxygen has a relatively strong permanent magnetic moment, which can be used to influence flow patterns of sample gas within an analyser.

The general characteristics of the extractive paramagnetic analysers are:

- Accurate and reliable measurement;
- Measure on a dry basis as part of an extractive system, therefore providing correct reference values for other extractive systems;
- Can be installed in the same sampling train as other analysers making use of common components, e.g. coolers, filters etc. This also ensures

that sample contamination by air in-leakage to the sampling system is taken into account; and

- Usually situated adjacent to other analysers, so can be part of an integrated monitoring package.

The types of paramagnetic analysers available are:

15.1 Paramagnetic Thermo-magnetic (Magnetic Wind) Analysers for Oxygen measurement

This method uses the temperature dependence of para-magnetism to generate a magnetically induced gas flow (magnetic wind), which is then measured. The sample gas to be analysed flows through a two-chamber system, consisting of sample and reference chambers. The two chambers hold temperature-dependent resistors that form part of a wheat stone bridge having thermodynamically identical conditions. The sample chamber is located in the field of a permanent magnet, while the reference chamber is not.

The bridge is connected to a constant current source. When oxygen-free gas flows through both chambers, the thermodynamic conditions in both chambers remain identical. If the gas in the sample chamber contains O₂, an enhanced circulatory flow proportional to O₂ content is established in the sample chamber. This disturbs the temperature dependent balance of the bridge circuit creating a DC signal proportional to O₂ content of the sample gas.

These analysers have a low maintenance requirement and are generally cheaper than other types of paramagnetic analysers. Because of the dependence of the principle on the thermal conductivity and specific heat of the sample gas, the composition of the background gas must be taken into account during calibration. The response time is also relatively slow.

15.2 Paramagnetic Automatic Null-Balance Analysers

The oxygen molecules in a flowing gas sample will establish a partial pressure gradient in a magnetic field. This gradient can be used to exert a force on a small dumbbell shaped body located within the field. The torque on the dumbbell causes a displacement that is detected by a mirror and photocell assembly, which measures its angular position. Compensation current

produced as a function of this position results in an electromagnetic torque counter acting the measurement torque and tries to restore the dumbbell to its original position. This compensation current is proportional to the O₂ content of the sample gas.

This measurement principle can achieve high sensitivity and accuracy. Analysers of this type have become a standard for flue gas analysis and are also type approved for emission monitoring.

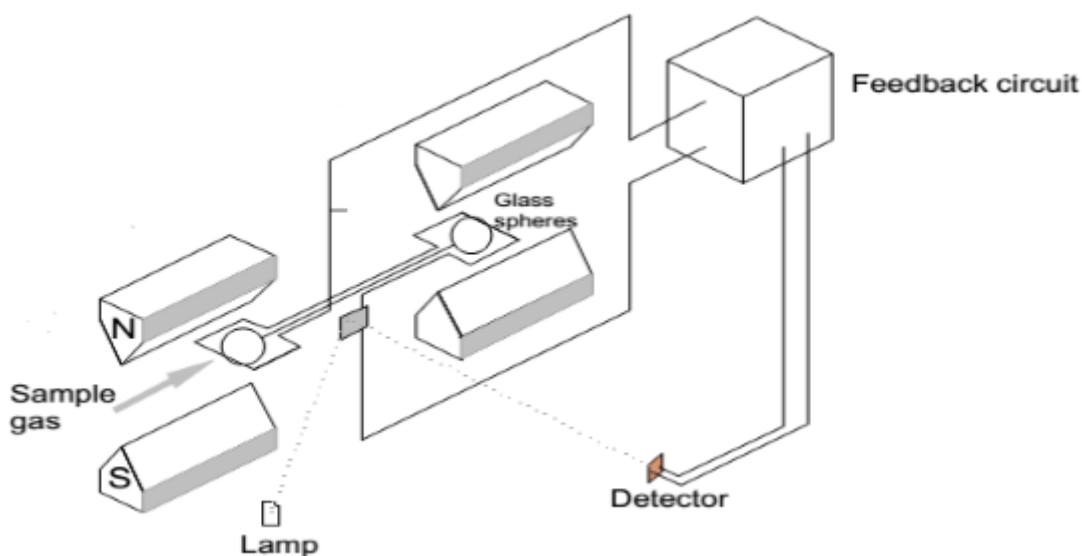


Figure 5.2.d: Magnetic Null-Balance Analysis

16. Electrochemical Fuel Cells for Oxygen Measurement

In recent years a wide range of portable flue gas analysers based on electrochemical fuel cell technology are available. In certain multi-component analyser applications, O₂ measurement is made using these cells. A typical cell used for the measurement would be of the metal air battery type comprising an anode, electrolyte and an air cathode.

Reaction takes place at the anode and cathode. During reaction, current is generated which is proportional to the oxygen content of the sample gas. The cross sensitivities of this cell are minimal and the use of gas filters, as used for CO or SO₂ measurement with electrochemical cells, is not normally required. Additionally, the problem of overloading (where the concentration is well above the measurement range) that causes problems for other sensors is not a problem for the O₂ cell due to the nature of the combustion process, as O₂ concentration in excess of 21 % are not possible.

Recent advances have led to O₂ cells designed for continuous use that have been incorporated into the continuous analysers discussed above. Measurement of O₂ would appear to be the most reliable and accurate measurement that can be made with flue gas analyser using fuel cell technology. This is approved technique with TUV/MCERT for O₂ measurement for normalization of CEMS measurement as it does not monitor pollutant but O₂ as a diluant for normalization.

6.0 FLUE GAS FLOW / VELOCITY MONITORING TECHNIQUES

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

6.1 Ultrasonic Flow Monitors

The volumetric flow rate of stack gas is measured by transmitting ultrasonic pulses across the stack in both directions. Ultrasonic flow monitors are also available in probe design with the instrument being installed on one side of the stack only, while having a shorter measurement length to cross stack instruments; these instruments have the advantage of not needing mounting and platforms at two different heights on the stack.

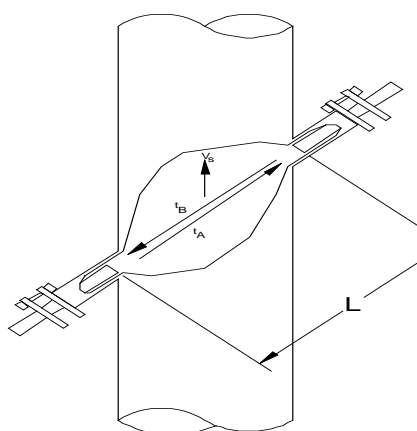


Figure 6.1: Ultrasonic Flow Monitor

The tone pulses are accelerated or retarded due to the gas velocity in the stack. The time required for traversing the distance of the stack 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 time 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.

6.2 Differential Pressure Flow Monitors

The S-type Pitot tube is designed as per 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.

6.3 Thermal Flow Monitors

Thermal flow monitors measure the electric power required to maintain a constant temperature of approximately 24 to 38°C 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.

6.4 Infrared Correlation

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

Table 3: 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			
Wet stack	x	✓	✓	✓	✓
Max Flue Gas Temperature	Up to 1200°C	Up to 12000°C	200 – 300 °C (model specific)	450° C - 850°C (model specific)	Up to 1000 °C
Low speed	x	3 m/s	x	✓	✓
High Speed	x	35 - 50 m/s	✓	✓	✓
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, 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.

7.0 ASSESSMENT OF MONITORING TECHNOLOGIES

The suitability of the technologies/instrumentation for monitoring the stack emission quality in different matrices, considering the limitations of the technologies, the varying Indian environmental conditions were assessed. Issues related to the utilities and maintenance required, operating costs, etc., wherever available were also considered. The parameters for online monitoring for various sectors of industries are specified at **Annexure-I**. The comparative chart depicting working limitations, including, specifications of above said technologies for measurement of particulate matter and gaseous pollutant is depicted in **Table-4** and **5**.

Table-6 depicts the composition analysis of available technologies for measurement of particulate matter and gaseous pollutants.

The prevailing industry specific emission standard and stacks in industries where CEMS are to be installed along with the CEMS options available for monitoring are presented in **Table-7**.

Table 4: PM CEMS Technology Applications and Limitations

Measurement Technology		Technology	Stack Diameter (m)	Concentration (mg/m ³)		Filter Type	Self-checks		Dry	Humid	Wet	Type of dust		Velocity Dependant
				Min	Max		Sensor contamination check	Zero & span				Same	Changing	
Probe Electrification	Charge Induction (AC)	ElectroDynamic	0.2-4	0.05	1000	Bag,Cyclone, Drier,Scrubber ⁽⁵⁾ , None ⁽⁶⁾	✓ (7)	✓ (7)	✓	✓	x	✓	x	No ⁽⁸⁾
	Contact Charge Transfer (DC)	DC Triboelectric	0.2-2	1	1000	Bag,Cyclone, None ⁽⁶⁾ ,Esp ⁽¹⁰⁾	x	x	✓	x	x	✓	x	Yes
	Combination AC & DC	Combination AC & DC/ Tribo	0.2-2	1	1000	Bag,Cyclone, None ⁽⁶⁾	x	✓ (7)	✓	x	x	✓	x	Yes
Transmissometry	Ratiometric Opacity	Dynamic Opacity	1-15 ⁽¹⁾⁽²⁾⁽⁷⁾	10 ⁽³⁾	1000	Bag ⁽¹⁾ ,Cyclone,EP,None	✓	✓ (7)	✓	x	x	✓	x	No
		Dyanamic Detection Principle	1-10 ⁽¹⁾⁽²⁾	20	1000	Bag ⁽¹⁾ ,Cyclone,EP,None	✓	x	✓	x	x	✓	x	No
	Opacity	Opacity	2-10 ⁽¹⁾⁽²⁾	30 ⁽⁴⁾	1000	EP,None	✓	✓	✓	x	x	✓	x	No
		Non Compliance Transmittance	2-10 ⁽¹⁾⁽²⁾	30 ⁽⁴⁾	1000	EP,None	x	x	✓	x	x	✓	x	No
Scattered Light	Light Scattering	Forward Scatter	1-3 ⁽²⁾	0.1	200	Bag,Cyclone,EP,None	✓	✓	✓	✓	✓ ⁽⁹⁾	✓	X	No
	Light Scattering	Backward / Side Scatter	1-4 ⁽¹⁾⁽²⁾	25	500	Bag ⁽¹⁾ ,Cyclone,EP,None	✓	✓	✓	x	x	✓	X	No

- Notes: (1) Concentration dependent (5) No water droplets (9) Using extractive wet stack monitoring system
 (2) Representative Flow dependent (6) No filter-not advised (10) Advised with Faraday Shield/edge
 (3) Application specific (7) Model specific
 (4) Stack diameter dependent (8) Varying velocity range 8-20 m/sec

There are a number of Opacity instruments with TUV approvals for particulate measurement. The certification ranges for opacity monitor are dependent on path length. The measuring range of 0-1000mg/m³ is suggested for a path length of 0.5 to 15 mt. However, low range i.e. 0 to 10 mg/Nm³ can be monitored in stack with minimum 5m path length.

This information is meant as a guide and reflects the majority of technology limitations of instruments currently commercially available, however specific models may offer decreased or increased capability the actual stack conditions will dictate instrument suitability

Table 5: Overview on Technical Selection & Suitability for Gaseous CEMS Technology

Technique	Type	Parameter(S) Measured	Comments& Limitations
Chimiluminescence	Dilution Extractive	NO, NO _x , NO ₂ * (Technology not suitable for other emission parameters like SO ₂ , CO ₂ , CO etc.)	<ul style="list-style-type: none"> - Indirect method for NO₂ measurement. NO and NO_x (NO + converted other Nitrogen oxides) measured in two cycles *NO₂ estimated as calculated (NO_x - NO). - Used for stack emission measurement with additional accessories like dilution probe, sample transfer line, dilution air, pumps and ozone generator. Advantageous in industries where heating probe and transfer lines are avoided. i.e. refinery, Petro chemicals. - Requires efficient purification system for dilution air. - Quench Effect of CO₂/water vapour, etc. maintaining Low Pressure becomes important. Can be eliminated by increased O₃ flow and requires continuous efforts and mechanism for it.
UV Fluorescence	Dilution Extractive	SO ₂ , H ₂ S*, TRS* (Total Reduced Sulphur) (Technology not suitable for other emission parameters like NO _x , CO ₂ , CO etc.)	<ul style="list-style-type: none"> * H₂S, TRS Cannot be measured simultaneously with SO₂. - Direct method for SO₂ -Used for stack emission measurement with additional accessories like dilution probe, sample transfer line, dilution air, pumps etc. - Advantageous in industries where heating probe and transfer lines are avoided. i.e. refinery, Petro chemicals. - Quench Effect of CO₂/Moisture, etc. maintaining Low Pressure becomes important.
NDIR (IR GFC, CFM-NDIR and NDIR) Basic principle follows IR (Infra-Red) spectroscopy GFC or CFM are applied techniques only.	In-Situ &Extractive	CO, CO ₂ , SO ₂ , NO _x , CH ₄ , HCl, H ₂ O etc.	<ul style="list-style-type: none"> - A direct method for continuous monitoring of multiple gases without any dilution. - Suitable for high concentrations <p>The IR technology has limitation that it can measure only NO. For measurement of NO_x a convertor to reduce other oxides of nitrogen to NO is required.</p>

Technique	Type	Parameter(S) Measured	Comments& Limitations
			<ul style="list-style-type: none"> - In-situ NDIR analyser uses Internal optical filters (GFC) for removal of interferences of other gases. - In extractive NDIR Issue of dissolution and stripping of CO₂/ SO₂ can underestimate the measured concentration, in case calibration does not follow the same system of sample transfer. Maintaining Low Pressure becomes important.
NDUV	In-situ and Extractive	SO ₂ , NO, NO ₂ , NH ₃ , Cl ₂ , CS ₂ , etc.	<ul style="list-style-type: none"> - A direct method for continuous monitoring of multiple gases suitable upto 2-3 gas measurements without any dilutions. - Popular in harsh applications in wide spectrum of Industrial process. - For NH₃ Hot wet extractive and Dilution system are suitable.
Fourier Transformed Infra-Red (FTIR)	Extractive	CO, CO ₂ , SO ₂ , NO, NO ₂ , N ₂ O, NH ₃ , HF, HCl, CH ₄ , Moisture (H ₂ O), VOC, etc.	<ul style="list-style-type: none"> - A direct method for continuous monitoring of multiple gases up to 5 - 12 gases using high end spectroscopy technique. - H₂O measurement in FTIR spectroscopy is necessary for moisture correction. - Uses Hot Wet Preferred technique for complex stack gas matrix like waste Incinerators or waste to power plants, alternative fuels fired Cement Plants, with high moisture and soluble gases. - High Price, however, with multi complex gases and integrated modules like VOC, O₂ makes it cost effective over all solution. - Ideal for very low concentration of NH₃, HF, HCl
Differential Optical Absorption Spectroscopy (DOAS)	Open Path cross duct	NO, NO ₂ , SO ₂ NH ₃ , Hg with DOAS- UV CO, CO ₂ , HCl, CH ₄ , VOC, H ₂ O, HF etc. DOAS-IR	<ul style="list-style-type: none"> - Suitable of monitoring of multiple gases. - Suitable for trace measurements - Indirect measurement technique. - Stable, comparatively low calibration requirements. - Measurement of Hg requires its conversion to elemental form for UV DOAS for which the system is required to be equipped with heated gas probe, heated sample transfer line and heated measurement cell. Removal of SO₂

Technique	Type	Parameter(S) Measured	Comments& Limitations
			interference is essential in case of UV measurement of mercury.
Flame Ionization	Extractive	Total HC (VOC), TOC, VOC	-Very selective technique for Total HC/ TOC/VOC. Requires H ₂ gas for flame and carrier Gas. -Integrated with extractive Hot wet / cold dry techniques.
Tunable Diode Laser	Path	CO, CO ₂ , NH ₃ , Moisture (H ₂ O), HCl, HF, CH ₄ , O ₂ & H ₂ S etc.	Usually selective laser techniques are not cost effective for single component. - Limitation in measuring SO ₂ and NO _x due to lack of selectivity. - Measurement of H ₂ O for moisture correction is necessary.
Electrochemical	Extractive	O ₂ , CO/CO ₂ , etc.	-Not accepted for online stack emission monitoring in Industries. -Electrochemical sensor is a consumable sensor, requires regular replacement and gets influenced by process stack background gas matrix. - Also gets influenced by moisture, dust, temperature, etc.
Zirconium Oxide / O ₂ Cell	In-situ& Extractive	O ₂	Widely used for boiler/ Stack O ₂ correction/ Normalisation.
Paramagnetic	Extractive	O ₂	Stable and accurate.
Atomic fluorescence / absorption	Hot Extractive	Hg	Total Gaseous Mercury. Always Hot extractive system A) Pre-treatment options Gold Amalgamation Followed by chemical/ thermal desorption (B) Adsorption in other media followed by Thermal desorption and measured using either atomic absorption/ atomic fluorescence / UV DOAS / UV measurement (after removal of SO ₂ interference/ Zeeman correction) are acceptable. For atomic absorption, Mercury lamp (NOT UV LAMP) should be used as energy source

Notes:

- (a) **CEM Systems must have flue gas flow measurement device installed where load based standards are stipulated.**
- (b) **Direct measurement systems for O₂ or CO₂ as prescribed in respective standards shall be installed.**
- (c) **For hazardous waste incinerator and Biomedical waste incinerator O₂, CO₂, and CO are important parameters to be monitored online.**

Table 6: Comparative analysis of technologies available for measurement of Gaseous pollutant

Type of Technology	Extractive NDIR/ IR GFC/ IR CFM and NDUV	In-situ NDIR & IR GFC	DOAS (Differential Optical Absorption Spectroscopy)	DILUTION EXTRACTIVE	TDLS	FTIR
How it works	Gas is extracted from stack, transported to sampling system, gas is conditioned and analyzed with a multi-gas NDIR analyzer	Optical head is directly mounted on the stack, by measuring light absorbed the analyzer measures the gases	Emitter, Receiver mounted across the stack. Xenon lamp emits light, amount of light absorbed at receiver sent to analyser through Optic Fibre cable	Very small amount of gas Extracted (Diluted) from stack to the analyser.	Derivative Laser spectroscopy which scan the spectral absorption peak and measure the derivative peak respective to be measurable parameters. It may be path insitu, close coupled, extractive system.	This methodology is strictly hot wet extractive. FTIR is a special type of spectroscopy in which spectrum is further analysed through an interferometric algorithm.
Advantage	<ul style="list-style-type: none"> -Suitable for high level of concentration. -Low failure rates as analyzer is not exposed to outside conditions, -easy to maintain when analyser is at ground, -addition of new analyzer at a later date is easy. -usually requires more calibration checks -widely used technique in harsh process applications -useful with close coupled technique 	<ul style="list-style-type: none"> -Suitable for high levels of concentrations. - Proper purging system is mandatory -Difficult to maintain at height -Addition is very simple, just new parameter monitoring arrangement required. -Usually requires more calibration checks as the system works in harsh/rough condition. 	<ul style="list-style-type: none"> -can measure low and high concentrations -No sampling requirement, except for mercury. -Low maintenance as there is no moving part. -Works well in harsh conditions like High moisture. -Provide High Data capture rate. -Single analyser can be used for multiparameter monitoring. -Requires less calibration because of low drift. 	<ul style="list-style-type: none"> -can measure low and high concentrations -sample is easy to dry -Ambient analysers technologies deployed. -Dilution ratio can be varied to reduce the interferences. 	<ul style="list-style-type: none"> -Multi-parameter monitoring is possible - Tuneable diode laser system is sensitive and can work in wet condition also. - Advantageous for Ammonia, HF, HCl monitoring alongwith H₂O 	<ul style="list-style-type: none"> -It is multi parameter monitoring technique suitable for most parameters except O₂. -suitable for most of the industries except for those such as petrochemical, refineries etc. where possibility of explosion and safety is a concern.

Type of Technology	Extractive NDIR/ IR GFC/ IR CFM and NDUV	In-situ NDIR & IR GFC	DOAS (Differential Optical Absorption Spectroscopy)	DILUTION EXTRACTIVE	TDLs	FTIR
Limitations	<ul style="list-style-type: none"> -Installation takes more time -Measures NO and not NO₂ -AC Rooms 	<ul style="list-style-type: none"> -The complete analyser system along with calibration equipment needs to be installed at stack and would require adequate arrangement for maintenance and calibration -Cannot measure low levels, -No expansion possible beyond the capacity of one device (Number of filters in the system), -consumes comparatively more calibration gas, -stack gas may corrode the probe and optics, -water interference is observed -Generally Measures NO not NO₂. -Expected life is less in comparison as system is exposed to harsh conditions 	<ul style="list-style-type: none"> - High Initial cost - Requires converter for Hg for which only extractive system should be used. -Calibration frequency requirement is low but needs a separate calibration bench. -AC Rooms 	<ul style="list-style-type: none"> -More time required for calibration as the calibration gases will pass the complete system from analyser till probe. - Dilution ratio - Operation of critical orifice -Maintaining dilution gas quality is challenging. -Individual analyser required for each parameter. -AC Rooms 	<ul style="list-style-type: none"> - High cost -Cannot measure SO₂ and NO_x . AC Rooms 	<ul style="list-style-type: none"> - High cost -AC Rooms
List of gases that can be measured	CO, CO ₂ , NO, SO ₂ , CH ₄ , etc, Moisture (number of gases limited to number of filters fitted in analyzer.	CO, CO ₂ , NO, SO ₂ , CH ₄ , HCl, Moisture (Note IR based system does not measure NO ₂ only calculates)	UV analyser- SO ₂ , NO, NO ₂ Phenol, Cl ₂ , Formaldehyde, Benzene, Hg	SO ₂ , NO, NO ₂ (NO _x), CO	CO,CO ₂ ,NH ₃ ,H ₂ O, HCL, HF,O ₂ and H ₂ S	SO ₂ ,NO,NO ₂ ,CO, CO ₂ , NH ₃ ,H ₂ O, HCL, HF and O ₂

Type of Technology	Extractive NDIR/ IR GFC/ IR CFM and NDUV	In-situ NDIR & IR GFC	DOAS (Differential Optical Absorption Spectroscopy)	DILUTION EXTRACTIVE	TDLS	FTIR
	(Note IR based system does not measure NO ₂ , only calculates) NO ₂ monitoring possible when convertor is used	NO ₂ monitoring possible when convertor is used	IR analyser- CO, CO ₂ , HCL, HF, H ₂ O, SO ₃ , NH ₃ , N ₂ O, CH ₄			
Effect of dust	Higher effect but can be controlled at sampling point	Higher effect but can be controlled with inbuilt mechanism	Low	Low Dilution probe clogging to be tackled	-	-
Effect of temperature	-	Limited Temperature Works upto 500 degC	-	Less than 400°C (Dilution probe with Quartz Orifice suitable upto 800°C	-	-
Effect of pressure	-	Limited Pressure	-	-	-	-
Effect of moisture	low as removed or Hot Wet	Very much affected, need to measure H ₂ O online Cannot work below dew point (below 95 degC)	If moisture over 40%, instrument gets effected	Gets affected at high moisture conditions. Can be controlled through properly dried dilution air	-	-
Requirement						
Adjustment during Zero and Span Check	Not allowed Zero and span check data needs to be transferred at real time	Not allowed Zero and span check data needs to be transferred at real time	- Zero and span check data needs to be transferred at real time	Not allowed Zero and span check data needs to be transferred at real time	Not allowed Zero and span check data needs to be transferred at real time	Not allowed Zero and span check data needs to be transferred at real time
Calibration & Check frequency	-Daily ZERO Check -Fortnightly ZERO and SPAN Calibration -Six Monthly Linearity Check	- Daily ZERO Check -Fortnightly ZERO and SPAN Calibration -Six Monthly Linearity Check --After Major maintenance	-Diagnostic check in every cycle -Six monthly ZERO and SPAN Calibration -Yearly Linearity Check ---After Major maintenance multipoint	-Daily ZERO Check -Fortnightly ZERO and SPAN Calibration -Six Monthly Linearity Check --After Major maintenance multipoint	-Diagnostic check in every cycle -Six monthly ZERO and SPAN Calibration -Yearly Linearity Check	-Diagnostic check in every cycle -Six monthly ZERO and SPAN Calibration -Yearly Linearity Check

Type of Technology	Extractive NDIR/ IR GFC/ IR CFM and NDUV	In-situ NDIR & IR GFC	DOAS (Differential Optical Absorption Spectroscopy)	DILUTION EXTRACTIVE	TDLS	FTIR
	--After Major maintenance multipoint Zero and SPAN Calibration	multipoint Zero and SPAN Calibration	Zero and SPAN Calibration	Zero and SPAN Calibration	---After Major maintenance multipoint Zero and SPAN Calibration	---After Major maintenance multipoint Zero and SPAN Calibration
Approvals for analyzers	TUV / MCERT approvals and conforms to US EPA / Indian certification	MCERT/TUV however, US EPA does not recommend In-situ system. / Indian certification	TUV, MCERTS and meets USEPA calibration protocols / Indian certification	Only conforms to USEPA / Indian certification	EU-TUV/MCERT / Indian certification	EU-TUV/MCERT / Indian certification
Multiplexing possible Y/N	NOT allowed as of now	NOT allowed as of now	NOT allowed as of now	NOT allowed as of now	NOT allowed as of now	NOT allowed as of now
Remote calibration Y/N	YES	YES	YES Possible with installation of calibration bench at site	Yes Dilution mechanism has to be compatible	Yes	Yes
Manual Online calibration Y/N	YES	YES	YES	YES	Yes	Yes

Note: Guidelines for calibration are in general. Wherever there are specific issues or difficulties related to method of remote calibration in different technologies, same should be brought into the notice of CPCB & SPCBs/PCCs.

Table 7: Parameter specific Emission Standards for industries need to install CEMS

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits			Options available for CEMS
1	Aluminum	Raw Material Handling	PM	PM 150 mg/NM ³			PM CEMS as per matrix Table no:4
		Calcination	PM, CO	PM 250 mg/NM ³ and CO 1% (Max)			PM CEMS as per matrix Table no:4
		Green Anode Shop	PM	PM 150 mg/NM ³			PM CEMS as per matrix Table no:4
		Anode Bake Oven	PM	PM 50 mg/NM ³			PM CEMS as per matrix Table no:4
			Total fluoride (F)	0.3 Kg/MT of Al			Extractive FTIR In-situ IR-DOAS,TDLS
		Pot room	PM	PM 150 mg/NM ³			PM CEMS as per matrix Table no:4
			Total Fluoride (as F)	Vertical Stud Soderberg (VSS)	4.7 Kg/MT	Extractive FTIR	
				Horizontal Stud Soderberg (HSS)	6.0 Kg/MT	In-situ IR-DOAS,TDLS	
				Prebacked Side Worked (PBSW)	2.5 Kg/MT	Extractive FTIR	
Prebacked Centre Worked PBCW)	1.0 Kg/MT	In-situ IR-DOAS,TDLS					
2.	Cement Plant (without co processing), Standalone Clinker Grinding Plant or, Blending Plant	Rotary Kiln – without co processing	Parameter	Date of Commissioning	Location	Emission Limits mg/Nm ³	CEMS Options
			PM	on or before or after the date of notification (25.8.2014)	anywhere in the country	30 mg/Nm ³	PM CEMS as per matrix Table no:4
			SO ₂	Irrespective of date of commissioning	Anywhere in the country	100, 700 and 1000 mg/Nm ³ when pyritic sulphur in the limestone is less than 0.25%, 0.25 to 0.5% and more than 0.5% respectively	In-situ NDIR / IR GFC/UV-DOAS
							Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM
				Dilution extractive			

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits			Options available for CEMS
				After the date of notification (25.8.2014)	Anywhere in the country	600 mg/Nm ³	In-situ UV-DOAS, NDIR, IR GFC Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM Dilution Extractive - Chemiluminescence
			NOx	Before the date of notification (25.8.2014)	Anywhere in the country	(a) 800 for rotary kiln with In Line Calciner (ILC) technology. (b) 1000 for rotary kiln using mixed stream of ILC, Separate Line Calciner (SLC) and suspension preheater technology or SLC technology alone or without Calciner.	In-situ UV-DOAS, NDIR, IR GFC Extractive – NDUV / FTIR, IR GFC, NDIR-CFM Dilution Extractive - Chemiluminescence
	Cement Plant with co-processing of wastes	Rotary Kiln – with co-processing of Wastes	Parameters	Date of Commissioning	Location	Emission Limits mg/Nm ³	CEMS Options
PM			on or after the date of notification (25.8.2014)	Anywhere in the country	30 mg/NM ³	PM CEMS as per matrix Table no:4	
SO ₂			before the date of notification (25.8.2014)	critically polluted area or urban centres with population above 1.0 lakh or within its periphery of 5.0 kilometer radius	100, 700 and 1000 mg/Nm ³ when pyritic sulphur in the limestone is less than 0.25%, 0.25 to 0.5% and more than 0.5% respectively	In-situ NDIR / IR GFC/UV-DOAS Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM Dilution extractive UV-Fluorescence	

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits			Options available for CEMS			
			NOx	After the date of notification (25.8.2014)	Anywhere in the country	600 mg/Nm ³	In-situ UV-DOAS, NDIR, IR GFC			
							Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM			
							Dilution Extractive - chemiluminescence			
			NOx	before the date of notification (25.8.2014)	anywhere in the country	(a) 800 mg/Nm ³ for rotary kiln with In Line Calciner (ILC) technology. (b) 1000 mg/Nm ³ for rotary kiln using mixed stream of ILC, Separate Line Calciner (SLC) and suspension preheater technology or SLC technology alone or without calciner.				In-situ UV-DOAS, NDIR, IR GFC
										Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM
										Dilution Extractive - chemiluminescence
			Parameters	Implementation Date	Location	Emission Limits	CEMS Options			
HCl (mg/NM ³)	NA	Anywhere in the country	10 mg/Nm ³	In-situ IR DOAS, TDLS, Hot Extractive FTIR						
HF (mg/NM ³)	NA	Anywhere in the country	1 mg/Nm ³	In-situ IR DOAS, TDLS, Hot Extractive FTIR						
TOC (mg/NM ³)	NA	Anywhere in the country	10 mg/Nm ³	Hot Ext. FID						
3	Distillery	Boiler Stack	PM	150 mg/NM ³			PM CEMS as per matrix Table no:4			

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits		Options available for CEMS
4	ChlorAlkli	(Hyper tower) (HCl Plant)	Cl ₂ , HCl	Cl ₂ -15 mg/NM ³ HCL-35mg/NM ³		IR DOAS, TDLS,
						Hot Extractive FTIR
5	Fertilizers	Phosphate	PM	PM-150 mg/NM ³		PM CEMS as per matrix Table no:4
			Fluoride	Total Fluorides-25 mg/NM ³		Extractive FTIR In-situ IR-DOAS,TDLS
		Urea (Old Plants) before 01/01/1982	PM	150 mg/NM ³		
		Urea (New Plants) after 01/01/1982	PM	50 mg/NM ³		
6	Integrated Iron & Steel Plants	Coke oven plant New Batteries at GF sites Rebuild Batteries Existing Batteries	PM	50 mg/NM ³		PM CEMS as per matrix Table no:4
			SO ₂	800 mg/NM ³		In-situ NDIR / IR GFC/UV-DOAS
						Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM
						Dilution extractive UV-Fluorescence
		NO _x	500 mg/NM ³		In-situ UV-DOAS, NDIR, IR GFC	
					Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM	
		Sintering Plant	150 mg/NM ³		Dilution Extractive - chemiluminescence	
					PM CEMS as per matrix Table no:4	
Blast Furnace		Existing Units	New Units (after 31 March 2012)			
	PM	50 mg/NM ³	30 mg/NM ³		PM CEMS as per matrix Table no:4	

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits		Options available for CEMS
			SO ₂	250 mg/NM ³	200 mg/NM ³	In-situ NDIR / IR GFC/UV-DOAS Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM Dilution extractive UV-Fluorescence
			NO _x	150 mg/NM ³	150 mg/NM ³	In-situ UV-DOAS, NDIR, IR GFC Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM Dilution Extractive - Chemiluminescence
			CO	1% (Max)	1% (Max)	NDIR Insitu Extractive FTIR
			Steel making shop-basic oxygen furnace	Parameters	Existing Units	New Units (after 31 march 2012)
		Blowing/lancing operation	PM	300 mg/NM ³	Should be with gas recovery	PM CEMS as per matrix Table no:4
		Normal operation	PM	150 mg/NM ³	Should be with gas recovery	PM CEMS as per matrix Table no:4
		Dedusting of desulphurisation	PM	100 mg/NM ³	50 mg/NM ³	PM CEMS as per matrix Table no:4
		Rolling mill	PM	150 mg/NM ³		PM CEMS as per matrix Table no:4
		Re-heating (reverberatory) furnaces	PM	Sensitive Areas	Other Areas	PM CEMS as per matrix Table no:4
				150 mg/NM ³	250 mg/NM ³	
		Arc furnaces	PM	150 mg/NM ³		PM CEMS as per matrix Table no:4

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits		Options available for CEMS
		Induction Furnace	PM	150 mg/NM ³		PM CEMS as per matrix Table no:4
		Cupola Foundry		< 3 MT / hr Melting capacity	> 3 MT / hr Melting capacity	
			PM	450 mg/NM ³	150 mg/NM ³	PM CEMS as per matrix Table no:4
			SO ₂	300 mg/NM ³ Corrected to 12 % CO ₂		In-situ NDIR / IR GFC/ UV-DOAS Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM Dilution extractive UV- Fluorescence
				Capacity upto 40 Tonne / day	Capacity above 40 Tonne / day	
		Calcination plant/lime kiln / dolomite kiln	PM	500 mg/NM ³	150 mg/NM ³	PM CEMS as per matrix Table no:4
		Refractory unit	PM	150 mg/NM ³		PM CEMS as per matrix Table no:4
	Sponge Iron Plants	Rotary Kiln	PM	100 mg/NM ³ (Coal based)		PM CEMS as per matrix Table no:4
				50 mg/NM ³ (Gas based)		PM CEMS as per matrix Table no:4
	7	Oil Refinery	Furnace boiler and captive power plant gas based		Before 2008	After 2008
PM				10 mg/NM ³	5 mg/NM ³	PM CEMS as pe matrix Table no:4
SO ₂				50 mg/NM ³	50 mg/NM ³	In-situ NDIR / IR GFC/ UV-DOAS Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM Dilution extractive UV- Fluorescence

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits		Options available for CEMS	
			NO _x	350 mg/NM ³	250 mg/NM ³	In-situ UV-DOAS, NDIR, IR GFC Extractive – NDUV/ FTIR, NDIR GFC, NDIR-CFM Dilution Extractive - chemiluminescence	
			CO	150 mg/NM ³	100 mg/NM ³	NDIR Insitu	
						Extractive FTIR, NDIR GFC / NDIR CFM	
			H ₂ S	150 mg/NM ³	150 mg/NM ³	TDLS/FTIR/IR DOAS However H₂S and SO₂ can not be measured simultaneously.	
		Furnace boiler and captive power plant liquid Fuel based		Before 2008	After 2008		
			PM	100 mg/NM ³	50 mg/NM ³	PM CEMS as pe matrix Table no:4	
			SO ₂	1700 mg/NM ³	850 mg/NM ³	In-situ NDIR / IR GFC/UV-DOAS	
						Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM	
						Dilution extractive UV-Fluorescence	
				NO _x	450 mg/NM ³	350 mg/NM ³	In-situ UV-DOAS, NDIR, IR GFC Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM Dilution Extractive - chemiluminescence
				CO	200 mg/NM ³	150 mg/NM ³	NDIR In situ
		Extractive FTIR, NDIR GFC / NDIR CFM					

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits		Options available for CEMS
				Existing SRU	New SR (after 1.1.2008)	
		Sulphur Recovery Unit (SRU)	Parameters	Existing SRU	New SR (after 1.1.2008)	
			H ₂ S	15 mg/NM ³	10 mg/NM ³	TDLS/FTIR/IR DOAS However H ₂ S and SO ₂ cannot be measured simultaneously.
			NO _x	350 mg/NM ³	250 mg/NM ³	In-situ UV-DOAS, NDIR, IR GFC
						Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM
						Dilution Extractive – Chemiluminescence
8	Petrochemical	Furnace, Boiler, Heater, Vaporizer Liquid Fuel based	CO	150 mg/NM ³	150 mg/NM ³	NDIR In situ
						Extractive FTIR, NDIR GFC / NDIR CFM
		Furnace, Boiler, Heater, Vaporizer Liquid Fuel based	Existing Plant	Existing Plant	New / Expansion (after 9 th Nov. 2011)	
			PM	100 mg/NM ³	50 mg/NM ³	PM CEMS as per matrix Table no:4
			SO ₂	1700 mg/NM ³	850 mg/NM ³	In-situ NDIR / IR GFC/UV-DOAS
						Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM
						Dilution extractive UV-Fluorescence
		Furnace, Boiler, Heater, Vaporizer Liquid Fuel based	NO _x	450 mg/NM ³	350 mg/NM ³	In-situ UV-DOAS, NDIR, IR GFC
						Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM
						Dilution Extractive - Chemiluminescence
			CO	200 mg/NM ³	150 mg/NM ³	NDIR In situ
						Extractive FTIR, NDIR GFC / NDIR CFM

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits		Options available for CEMS
				Existing Plant	New / Expansion	
		Furnace, Boiler, Heater, Vaporizer Gas based	PM	10 mg/NM ³	5 mg/NM ³	PM CEMS as per matrix Table no:4
			SO ₂	50 mg/NM ³	50 mg/NM ³	In-situ NDIR / IR GFC/UV-DOAS Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM Dilution extractive UV-Fluorescence
			NO _x	350 mg/NM ³	250 mg/NM ³	In-situ UV-DOAS, NDIR, IR GFC Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM Dilution Extractive - Chemiluminescence
			CO	200 mg/NM ³	150 mg/NM ³	NDIR In situ Extractive FTIR, NDIR GFC / NDIR CFM
9	Power Plant **	TPP installed before 31/12/2003		Less than 500 MW	More than 500 MW	
			PM	100 mg/NM ³	100 mg/NM ³	PM CEMS as per matrix Table no:4
			SO ₂	600 mg/NM ³	200 mg/NM ³	In-situ NDIR / IR GFC/UV-DOAS Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM Dilution extractive UV-Fluorescence
			NO _x	600 mg/NM ³	600 mg/NM ³	In-situ UV-DOAS, NDIR, IR GFC Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM Dilution Extractive – Chemiluminescence

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits		Options available for CEMS
			Hg	0.03 mg/NM ³	0.03 mg/NM ³	Total Gaseous Mercury. Always Hot extractive system A) Pre-treatment options Gold Amalgamation Followed by chemical/ thermal desorption (B) Adsorption in other media followed by Thermal desorption and measured using either atomic absorption/ atomic fluorescence / atomic absorption / UV DOAS / UV measurement (after removal of SO ₂ interference / Zeeman correction) are acceptable. For atomic absorption, Mercury lamp (NOT UV LAMP) should be used as energy source
		TPP Installed on & after 01/01/2004 upto 31/12/2016		Less than 500 MW	More than 500 MW	
			PM	50 mg/NM ³	50 mg/NM ³	PM CEMS as per matrix Table no:4
			SO ₂	600 mg/NM ³	200 mg/NM ³	In-situ NDIR / IR GFC/UV-DOAS Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM
						Dilution extractive UV-Fluorescence
			NO _x	300 mg/NM ³	300 mg/NM ³	In-situ UV-DOAS, NDIR, IR GFC Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM Dilution Extractive – Chemiluminescence

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits		Options available for CEMS
			Hg	0.03 mg/NM ³	0.03 mg/NM ³	Total Gaseous Mercury, Always Hot extractive system A) Pre-treatment options Gold amalgamation Followed by chemical/ thermal desorption (B) Adsorption in other media followed by Thermal desorption and measured by either Cold vapour atomic fluorescence / Cold Vapor atomic absorption / UV DOAS / UV measurement (after removal of SO ₂ interference) are acceptable. For atomic absorption, Mercury lamp (NO UV LAMP) should be used as energy source
		TPP to be installed from 01/01/2017	PM	30 mg/NM ³		PM CEMS as per matrix Table no:4
			SO ₂	100 mg/NM ³		In-situ NDIR / IR GFC/UV-DOAS Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM Dilution extractive UV-Fluorescence
			NO _x	100 mg/NM ³		In-situ UV-DOAS, NDIR, IR GFC Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM Dilution Extractive – Chemiluminescence

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits		Options available for CEMS
			Hg	0.03 mg/NM ³		Total Gaseous Mercury, Always Hot extractive system A) Pre-treatment options Gold amalgamation, followed by chemical/ thermal desorption (B) Adsorption in other media followed by Thermal desorption and measured by either Cold vapour atomic fluorescence / Cold Vapor atomic absorption / UV DOAS / UV measurement (after removal of SO ₂ interference) are acceptable. For atomic absorption, Mercury lamp (NO UV LAMP) should be used as energy source
10	Zinc	Smelter, SRU		Existing Units	New Units (after 2 nd May 2011)	CEMS options available
			PM	100 mg/NM ³	75 mg/NM ³	PM CEMS as per matrix Table no:4
			SO ₂ (for upto 300 T /day)	1370 mg/NM ³	1250 mg/NM ³	In-situ NDIR / IR GFC/UV-DOAS Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM Dilution extractive UV-Fluorescence
			SO ₂ (for > 300 T /day)	1250 mg/NM ³	950 mg/NM ³	In-situ NDIR / IR GFC/UV-DOAS Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM Dilution extractive UV-Fluorescence

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits		Options available for CEMS
				Existing Units	New Units (after 2 nd May 2011)	
11	Copper	Smelter, SRU	Parameters	Existing Units	New Units (after 2 nd May 2011)	CEMS options available
			PM	100 mg/NM ³	75 mg/NM ³	PM CEMS as per matrix Table no:4
			SO ₂ (for upto 300 T /day)	1370 mg/NM ³	1250 mg/NM ³	In-situ NDIR / IR GFC/UV-DOAS
						Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM
						Dilution extractive UV-Fluorescence
			SO ₂ (for > 300 T /day)	1250 mg/NM ³	950 mg/NM ³	In-situ NDIR / IR GFC/UV-DOAS
			Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM			
			Dilution extractive UV-Fluorescence			
12	Biomedical waste Incinerator	Incinerator Stack	PM	50 mg/NM ³		PM CEMS as per matrix Table no:4
			NO _x	400 mg/NM ³		In-situ UV-DOAS
						Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM
						Dilution Extractive – Chemiluminescence
			HCl	50 mg/NM ³		IR DOAS, TDLS,
			Temp. P.C.C.	800 °C		Temperature probe
			Temp. S.C.C.	1050 ± 50 °C		Suitable Temperature Probe
Combustion Efficiency CO and CO ₂	99%		Extractive NDIR			
13	Common Hazardous Waste Incinerator	Incinerator Stack	PM	50 mg/Nm ³		PM CEMS as per matrix Table no:4
			HCl	50 mg/Nm ³		In-situ IR DOAS, TDLS
						Hot Extractive FTIR, IR
			SO ₂	200 mg/Nm ³ -30 minute average		In-situ NDIR / IR GFC/UV-DOAS

S. No.	Industries/ Facilities	Units of Operation	Parameters Prescribed	Emission Limits	Options available for CEMS
			NO _x	400 mg/Nm ³	Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM
					Dilution extractive UV-Fluorescence
					In-situ UV-DOAS
					Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM
					Dilution Extractive - chemiluminescence
					In-situ IR DOAS, TDLS
					Hot Extractive FTIR
HF	4.0 mg/Nm ³	In-situ IR DOAS, TDLS			
TOC	20 mg/Nm ³	Hot Extractive FID			
			CO	100 mg/Nm ³ -30 minute average 50 mg/Nm ³ -24 Hrly average	NDIR In situ
					Extractive FTIR, NDIR GFC / NDIR CFM
14	Sugar	Boiler	PM	150 mg/NM ³	PM CEMS as per matrix Table no:4
15	Sugar, Cotton Textile, Composite Woolen Mills, Synthetic Rubber, Pulp & Paper, Distilleries, Leather Industries, Calcium Carbide, Carbon Black, Natural Rubber, Asbestos, Caustic Soda, Small Boilers , Aluminium	Boiler (Other fuels)	SO ₂	600 mg/NM ³ at 6% dry O ₂ , for solid fuel and 3% dry O ₂ for liquid fuel	In-situ NDIR / IR GFC/UV-DOAS
					Extractive NDUV / FTIR / NDIR / IR-GFC / IR-CFM
			NO _x	600 mg/NM ³ at 6% dry O ₂ , for solid fuel and 3% dry O ₂ for liquid fuel	Dilution extractive UV-Fluorescence
					In-situ UV-DOAS, NDIR, IR GFC
		Extractive – NDUV / FTIR, NDIR GFC, NDIR-CFM			
		Dilution Extractive – Chemiluminescence			

	Plants, Tanneries, Inorganic Chemicals & other such industries using boilers				
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Note:

- Temperature measurement and reporting are compulsory for all installations.
- CO₂ and or O₂ as prescribed in notified standards for respective sectors and processes to be monitored.
- All the data has to be corrected to mass/volume at STP (760mm Hg Pressure and 25 degree C temperature in dry condition).
- All In-situ and Dilution extractive and Hot Wet Extractive systems shall monitor and report Moisture to correct the results in dry condition. Waste incineration plants including Hazardous waste incinerators and Waste to Energy plants requires continuous moisture monitoring.
- Installations using dilution techniques must inform CPCB and SPCBs/PCCs in case of any change in dilution ratio.
- NDIR based NO_x analyzer ideally converts all NO_x to NO for measurement purpose. 5% of total converted NO represents NO₂. NDIR based In-situ Analyzers without converters are measuring NO and considering upto 5% of NO values as NO₂ resulting under reporting of NO_x. Hence, in order to correct the data special calculation as given below will be applied.
Reported NO values will be multiplied by 1.05 and then 95% of the product will be considered as NO and 5% of the product will be considered as NO₂. Final reporting shall follow the equation $NO_x = NO + NO_2 = NO \times 1.53 + NO_2 = NO_x \text{ as } NO_2$
In other cases, NO_x values are required to be reported as NO₂mg/NM³: $NO_x = NO + NO_2 = NO \times 1.53 + NO_2 = NO_x \text{ as } NO_2$
For the IR based instrument without converter the reported NO values will be multiplied by 1.05 and then 95% of the product will be considered as NO and 5% of the product will be considered as NO₂. Final reporting shall follow the equation $NO_x = NO + NO_2 = NO \times 1.53 + NO_2 = NO_x \text{ as } NO_2$
In other cases NO_x values are required to be reported as NO₂mg/NM³: $NO_x = NO + NO_2 = NO \times 1.53 + NO_2 = NO_x \text{ as } NO_2$
- Recommended to go for NO + NO₂ measurement for correct reporting as NO₂
- Hg CEMS requirement is applicable for thermal power plants only in case such condition is specified in Environmental Clearance granted by MoEF&CC / SEIAA
- Formulae for data reporting are given in **Annexure-II**.

** CEMS requirement applicable with the time period specified for compliance with the new emission norms for thermal power plants & as per Environmental Clearance Conditions specified by MoEF&CC.

*** Parameters for CEMS shall be as prescribed by SPCB/PCCs under Schedule II of Biomedical Waste Management Rules, 2016

8.0 SITE REQUIREMENT AND PREPARATION FOR MOUNTING OF CONTINUOUS EMISSION MONITORING SYSTEM

1. Infrastructure and mounting

- a. All measurement ports in the stack / duct, etc. will have to be made available as per CEMs system requirement and confirming the regulatory requirement
- b. CEMs analyser mounting flanges needs to be welded/grouted as per the mounting guidelines furnished by the vendor.
- c. Industry to ensure availability of permanent, strong & reliable platforms at CEMs analyser mounting location with safe approach ladders or stair case (spiral) or elevator. Vertical ladders if provided, should have back guard, stair case if provided, should be with proper hand rail, steps should be evenly distributed with adequate height, length & width. Monkey ladder is not preferred in case the height of platform is more than 30 meter from the ground.
- d. For ease of maintenance work, the stack platform width for metallic stacks should be 800mm minimum & for concrete stack platform width should be minimum of 1000mm. All platforms should have hand rails.
- e. All the power cables, signal cables, instrument air tubing's should be properly laid & clamped so that should not be an obstacle for personnel movements.

2. Utilities

- a. Uninterrupted power supply - single phase, 110/ 230 VAC as applicable should be supplied up to the analyser mounting location
- b. Power supply should be properly earthed; lightning arrestor wire line & earthing cable wire line should be separate.
- c. Instrument air connection – Clean and dry compressed air will have to be supplied by end user upto the analyser probe mounting location.
- d. Quality of instrument air shall depend upon the specific demand of parameter being measured.

3. Safety

With respect to instrument safety, all the instructions in the vendor specific CEMs manual shall be followed. All flanges, ports must be well supported

and welded as per required standards. Mounting bolts, etc. must be fully tight before commissioning. All personnel safety standards and procedures for working at height must be adhered to at site.

- a. If the approach to platform is by using vertical ladder's, then at every 10-12 mtrs landing platform should be provided. The entire length of ladder must have protective back guard/cage.
- b. Ladder must continue through platform approach to some distance above such that landing on platform is easy.
- c. Ladder must be well maintained with all fasteners rigidly fixed in the stack wall.
- d. The completed ladder network and stack has to be regularly inspected for corrosion and must be painted periodically.
- e. Platform railing must be rigid at least reach 1.2 mtr in height from platform surface.
- f. If analyser mounting location is above 45meter elevation then for ease of maintenance and personnel safety, proper stair case or lift/elevator should be provided
- g. Industry to ensure removal of bee hive from stack or stack nearby location before proceeding for any CEMS mounting/maintenance work on stack platform.

9.0 CALIBRATION, PERFORMANCE EVALUATION AND AUDIT OF CEMS

9.1 Practices in other Countries

The calibration process for CEMS is well established in European Union and USA. The European Union follow EN 14181 which specifies procedures for establishing Quality Assurance level in terms of QAL 2, QAL 3 and Annual Surveillance Test (AST) for ***CEMS (CEMS is also called Automated Measurement Systems (AMS) in Europe)*** installed at industrial plants for flue gas parameters. In the UK QAL 1 procedures are covered by certification under MCERTS Scheme for Continuous Monitoring System. The suitability evaluation of CEMS and its measuring procedures are described in EN ISO 14956 (QAL 1), which subsequently became EN 15267-1.

The USEPA follows a different route by using Relative Accuracy Test Audit (RATA) for gases and Relative Response Assessment (RRA) for Particulate. The difference between the European System and that followed in USA for Quality Assurance of CEMS is given in **Table 8**.

Table 8: Difference between the two QA systems followed in European Union & USA

	Selection of CEM	Installation	Stability before calibration	Valid calibration	Ongoing instrumental stability	Ongoing calibration stability
EU	QAL1 (EN15267 parts 1 to 3) with appropriate certification range	EN15259	QAL3	Functional test and QAL2	QAL3 plus annual linearity	Functional test and annual surveillance tests (AST)
USA	None but legal onus on the operator to provide valid data	Field Performance Test	7-day drift test	Correlation tests over 3 days	Zero and Span plus, quarterly linearity test	Annual correlation test and Relative Accuracy Test Audits (RATA) for gases and Relative Response Assessment (RRA) for particulate

The system for Quality Assurance followed in European Union as well as in EPA requires a well-established infrastructure for calibration of the systems, for uncertainty calculations and performance evaluation besides requiring skills and expertise to support each CEM, since the CEM is specifically characterized and calibrated for the individual application.

9.2 Recommended Instrumentation/Methodology for Monitoring

- a. The USEPA TUV & MCERTS certified analysers *for emissions* are recognized for use as CEMS. Any alteration invites invalidation of the certificate.
- b. All indigenous and foreign Manufacturers of analysers/ instruments for real time monitoring of industrial emissions shall obtain certificate for their system within twelve months after the Indian certification system is in place.
- c. The analysers/ instruments will not be considered for installation; in case their manufacturer fails to obtain the required certification from the Indian Certification Agency/ agencies within 12 months of the establishment of Indian Certification System.

9.3 Acceptance of CEMS Until Indigenous Certification System is Placed

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 QAL 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 industries shall submit details of the CEMS installed and operationalized as per in CPCB's Compliance Reporting Protocol (CRP) for OCEMS.

Field-testing is a procedure for the determination of the calibration function and its variability. In this process, variability of the measured values of the CEMS compared with the data quality objectives specified.

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. The ranges/values mentioned in Tables below are technology specified and may slightly deviate from those specified.

Table 9: Performance Specification for SO₂, NO_x and CO

S.No.	Specification	Tolerance ranges/values
1	Zero Drift/Weekly	$\leq \pm 1\%$ of Span
2	Span Drift /Weekly	$\leq \pm 1\%$ of Span
3	Analyzer's Linearity	$\leq \pm 1\%$ of Span from calibration curve
4	Performance Accuracy	$\leq \pm 10\%$ of compared Reference measurement

Table 10: Performance Specification for O₂, and CO₂

S.No.	Specification	Tolerance ranges/values
1	Zero Drift /Weekly	$\leq \pm 1\%$ of O ₂
2	Span Drift /Weekly	$\leq \pm 1\%$ of O ₂
3	Analyzer's Linearity	$\leq \pm 1\%$ of O ₂
4	Performance Accuracy	$\leq \pm 10\%$ of compared Reference measurement or within 1% of O ₂

Table 11: Performance Specification for PM CEMS

S.No.	Specification	Tolerance ranges/values
1	Zero Drift between two servicing intervals	$\leq \pm 2\%$ of Full Scale range
2	Reference point Drift between two servicing intervals	$\leq \pm 2\%$ of Reference value range
3	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).
4	Performance Accuracy	$\leq \pm 10\%$ of compared Reference measurement

Table 12: Specification for Analyser

S. No.	Specification	Tolerance ranges or values
1	Zero Drift /Weekly	$\leq 1\%$
2	Span Drift /Weekly	$\leq 1\%$
3	Analyzer's Linearity	$< 1\%$ of full scale
4	Performance accuracy	$\leq \pm 10\%$ 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.

9.4 Calibration of Air Analysers (Gaseous Parameter)

- a. The instruments/analysers for real time monitoring of gaseous emissions shall be calibrated with respect to their functioning, drift, linearity, detection limit, output, operating temperature and other relevant parameters before installation.
- b. Demonstration of performance specifications as outlined in section 9.3 for both indigenous as well as certified analysers.
- c. 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 methods and certified reference materials.
- d. The data comparison and calibration verification shall be done once in 06 months by empaneled laboratories following standard procedures and using certified reference standards.

- e. The health of the instruments/analysers shall be assessed on daily basis by checking the zero drift.
- f. In case the daily zero drift is more than the acceptable limit as specified in the catalogue/brochure of the instrument/analyser manufacturer and persists continuously for five days, the instrument/ analyser shall be recalibrated following procedure laid down at point (c) above.
- g. The instruments/analysers shall be checked for zero and span on fortnightly basis i.e. second Friday of the fortnight at fixed time (10:00 a.m.) using standard methods and standard reference materials including certified calibration gases. The drift needs to be recorded and suitably incorporated in the data collected over the period.
- h. For Differential Optical Absorption Spectroscopy (DOAS), Non Dispersive Ultra Violet (NDUV)/Non Dispersive Infra-Red lamp/laser based systems / FTIR based systems, the calibration shall be revalidated once in 06 months, and after replacement of lamp.
- i. The instrument/ analyser shall be recalibrated after any major repair/replacement of parts/lamps or readjustment of the alignment using standard methods and certified reference materials.
- j. The instrument/analyser system shall have provision of remote calibration, for verification of the system performance by SPCBs/PCCs whenever, felt necessary.
- k. The intensity of the lamp shall be checked once every fortnight.
- l. Data capture rate of more than 85% shall be ensured.
- m. Using Ambient Air for Zero/Span calibration is not acceptable, Zero air, instrument air, Span Gas/Gas filled Cuvette can be used with required certifications.

9.5 Calibration of Air Analysers (Particulate Matter)

The PM CEMS device is ready for calibration only after performing all of the required installation, registration, and configuration steps. Details of Particulate Matter CEMS calibration are given below.

- a. The continuous Particulate Matter monitoring system (PM-CEMS) shall ideally be calibrated at three operational loads against isokinetic sampling method (triplicate samples at each load) nine samples in three loads at the

- time of installation and thereafter, every twelve months of its operation or after any change in solid fuels.
- b. The results from the Particulate Matter monitoring system shall be compared on monthly basis i.e. last Friday of the month, at fixed time (replicate sample) starting 10.00 am. with standard isokinetic sampling method.
 - c. In case, deviation of the comparison values (dust factor) for 02(two) consecutive monitoring is more than 10%, the system shall be recalibrated against isokinetic sampling method (triplicate samples), if possible at three variable loads.
 - d. Adjustment of Calibrated Dust Factor (CDF) allowed only after full-scale calibration of PM CEMS. Change of CDF permitted only after approval by SPCB/ PCC or after one week of submission of request to SPCB/PCC whichever is earlier.
 - e. 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)
 - f. The data capture rate of more than 85% shall be ensured.
 - g. The intensity of lamp shall be checked once every fortnight.
 - h. The data comparison (calibration verification) shall be done by laboratories empaneled by CPCB using standard reference methods and at a frequency specified.

9.6 Emission Monitoring

- a. To ensure laminar flow the Particulate Matter monitoring systems (CEMS) shall be installed at a distance at least at Eight times the stack diameter downstream and Two times stack diameter upstream from any flow disturbance.

In rare cases, when the PM CEMS analyzers are installed at a distance atleast four times the stack diameter downstream from any flow disturbance; however, correction for stratification (pl. refer para 4.1.1) shall be made. The full scale calibration shall cover atleast 03(three) working loads and atleast 09(nine) (triplicate sample at variable load) sampling shall be carried out for dust factor.
- b. CEMS devices shall be installed at minimum 500mm below from the port hole designed for manual sampling.

- c. All measurement ports into the stack shall be as per CEMS system requirement.
- d. Particulate CEMS devices (Cross Duct) or probe shall be installed in horizontal plane;
- e. Probe / sampling device for gaseous CEMS shall be installed protruding downwards with suction system facing the direction of flow of flue gases.
- f. 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.
- g. The monitoring of PM parameter at different loads is to be conducted at least once at the time of initial installation. It is advised to carry out PM emission monitoring on the day when plant operates, under capacity due to any reason besides the routine monitoring. The data obtained can be used for linearity verification and CDF should be calculated and informed to CPCB.
- h. Similarly, when ESP or APCC device is operating under capacity, or its fields are under maintenance, the emission monitoring should be practiced to carryout linearity check of the particulate monitoring beside routine monitoring, CDF should be calculated and informed to CPCB.
- i. The parameters like flow if not installed requiring changes in the stack/duct may be monitored within a period of four months from the date of issue of the 1st revision guidelines or immediately after scheduled shutdown whichever is earlier.
- j. Other parameters like temperature which do not require an modification in the structure of the stack shall be installed within a month from the date of issue of 1st Revision of Guidelines.

9.7 Data Consideration/Exceedance

- a. Any exceedance of values over the prescribed standards or norms shall be considered as alarm for exceedance. However, time average value (as decided by CPCB) will be used for compliance check.
- b. Instantaneous elevated data i.e. spikes with duration less than one minute shall be dealt separately and not considered for data averaging.

- c. In case of loss of data for more than 10 minutes per half hour it will be considered as loss of half hourly value. In case more than 5 half hourly data is lost per day, it will be considered as data loss for a day.
- d. Any day in which more than three hourly average values are invalid due to malfunction or maintenance of the automated measuring system shall be considered lost date for the day 85% data capture in based on available daily average.
- e. In the case of a breakdown of the RTMS, the operator shall reduce or close down operation if the problem is not rectified within 72 hours, subject to information to SPCBs/PCCs and CPCB.
- f. Operating hours – means the time expressed in hours during which the plant in whole or in part is operating and discharging emission into the air, excluding start up and shut down periods.
- g. Any Exceedance of the monitored values against the standards shall invite SMS & email to the industry from SPCBs/PCCs, requiring immediate feedback on the corrective action initiated/taken.
- h. The values recorded during calibration or during preventive maintenance shall not be considered for Exceedance and assessing the data capture rate.
- i. 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 as per the schedule specified in the Compliance Reporting Protocol.
- j. Plant shut down period shall be excluded while calculating data capture rate.

9.8 Data Acquisition System (DAS)

- a. DAS (Data Acquisition System) defines the logging of digital data from the analysers.
- b. The data shall be transferred directly from Data Acquisition and Handling System at the analyser end to a cloud server of a technology provider (with no in between logic), who ensures seamless transmission of data from analysers to central server located at SPCB/CPCB. In this context technology provider is an agency who provides data transmission service in transparent manner ensuring high degree of integrity.

- c. Technology provider may be a manufacturer of analyzers or any technology service provider having capability of building such system.
- d. The cloud server of Technology Provider (TP) to meet the needs of local SPCBs, Industry and CPCB in implementation of CEMS.
- e. It shall be the responsibility of industry to choose appropriate technology provider to ensure seamless transmission of data to Central Server
- f. Central Server at SPCBs/PCC / CPCB to accept the data from Cloud Server of TP only if their system has requisite features to transfer direct data and also facilitate remote calibration.
- g. Data should be in encrypted format (tamper proof)
- h. The system shall operate on Open Application Programme Interface (API) protocol based on REST based technology.
- i. The system shall record all the monitored values and transfer 15 minutes average value to DAHS. The system shall have provision to assess the momentarily values as and when required.
- j. Data validation protocol inbuilt with data quality codes to defined specification in DAS/DATA LOGGER.
- k. Cloud Sever of TP to meet the needs of local SPCBs, industry and CPCB

10.0 DATA ACQUISITION, MANAGEMENT AND REPORTING

Considering the heterogeneity of real time monitoring systems industries are required to submit real time data through their respective instrument suppliers. This mechanism shall help in consolidating the data avoiding the complexity of different technologies and availability of monitored data in different data formats while involving the instrument suppliers in data transferring mechanism. The system enables two ways communication required to manage such real time systems.

The functional capabilities of such software systems shall include:

- a. The system should be capable of collecting data on real time basis without any human intervention.
- b. The data generation, data pick up, data transmission, data integration at all servers end should be automatic.
- c. The submitted data shall be available to SPCBs/PCCs and CPCB for immediate corrective action.

- d. Raw data should be transmitted simultaneously to SPCBs /PCCs and CPCB.
- e. In case of delay in collection of data due to any reason, the data transmission should be marked delayed data and reports of delayed data should be displayed on the portal
- f. At no point of time, manual data handling shall be permitted. Data validation should be permitted only through the administrator and data changes recorded with date and time stampings.
- g. Configurations of the systems once set up (through remote procedure) and verified, should not be changed. In case any setting change is required it should be notified and recorded through the authorized representatives only.
- h. The data submitted electronically shall be available to the data generator through internet, so that corrective action if any required due to submission of erroneous data can be initiated by the industry.
- i. The software should be capable to verify the data correctness which means at any given point of time the regulatory authorities/data generator should be able to visualize the current data of any location's specific parameter.
- j. A system for data validation shall be incorporated in the software with fixed responsibilities of stakeholders;
 - Data Generator
 - SPCBs/ PCCs
 - CPCB
- k. Change Request Management: window for requesting data changes due to actual field conditions shall be provided by the industry in line to SPCBs/ PCCs to consider the request or not. The data validation/ changes can be incorporated after approval respective SPCBs/PCC or after one week of submission of request to SPCB/PCC. The environmental conditions around the site surrounding shall also be recorded along with other environmental parameters, as these have the potential to affect the monitoring system adversely and corrupt the data generated.
- l. System should have capability to depict data at the actual location of industry over the map. CPCB and or SPCBs/ PCCs shall develop a map based system for data integration at a single location.
- m. The software should be capable of analyzing the data with statistical tools

and shall have the following capabilities:

- Statistical data analysis (customizable) for average, min., max., diurnal variation, RSD, correlation, covariance, etc.
 - Comparison of parameters of different locations in user selectable time formats i.e. in graphical and tabular formats compatible to MS Excel, MS Word, *.txt etc.
 - Capability of comparison of data with respect to standards/threshold values.
 - Auto report and auto mail generation etc.
 - Providing calibration database for further validation/correction of data.
 - Transmitting data to different locations as per EC, CTE/CTO, and other directives in force.
 - Channel configuration for range, units, etc. as required for specific parameters and facility.
 - Providing data in export format on continuous basis through central/station computer system to other system.
- n. Data transmission through Leased Line (1Mbps) and Broadband with two medias supported which can be alternately used for data submission without fail.
- o. Data Storage for next five years.
- p. System should be connected to a backup power source with adequate capacity to avoid any power disruption.
- q. In case of dilution extractive systems, a mechanism to report dilution ratio maintained in the system should be reported alongwith data as a separate parameter to ensure dilution all the time.

11.0 SUMMARY

- a. The industries falling in 17 categories of highly polluting industries, Common Bio Medical waste and Common Hazardous waste incinerators have to install Continuous Emission Monitoring System.
- b. Industries other than 17 categories should consider installation of CEMS system as a tool of self-regulation.

- c. The G.S.R. 96(E) January 29, 2018 Notified by MoEF&CC under Environment (Protection) Act, 1986 mandates installation of CEMS with the Boilers used in the Industries namely Sugar, Cotton Textile, Composite Woolen Mills, Synthetic Rubber, Pulp & Paper, Distilleries, Leather Industries, Calcium Carbide, Carbon Black, Natural Rubber, Asbestos, Caustic Soda, Small Boilers, Aluminium Plants, Tanneries, Inorganic Chemicals & other such industries using boilers.
- d. The responsibility of data submission lies with the Individual units. The instrument supplier or manufacturer may facilitate data transmission on behalf of industries. Industry will ensure at least 85% data availability from the system installed.
- e. The Technology providers shall install their server in cloud and should send the real time data to CPCB, SPCBs servers or any Govt. bodies servers in consultation.
- f. The vendor/instrument supplier shall make provisions to provide data continuously at least at 04 locations in SPCBs/PCCs, RO/DO of SPCBs, CPCB, and industry directly from the analyzers.
- g. The plausibility control of data received shall be done. The team members will be responsible for validating, interpreting and interpolation of data on periodic basis.
- h. The vendor/instrument supplier will regularly cross check the data obtained from CEM system with that of the samples collected manually and analyze using approved laboratory techniques and revalidate the calibration factor essential for generating better quality data.
- i. The industries shall ensure that the monitoring systems are covered under Maintenance Contract with the vendors/ authorized Indian service partners of the instrument manufacturer after installation.
- j. The authorized Indian service partner/instrument manufacturer shall ensure that any problem in monitoring system/data acquisition and transfer system does not persist beyond 72 hours else it should be notified to SPCB & CPCB.
- k. The Technology Provider /instrument manufacturers shall ensure availability of spare parts for atleast 07 years after installation of the system.

- I. Role of manufacturers/supplier authorized Indian Service Partner:
 - Supply and install equipment suitable to monitor the emission in the available matrix
 - Supply all the supporting equipment, analyzers and software
 - Supply equipment/instruments capable of monitoring/measuring the parameters identified in the range of occurrence in the industrial unit
 - Supplied software should establish two-way communication sending diagnostics of instruments on demand, with central servers at SPCBs/PCCs and CPCB
 - The software should be capable of transmitting the data along with diagnostics of the instrument
- m. CPCB empaneled laboratories shall only be engaged as third party agency for all activities related to assessment of installation, calibration of CEMS, validation of data, etc However, till the time such empanelment is done, industries can use their own laboratories if these are EPA approved or NABL accredited (respective parameters shall be included in scope for accreditation) else may engage an EPA approved or NABL accredited (respective parameters shall be included in scope for accreditation) external lab.
- n. Industries shall not carry out the performance audit of OCEMS on their own or through the labs engaged for the routine calibration and data verification activities.
- o. Performance audit shall necessarily be carried out by the empaneled third party independent laboratory other than already engaged for routine calibration and OCEMS data verification.
- p. Industries have to inform SPCBs/PCCs and CPCB through online system at cems.cpcb@nic.in via email providing date and time of visits of the lab engaged for the calibration, data verification, performance audit and other activities every time before starting the work.

12. Parameters for online monitoring as per Guidelines

Sl. No	Category	Emission Parameters
1	Aluminium	PM, Fluoride
2	Cement	PM,NO _x ,SO ₂
3	Distillery	PM
4	Dye and dye Intermediate	-
5	Chlor Alkali	Cl ₂ , HCl
6	Fertilizers	PM, HF, Ammonia
7	Iron & steel	PM,SO ₂ , NO _x
8	Oil refinery	PM,CO,NO _x ,SO ₂
9	Petro chemical	PM,CO,NO _x ,SO ₂
10	Pesticides	-
11	Pharmaceuticals	-
12	Power Plants	PM, NO _x , SO ₂
	Thermal Power Plants	PM, NO _x , SO ₂ , Total Mercury(Gaseous)**
13	Pulp & paper	-
14	Sugar	-
15	Tannery	-
16	Zinc	PM, SO ₂
17	Copper	PM, SO ₂
18	Textile (GPI)	-
19	Dairy (GPI)	-
20	Slaughter House	-
21	Boiler	SO ₂ , NO _x , PM

** Online CEMS for Mercury may be applicable in case such condition is stipulated in EC issued by MoEF&CC / SEIAA

13. Formulae for Data Reporting

ANNEXURE II

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		$x \text{ }^\circ\text{C} + 273.15$	x = temperature in stack
05	Temperature at Analyser (T_m)	Kelvin		$x \text{ }^\circ\text{C} + 273.15$	x = temperature in stack
06	Standard Temperature (T_{std})	Kelvin	298	$25 \text{ }^\circ\text{C} + 273.15 = 298$	
07	Moisture (M)	%			
08	Moisture Fraction (Mw)	Ratio		(M) /100	
09	Wet m ³ to Wet Nm ³	Wet Nm ³		$x \text{ m}^3 * \{(P_{actual}) / (P_{std})\} \{ T_m / (T_{std}) \}$	x=volume measured by analyser
10	Wet Nm ³ to Dry Nm ³	Dry Nm ³		$x \text{ m}^3 * \{(P_{actual}) / (P_{std})\} * \{ T_m / (T_{std}) \} * \{ 1 / (1 - Mw) \}$	x=volume measured by analyser
11	Conversion of ppmw of any gas to mg/Nm ³	mg/Nm ³		$(x \text{ ppmw}) * (\text{molecular weight}) / 24.45$ x=value measured by analyser in Nm ³	All the instantaneous values required to be corrected in CEMS
12	Conversion of ppmv of any gas to mg/Nm ³	mg/Nm ³		$\{ (x \text{ ppmv}) * \{ (12.187) * \{ (MW) \} / \{ (273.15 + 25 \text{ }^\circ\text{C}) \} \}$ x=value measured by analyser in Nm ³	This is not applicable for CEMS as Pressure correction is not applied
13	CO ₂ Correction		12 % or as specified	$C_f = \{ x \text{ mg/Nm}^3 \} * \{ (12 / \text{Measured CO}_2) \}$ <u>Correction not needed wherever CO₂ is > 12%</u> <i>C_f=correction factor</i>	All the instantaneous values required to be corrected in CEMS wherever mandated as per standard
14	O ₂ Correction		11%	$C_f = \{ x \text{ mg/Nm}^3 \} * \{ (20.9 - 11) \} / \{ (20.9 - \text{Measured O}_2) \}$ <u>Correction not needed wherever O₂ is < 11%</u>	All the instantaneous values required to be corrected in CEMS wherever mandated as per standard

				<u><i>C_f</i>=correction factor</u>	
15	O ₂ Correction		3 %	$C_f = \{x \text{ mg/Nm}^3 * (20.9 - 3)\} / \{(20.9 - \text{Measured O}_2)\}$ <u>Correction not needed wherever O₂ is < 3%</u> <u><i>C_f</i>=correction factor</u>	Applicable for gas and liquid fuel in Petrochemical industries
16	Combustion Efficiency			$\{(\%CO_2)*100\} / \{(\%CO_2 + \%CO)\}$	Applicable for Biomedical Waste Incinerator

S. No.	References
1.0	<p>CPCB's CEMS related Documents</p> <ul style="list-style-type: none"> i) Direction for installation of CEMS and CWQMS in 17 Categories 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	<p>USEPA Documents related to CEMS</p> <ul style="list-style-type: none"> a) Continuous Monitoring Manual b) 40 CFR Part 75: CEMS Field Audit Manual c) USEPA CEMS Performance Specification <ul style="list-style-type: none"> i) PS – 2 : Performance Specification for SO₂ and NO_x ii) PS – 3 : Performance Specification for O₂ and CO₂ 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 O₂ 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 <ul style="list-style-type: none"> 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	<p>EN Documents</p> <ul style="list-style-type: none"> 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	<p>UK Documents</p> <ul style="list-style-type: none"> a) RM:QG-06: Calibration of PM CEMS (Low Concentration) b) MCERTS : BS EN 13284: PM CEMS
5.0	<p>Standard Operating Procedure for Compliance Monitoring using CEMS – Abu Dhabi</p>