Air Emissions Guidance Note on CEMS maintenance and operation requirements (AG13)

Environmental Protection Agency Office of Environment Enforcement (OEE)

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1 Preface

The Office of Environmental Enforcement (OEE) is one of the five offices in the Environmental Protection Agency. The OEE's functions include the regulation of activities licensed under the EPA and Waste Management Acts. It is the policy of the OEE to provide information and advice, via published guidance to those it regulates, to secure environmental improvements, while ensuring value for money.

This Air Guidance Note on the use of continuous emission monitors in processes not requiring the use of EN 14181 is one of a series of guidance notes that the OEE has published on the general theme of air pollution monitoring. A forerunner to this document is Guidance Note No. AG1 Air Emissions Sampling Facilities which describes the facilities that must be provided for the safe and effective monitoring of emissions, and the Air Emission Monitoring Guidance Note (AG2) which is aimed at improving the overall quality of stack emission monitoring by emphasising best practice standards and techniques.

The guidance note is intended for use by all Agency staff involved with regulated plant (e.g. licensing and enforcement staff), the licensed operator, and testing laboratories that provide an air emissions monitoring service. The document is intended to give clear and practical guidance on how to use Continuous Emission Monitoring Systems (CEMS) in Ireland, which is mainly based on an interpretation of the experiences to date in the rest of Europe.

This is the first version of this guidance note to be published.

1.1 Revision of this document

This guidance note may be the subject of periodic review and amendment. The most recent version of this note is available on the Agency website: http://www.epa.ie/downloads/advice/air/emissions/ If you have any queries on this document then please contact airthematic@epa.ie.

1.2 Abbreviations

AMS	Automatic monitoring system
BAT	Best Available Techniques
CEMS	Continuous Emission Monitoring system – alternatively referred to as Automated monitoring System (AMS)
CPCB	Indian Central Pollution Control Board
DAHS	Data acquisition and handling system
EA	Environment Agency (England)
ELV	Emission Limit Value
EPA	Environmental Protection Agency
FTIR	Fourier Transform Infrared (measurement technique)
IE	Industrial Emissions (category of licence)
IED	Industrial Emission Directive
IPC	Integrated Pollution Control (category of licence)
NDIR	Non-dispersive infrared (measurement technique)
OEE	Office of Environmental Enforcement
PM	Particulate Material
PVR	Petrol Vapour Recovery Directive
SRM	Standard reference measurement/method
TOC	Total Organic Carbon
TRS	Total Reduced Sulphur
VOC	Volatile Organic Compounds
VRU	Vapour Recovery Unit
WMA	Waste Management Act

1.3 Definitions and Explanations

Term	Explanation
Alarm	Can be a visual and/or audible warning of an unacceptable condition.
Calibration	Setting the CEMS to a known value provided by a reference material, e.g. Calibration gas. This involves adjustment of the CEMS to match the reference value.
Isokinetic Sample	Collecting a sample at the same flow rate as found at the sample point. This ensures that there is no bias in the sample. Especially for particulate material where there can be ranges of sizes which are influenced differently by the flow of the gas stream that they are in.
Hydraulic duct diameter (d_h)	Calculated $d_h = \frac{4A}{p}$ where : A= Area (m^2), p = perimeter (m)
Sampling plane	The plane within a duct where measurements are made.
Sampling point	The point within a sampling plane, from which the sample is taken.
Zero & span checks	Record of the response of a CEMS against a known concentration of span and zero gases. No adjustments are made.
Zero gas	Either Nitrogen (99.999%) or synthetic Air (British Technical Council Certification Standard- BTCA).

2 Introduction

The objective of this guidance document is to provide information, and an understanding of Continuous Emission Monitoring Systems (CEMS), also known as Automatic Monitoring Systems (AMS), their applicability, and how to utilise them in accordance with best practice. Consequently, to provide confidence in data produced and enable operators to demonstrate compliance with licence requirements.

Example arrangements of stack and analysers are shown in Figure 1.

Figure 1 - Examples of Probes and Analysers[1]

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There are a number of steps that should be followed to ensure that a CEMS is providing data that is representative of the process being monitored. These steps are expressed in standards such as EN 14181. The application of this standard may be considered excessive for some processes, as it is only required for sites in the Power and Incineration sectors. But the principles of EN14181 are applicable to all CEMS. These principles can be applied at different levels of implementation. Importantly, this approach provides regulators with confidence in the data being presented, and also assists operators in achieving licence requirements.

The use of CEMS also has benefits for process operators in that they present an opportunity to control and improve processes as a result of the continuous nature of the data provided.

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[1] By Courtesy of SICK UK and Envea

The purchase and operation of CEMS is recognised as an exercise requiring investment and commitment. Consequently, the objectives of this guidance document are to:

- define the EPA approach and requirements for CEMS;
- provide operators guidance on how these can be achieved, provide information and explanations on CEMS, and the different technologies, best practice and its implementation;
- Provide guidance on the supporting activities needed, such calibration and maintenance.

2.1 Other EPA Guidance Documents

Other EPA guidance documents:

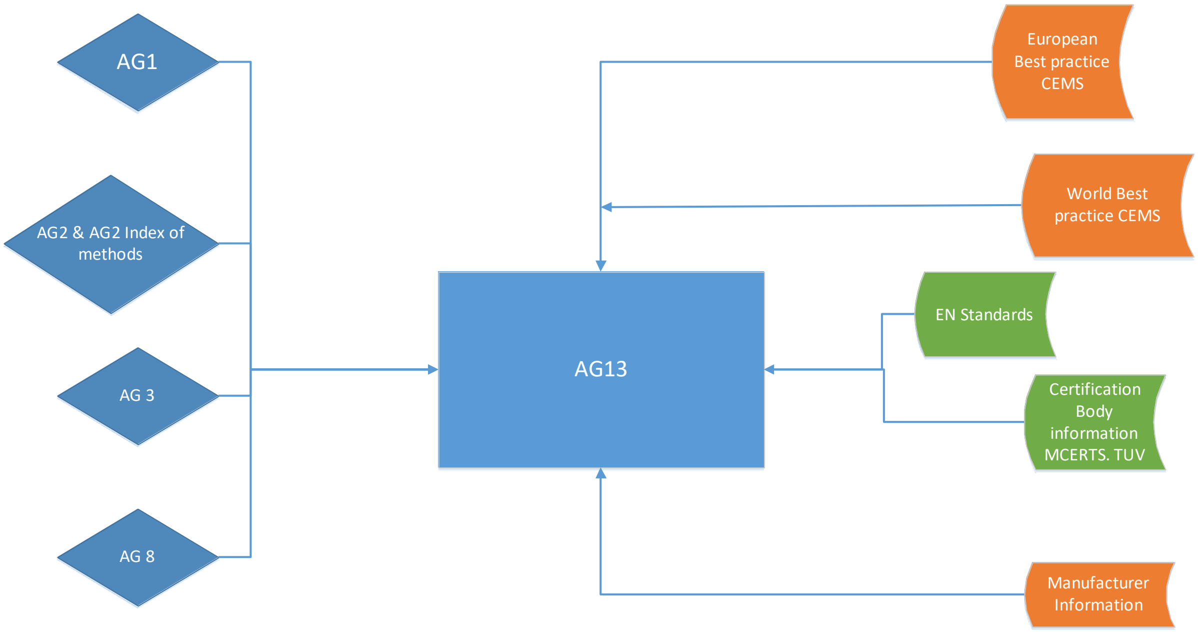
- AG1 Guidance Note on Site Safety Requirements for Air Emissions Monitoring;
- AG2 Air Emissions Monitoring Guidance Note;
- AG2 Index of Preferred Methods;
- AG3 Air Guidance Note on the Implementation of I.S. EN 14181;
- AG4 Air Dispersion Modelling;
- AG5 Odour Impact Assessment Guidance Note for EPA Licensed Sites;
- AG6 Surface VOC Emissions Monitoring on Landfill Facilities;
- AG7 Guidance Note on Landfill Flare and Engine Management and Monitoring;
- AG8 Air Guidance Note for In-house Air Monitoring Teams;
- AG 9 Odour Emissions Guidance;
- AG 10 Guidance Note on EPA requirements for calculation of flue gas volume flow rate from energy consumption using Annex E of ISO EN 16911-1;
- AG11 Guidance Note on monitoring of Stack Gas Emissions from Medium Combustion Plants;
- AG12 Alternative monitoring when continuous emission monitoring systems are off-line.

3 When do I need a CEMS?

The requirement for a CEMS is specified in the licence for the facility, which is developed from the European and national legislation, and where applicable, Best Available Techniques (BAT) and EPA guidance apply.

Figure 2 shows the sources of information used in the formulation of this document including other EPA Guidance, standards, certification schemes, and other useful sources of information.

Figure 2 – Information used



Key Licence points for CEMS operation:

- CEN standards must be used where available;
- CEMS must be operative at all times;
- The CEMS must be suitable for use on the licenced process;
- The data collected must be representative of the process emission;
- The CEMS must be calibrated as per standards or manufactures requirements, using traceable materials;
- The data produced must be to defined reporting requirements;
- CEMS must be operated in conjunction with the process, in accordance with the licence requirements, e.g. if there is a requirement that the process is not operated without an operable CEMS then there should be an interlock or system in place to ensure this happens.

3.1 Benefits of CEMS

There are a number of benefits associated with CEMS and their use, that are recognised by the EPA. These include:

- Provision of real time data to demonstrate compliance with regulatory requirements;
- Greater transparency in monitoring of performance;
- Checking of air abatement equipment;
- Time series analysis possible with continuous data;
- Expected better compliance through more rapid intervention by operators, hence lower emission;
- Capability to display data to a wider audience;
- Enable process optimisation and continuous control - improving efficiency and limiting environmental impact;
- Capability to make real time data available for viewing on a company website.

3.2 Principles for CEMS Use

There are a number of standards and specifications used throughout the world that constitute best practice. These are described in Appendix 1.

The regulatory objective for using CEMS is to demonstrate the compliance of a process to help to avoid, or minimise, environmental impacts of the activity. To enable this, any data produced by the CEMS must be representative of the process, and be of sufficient quality to provide confidence that the data produced is capable of demonstrating compliance. To achieve these objectives, a range of procedures and standards have been developed. The approaches developed are recognised as best practice and are applicable to other processes where CEMS are used. The same basic principles are used for CEMS used throughout the world, e.g. Europe, United States of America, India, Malaysia, Korea and China. These principles form the basis of this document, and include:

- CEMS Technology and equipment choice – The technology should be capable of providing data of sufficient quality. In the case of European Directives, specific quality criteria are defined;
- Measurement Location – Critical in ensuring data is representative of the process;
- Reference test comparison – Relates the CEMS output to data produced by a recognised standard reference methodology;
- Calibration – This provides a link to a traceable value/concentration, and is undertaken using gases and other reference materials;
- Calibration Checks, i.e. Drift checks – this demonstrates that the unit is continuing to provide data that is representative, and of significant quality to demonstrate compliance;
- Management system – Involves collection of information/documentation on the operation and performance of the CEMS, including service reports, maintenance reports, repairs, staff training and competency;
- Supplier support – required to enable CEMS to operate consistently, and for long periods;
- Data Validity – Clearly defined data requirements.

4 Legal Background

4.1 EPA Responsibilities

The EPA are responsible for the implementation and enforcement of environmental regulation in Ireland. The activities regulated by the EPA are described in a Schedule to the Environmental Protection Agency Act 1992 (as amended). Industrial sites are licensed under the Environmental Protection Agency (Industrial Emissions) (Licensing) Regulations 2013, SI 138/2013, the Environmental Protection Agency (Integrated Pollution Control) (Licensing) Regulations 2013, SI 283/2013, and the Environmental Protection Agency Act, 1992 (Control of Volatile Organic Compound Emissions Resulting From Petrol Storage and Distribution) Regulations 1997, SI No. 374/1997. Note that regulations are subject to amendment. Other regulations apply for waste incineration, large combustion plant and some solvents activities.

The EPA is responsible for:

- Advising applicants on licence applications;
- Consideration of the content of applications, and of comments from statutory and non-statutory consultees;
- Determination of applications, and drafting and issuing appropriate licences;
- Supervision of regulated activities including: Inspection, Considering and acting on information provided by licence holders under the IED, IPC, VOC (and waste) licensing regimes, and where necessary, enforcement of licence requirements in cases where operator performance is not satisfactory.

The licensing system differentiates between facilities which fall within the scope of EU Directive 2010/75/EU on Industrial Emissions (IED), facilities requiring Integrated Pollution Control (IPC) licensing, and those requiring a volatile organic compound (VOC) petrol storage permit. The Licence or permit sets out conditions for operation to manage environmental impacts of a facility. The licence is the legal basis for operation of the facility and sets the air emissions limit values, monitoring requirements, reporting conditions and other controls.

Petrol storage controls apply to terminals for storage and distribution of petrol. A summary of IED and IPC regulated activities[2] is provided in Table 1.

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[2] Based on information here : https://www.epa.ie/publications/licensing--permitting/industrial/ipc/First-Schedule-of-EPA-Act-1992-as-amended---V5-Peat-Regs-updates.pdf

EPA Act Schedule 1 Activity	IED BAT Conclusions	IED When are CEMS required?	IPC activity	IPC When are CEMS required?
Minerals and other materials	None		Various	No CEMS, Periodic monitoring
Energy	Large Combustion Plant	NOx, CO, SO_2, PM (non-gaseous fuels), NH_3 (if SCR/SNCR used), HCl for biomass or waste plant,	None	
Metals	Iron & Steel	PM (Electric arc furnace), other emissions depending on mass flow and impact.	Various	PM, for example, on main emissions where technically feasible (non-ferrous metals) PM (ferrous cupola, calciners, roasters, sinters) PM, NOx, SO2, HCl where significant impact, to monitor controls (iron/steel melting/production)
	Non-ferrous metals	PM and if a high emission Hg, HCl, NOx, TVOC, HF but not for all metal works.		
Mineral fibers and glass	Glass	PM, NOx, SO_2, NH_3 (if SCR/SNCR), CO. Can be periodic. Continuous surrogates.	Various	PM (asbestos) PM and TVOC (glass, mineral fibers) On main emissions where technically feasible (glass, glass fiber)
Chemicals	Common wastewater/gas treatment	Periodic monitoring.	Various	Where technically feasible or main emissions where technically feasible
	Large volume organic chemicals	CO, PM, NH_3, NOx, SO_2 (furnaces if total capacity >50MWth)		
Intensive agriculture	Intensive rearing of poultry and pigs	Periodic monitoring.	None	
Food and drink	Food & Drink	Periodic monitoring.		PM (above a flow threshold)
Wood, paper, textiles and leather	Pulp, paper and board	CO, NOx, SO_2, TRS (recovery boiler). PM can be periodic. NH_3 if using SNCR.	Board manufacture, synthetic fibers	PM where practicable (board manufacture), PM, organic/inorganic substances where technically feasible (synthetic fiber) TVOC for adsorption, condensation plant (textile processing)
	Wood-based panels	Periodic monitoring.		
	Tanning of hides and skin	TVOC (can be periodic)		
Fossil fuels	Refining of mineral oil and gas	SO_2, NOx, PM cat cracker, combustion units ≥50MWth. SO_2 on sulphur recovery unit. NH_3 where SCR/SNCR fitted. CO on cat cracker combustion units ≥100MWth		

EPA Act Schedule 1 Activity	IED BAT Conclusions	IED When are CEMS required?	IPC activity	IPC When are CEMS required?
Cement, lime and magnesium oxide	Cement & lime	Cement - PM, NOx, SOx, CO potentially TVOC, HCl, NH_3 Lime – continuous or periodic PM, NOx, SOx, CO potentially TOC, HCl, NH_3 Magnesium oxide -continuous or periodic PM, NOx, SOx, CO		
Waste	Incineration	NOx, CO, SO_2, HCl, PM, Hg, TVOC (NH_3 if SCR/SNCR used)		
	Treatment	Periodic monitoring.		
Surface coatings	Surface treatment using organic solvents and preservation of wood with chemicals	TVOC if ≥10kg C/hr release.	Coatings	TVOC (if >10 kg/h emission)
Other activities			Integrated Circuits	As required by licence based on impact, sensitivity, and scale of plant

Table 1 - Regulated Activities

Note: CEMS for Energy and Incineration activities are subject to separate guidance (AG3).

4.2 EPA IED licences

4.2.1 Best Available Techniques

The IED was implemented in Ireland in 2012, and the IED Annex I activities are listed in an amended First Schedule to the Environmental Protection Agency Act 1992. The IED aims to ensure that emissions from different industrial sources are dealt with in an integrated way, and prevented or minimised. Chapter 2 of the IED covers installations conducting activities listed in Annex I to the IED. These installations are required to apply Best Available Techniques (BAT) to avoid or minimise environmental impacts, and are required to operate according to a licence, issued by the EPA, reflecting the principles and provisions stipulated by the IED.

Environmental licences specify emission limit values (ELV), and other conditions which are based on the legal definitions of BAT, published by the European Commission[3] – the BAT Conclusions. The BAT Conclusions set out a range of elements which are considered to represent BAT for the activity, and include emission monitoring, and can include use of CEMS. Where BAT Conclusions are not yet in place (or do not provide BAT for an aspect of the activity), the BAT Reference documents (BREF notes) provide guidance for determining BAT and licence conditions. In addition to BREF notes for regulated activities, the European Commission has also published cross-sector guidance, including guidance on monitoring.

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[3] BAT Conclusions, BREF Notes and the Monitoring reference document can be downloaded here https://eippcb.jrc.ec.europa.eu/reference

Industrial sites with IED Chapter 2 activities are licensed under the Environmental Protection Agency (Industrial Emissions) (Licensing) Regulations 2013, SI 138/2013. Monitoring requirements may be defined in BAT Conclusions, or in guidance in the BREF note for the activity, or in the Monitoring Reference guidance.

4.2.2 Minimum requirements

Other chapters in IED set minimum requirements on specified processes, and these include emission limit values and monitoring. The activities covered by these chapters are outlined below:

- Large combustion plant (IED Chapter 3) – all large combustion plant will also be subject to BAT (Chapter 2) controls;
- Waste incineration plant (IED Chapter 4) – larger waste incineration/co-incineration activities will also be subject to BAT (Chapter 2) controls, all incineration and co-incineration plant within scope are subject to EPA licensing;
- Solvent activities (IED Chapter 5) - a few larger solvent activities will also be subject to BAT (Chapter 2) controls. Coatings activities using more than 10 tonnes of solvent per year are subject to EPA IPC licensing and the remaining smaller solvent activities are subject to Local Authority controls;
- Titanium dioxide (IED Chapter 6) - all such plant will also be subject to BAT (chapter 2) controls.

Separate guidance on CEMS has been developed by the EPA for large combustion plant and waste incineration activities[4].

IED Solvent activities which use less than 10 tonnes solvent per year are controlled by local authorities under the European Union (Installations and activities using organic solvents) Regulations 2012; above this threshold an IPC licence is required (or IED licence if the capacity exceeds the IED Chapter 2 threshold).

For an IED Chapter 2 solvent activity, the monitoring requirements are described in the BAT Conclusions for surface treatment using organic solvents. Continuous VOC measurements are required where the VOC release on a stack or vent is ≥10kg C/hr.

4.3 EPA IPC Licences

EPA IPC licences are required for the activities detailed in the First Schedule to the Environmental Protection Agency Act 1992 (as amended), and selected sectors with a requirement for CEMS in EPA Guidance are summarised in **Error! Reference source not found.**.

Continuous monitoring for the IPC activities will depend on operator engagement (for example using CEMS for process control), the EPA guidance, and whether continuous monitoring is specified in the licence. In general, there are no requirements in legislation for continuous emission monitoring for IPC activities, except on IPC solvent activities with a stack or vent with abatement equipment connected, and which at the final point of discharge emit > 10 kg/h of total organic carbon.

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[4] Air Guidance Note on the Implementation of I.S. EN 14181 (AG3) available here https://www.epa.ie/publications/compliance--enforcement/air/air-guidance-note-on-the-implementation-of-is-en-14181-ag3.php

4.4 EPA Petrol storage (VOC) permit

The Environmental Protection Agency Act, 1992 (Control of Volatile Organic Compound Emissions Resulting From Petrol Storage and Distribution) Regulations 1997 (SI No. 374/1997) implement Directive 94/63/EC on the control of VOC emissions from the storage and distribution of petrol (PVR 1). Application of CEMS and other monitoring approaches to petrol storage discharges requires consideration of the flammability of petrol vapours, including use of equipment which is certified for use in flammable/explosive atmospheres. In addition, the high concentrations (compared to emission concentrations from most other types of regulated source) mean that the CEMS applied for petrol storage sites have different characteristics from a CEMS applied at a combustion or manufacturing facility.

Annex II of the Directive sets requirements for loading and unloading installations at terminals including:

- A VOC emission concentration limit of 35 g/Nm^3 (over a one-hour period);
- Measurement methods to be decided by competent authorities in Member States (the EPA);
- Measurements shall be determined over the course of one working day (seven hours minimum);
- Measurements may be continuous or periodic (periodic measurements need a minimum of four measurements per hour);
- Overall measurement error ≤10%;
- Limit of detection ≤3 g/Nm^3;
- Precision must be at least 95% of the measured value.

These requirements are included in VOC or petrol storage permits issued by the EPA. Example conditions for CEMS include:

- A Continuous Emission Monitor shall be maintained on the VRU (Vapour Recovery Unit). The monitor shall be calibrated with propane on a bi-annual basis. A summary of the monitoring results shall be submitted to the Agency by the 1'' February each year. These results shall cover the previous calendar year.
- Data generated by the continuous emission monitor shall be recorded, and retained in digital format, for a period of three years. The data shall be available for inspection by authorised persons of the agency.

4.5 Greenhouse Gas Emission Trading Scheme

The EU Emission Trading Scheme (EU ETS) is implemented through the European Communities (Greenhouse Gas Emissions Trading) Regulations 2012 (SI 490 of 2012), as amended. EU Emissions Trading System (ETS) permits are managed by the EPA, and require a monitoring, reporting, and verification plan to set out how greenhouse gas emissions will be determined and verified. Monitoring for ETS can be based on a calculation approach, using fuel use and fuel analysis, or emission factors (typically applied for traded fuels such as natural gas, oils and coals), or a measurement approach applying a CEMS. A CEMS approach is unusual, but may be applied for non-standard fuels, or processes where fuel composition can change, or is uncertain.

4.6 Bypass Emissions and CEMS

The EPA protocol for bypass of air emission control equipment[5] sets out guidelines for operation of facilities with IE or IPC licences (excluding Large Combustion Plant). Operation of a process without air emission control would be outside the conditions of the licence, but may be necessary on occasions, for example to protect emission control equipment from damage, or to achieve a controlled shutdown of the process. Typically, during a bypass event, the pollutant emission concentrations would be expected to exceed emission limit values, and may exceed the upper operating limit of CEMS. However, if a separate bypass or 'dump' stack is used, the emissions may also bypass the plant CEMS.

Following a bypass event, the operator is required to notify the EPA of any ELV exceedance, and of any significant releases. If CEMS data are available for the bypass event then they can provide evidence of an exceedance of an ELV, and may help the operator to assess the significance of the release. However, if the licence does not require a CEMS on a bypass stack then the significance of a bypass event may be assessed by other means, including design or commissioning data for unabated concentrations/flow and, process monitoring data (damper position, temperature, pressure) for the period of operation of a bypass stack.

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[5] Available here : https://www.epa.ie/publications/licensing--permitting/air/Agency-Protocol-for-the-Bypass-of-Air-Emissions-Abatement-Equipment---2016.pdf

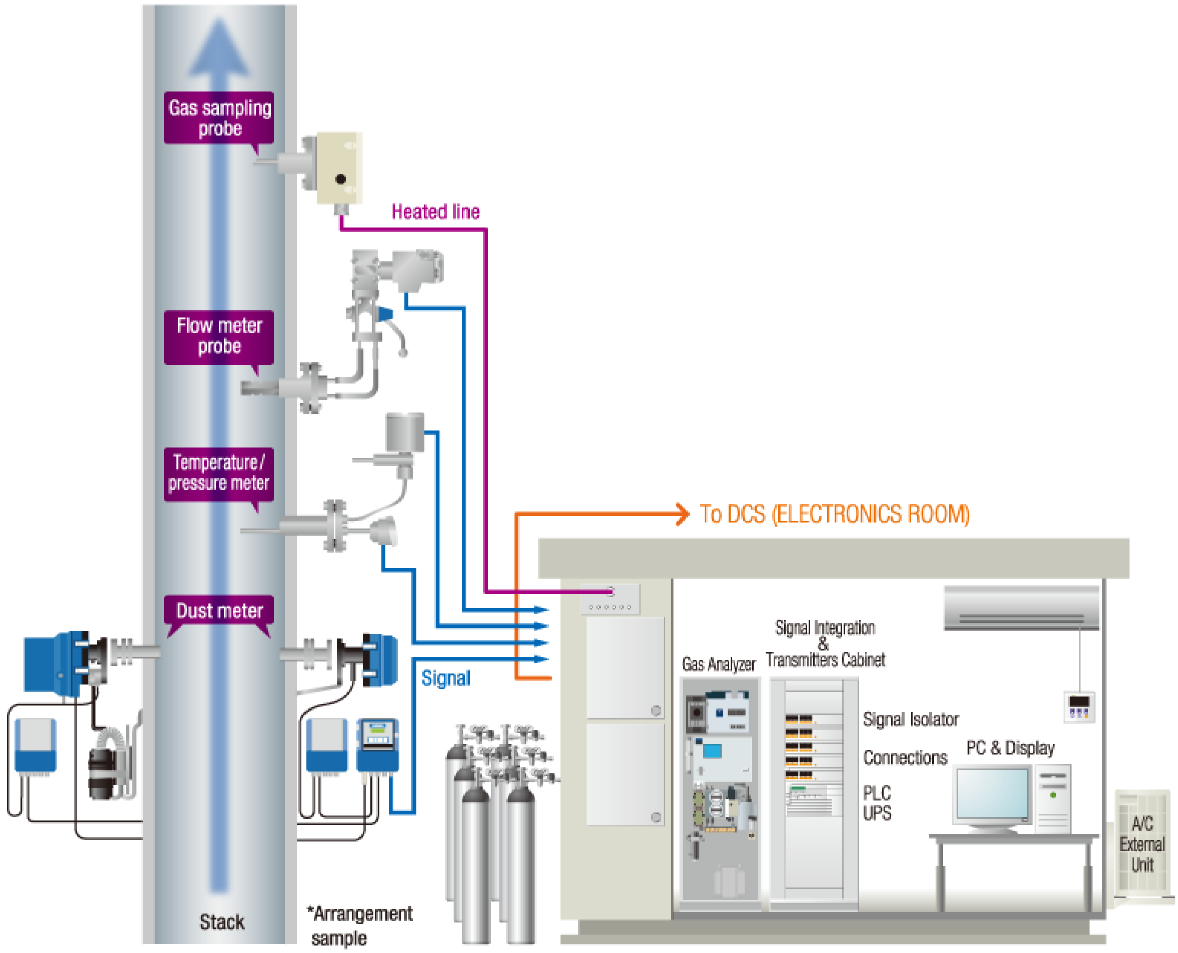
5 Fundamentals of CEMS monitoring

5.1 Introduction

CEMS are recognised as a way of capturing large amounts of data to illustrate the emissions from a process, including its variability. Consequently, CEMS provide an ideal way of monitoring the compliance of a process against a regulatory emission limit value (ELV), providing more scope for protection of the environment than occasional or periodic monitoring. In addition, CEMS provide opportunities for operators to monitor and control a process, improving efficiency, and providing early warning of issues with the process and abatement systems. CEMS carry out automatic measurements continuously. This is usually done via two different approaches:

- **Extractive stack-emission monitoring**, with sample removed from the duct, and passed to analysis instruments permanently located at or near the stack. An example is shown in Figure 3.

Figure 3 - Example of Extractive CEMS[6]



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[6] Courtesy of Horiba

- **Monitoring in the stack** – known as cross-stack or in-situ configurations, and are shown in Figure 4 and Figure 5 respectively.

Figure 4 - Cross Duct CEMS configuration

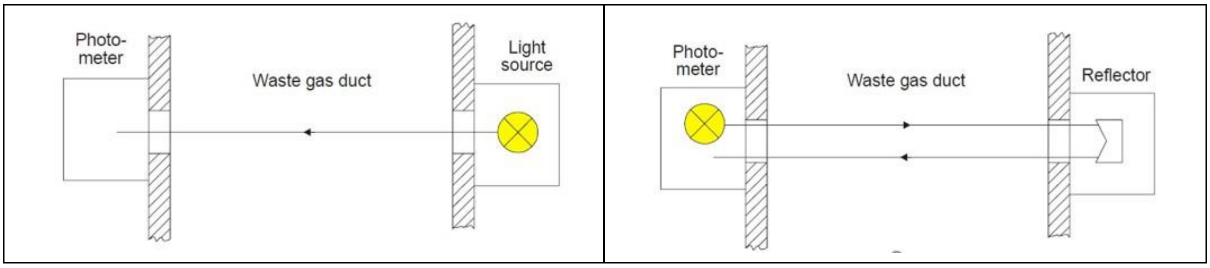
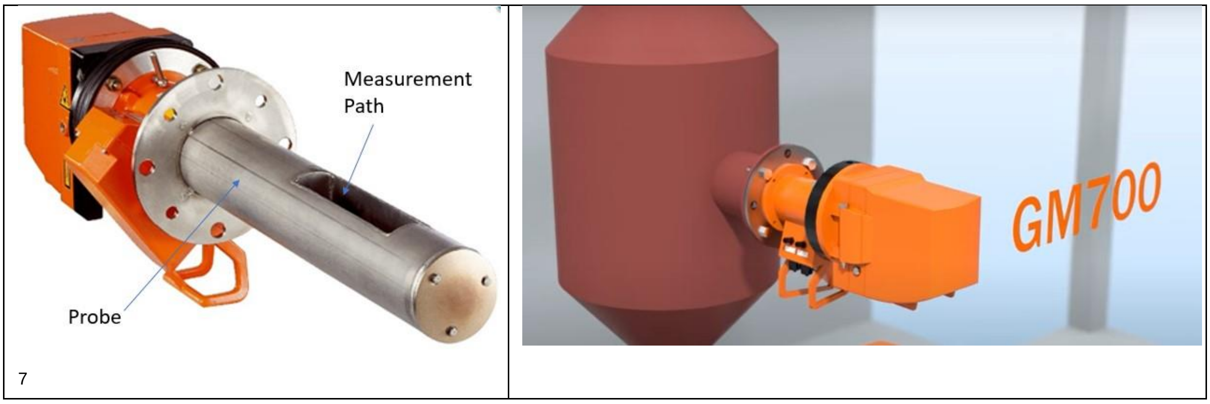


Figure 5 - In-situ CEMS



[7]

A summary of the typical configurations of CEMS is given in **Error! Reference source not found.**

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[7] Courtesy of SICK UK Ltd

Element	Cross Stack/Duct	In-situ	Extractive	
			Dry	Hot/wet
Installation	Installation requires access to both sides of the duct to enable the installation of a: • source on one side and detector on the other • Source and detector on one side and reflector on the other Requires services such as power and air to installed to the stack to power the complete system Data connection required at the stack Calibration gases are required Must be installed in a representative location Requires two dedicated ports	Installation requires access to only one side of the duct as measurement path is defined typically by an open area in a probe assembly. Requires power supply capable of powering the complete system at the stack. Calibration gases are required. Must be installed in a representative location. Requires a dedicated port.	Installation requires access to only one side of the duct to enable probe installation Requires power supply for probe Requires calibration gases to available at the probe Must be installed in a representative location Requires dedicated port	Installation requires access to only one side of the duct to enable probe installation Requires power supply for probe Requires calibration gases to available at the probe Must be installed in a representative location Requires dedicated port
Measurement path	Uses the duct as the measurement path	Measurement path is defined in a probe	N/A	N/A
Measurement location	Provides an average across axis of the sample plane. Must be representative of the emissions	Uses a relatively small area of the duct which must be representative of the emission	Single representative point in sample plane	Single representative point in sample plane
Sample Conditioning	None	None	Heated probe, heated filter, heated transport line, heated sample cell, pump or eductor, flow control system. Can be under negative pressure all the way through the system making leak checking very important	Heated probe, heated filter, heated transport line, Heated pump, particulate filter flow control system, heated distribution system, moisture removal. Usually under negative pressure prior moisture removal the positive pressure
Alarm systems	System failure e.g., source, Contamination of optics Maintenance mode	System failure e.g., source, Contamination of optics Maintenance mode	Heated probe, line temperature low, high and failure. Results in sample pump shut down and flushing of system with air/ nitrogen	Heated probe, line temperature low, high and failure. Results in sample pump shut down and flushing of system with air/ nitrogen

Element	Cross Stack/Duct	In-situ	Extractive	
			Low flow warning	Low flow warning Moisture sensors on detection of moisture shut down sample pump
Response time	Usually, rapid due to measurement being in stack and not involving transport of the sample prior to analysis Use for process control	Usually, rapid due to measurement being in stack and not involving transport of the sample prior to analysis Use for process control	Impacted by heated filter, length of heated line Standard requirement < 180secs	Impacted by heated filter, length of heated line Standard requirement < 180secs
Leak check	Instrument check not required as measurement is made in the duct. However, leaks in the mounting or the duct can influence the measurement	Instrument check required as measurement is made using a probe system with an open area. Any leaks into the probe can influence the measurement. However, leaks in the mounting or the duct can influence the measurement	Full System leak check i.e., from probe (ideally prior to filter)	Full System leak check i.e., from probe (ideally prior to filter)
Calibration using calibration gases	Required to provide calibration of system against a known traceable zero and span point	Required to provide calibration of system against a known traceable zero and span point	Required to provide calibration of system against a known traceable zero and span point	Required to provide calibration of system against a known traceable zero and span point
Calibration using reference methods	Required for dust measurement and when used on some regulated process e.g., IED	Required for dust measurement and when used on some regulated process e.g., IED	Required for dust measurement and when used on some regulated process e.g., IED	Required for dust measurement and when used on some regulated process e.g., IED
Correction to reference conditions	Requires additional sensors to measure oxygen, moisture (separate wet and dry measurements), temperature and pressure	Requires additional sensors to measure oxygen, moisture (separate wet and dry measurements), temperature and pressure	Requires additional sensors to measure oxygen, moisture (separate wet and dry measurements), temperature and pressure	Requires additional sensors to measure oxygen, moisture (separate wet and dry measurements), temperature and pressure
On-going control	Required on IED process Others regular span and zero checks to assess drift is recognised as best practice	Required on IED process Others regular span and zero checks to assess drift is recognised as best practice	Required on IED process Others regular span and zero checks to assess drift is recognised as best practice	Required on IED process Others regular span and zero checks to assess drift is recognised as best practice
Servicing	Required minimum annually	Required minimum annually	Required minimum annually	Required minimum annually

Table 2 - Comparison of CEMS typical configurations and requirements

As well as ensuring emission limits are met, CEMS can provide the process operator with the data to ensure that pollution abatement equipment is working properly, and provide immediate alarms, if there is a plant malfunction. This is particularly relevant for bag-filter arrestment plant, to control particulate emissions from industrial processes; CEMS can monitor for changes in the operation of dust arrestment plant (measuring trends of plant operation over time). By using CEMS for identifying potential leaks, this influences confidence in the data that can be used for simple process control. In terms of alarms, step changes can be seen from analyses for trends over time.

CEMS can provide both qualitative and quantitative data; it is recognised that under some circumstances, qualitative data is acceptable (depending on the pollutant, process, risk and historical compliance). A CEMS would usually provide quantitative data that can be used to demonstrate regulatory compliance. The change from quantitative to qualitative is usually a consequence of emissions being consistently well below ELV. This can occur with PM measurement, due to the high efficiency of some bag filter systems. As a result, the CEMS is effectively monitoring the performance of the abatement technology. Action limits at which intervention or corrective action must be taken and the associated measures are agreed by the EPA (e.g. replace bag filters).

5.1.1 Surrogate Measurements

In addition to conventional CEMS approaches, a system may monitor parameters of process operation, which are indirect indicators of pollution, such as differential pressure in a fabric filter, or carbon filter, or temperature of a thermal oxidiser. These surrogate measurements can provide indications that a process or abatement equipment are operating correctly, or more importantly, identify issues that could lead to pollution or an environmental impact. The use of surrogate measurements that provide information on abatement performance are used for qualitative purposes, rather than compliance with an emission limit value.

5.1.1.1 Bag House Differential Pressure Measurement

Differential pressure measurement across the bag house can be used to monitor the on-going performance of the system with a:

- Reduction in pressure, indicating the possibility of a bag or seal failure.
- Increase in pressure, suggesting that the bags are becoming blinded or blocked.

This measurement is usually installed as part of the bag house control system (to trigger maintenance actions or alarms), so is available to be used as an indicative tool to monitor the emissions.

5.1.1.2 Surrogate measurements used to monitor carbon beds

The primary indicator of the performance is the adsorber outlet VOC concentration. However, there are other indicators of adsorber performance that can be used, and act as surrogate measurements. These include inlet gas temperature, gas flow rate, inlet VOC concentration, pressure differential, inlet gas moisture content, and leak check monitoring.

- Reduction in pressure may indicating the possibility of channelling in the carbon bed, which reduces residence time, and the surface area of carbon available for emission control.
- Increase in pressure suggesting that the bed is becoming blocked with material, which will reduce effectiveness of abatement.

5.1.1.3 Temperature of thermal oxidisers

Thermal oxidisers are used for VOC or odour control, and are operated at a temperature to maximise destruction of the VOC or odorous compounds. Destruction efficiency will diminish if temperatures are too low. This can occur if the levels of VOC are low, if the oxidiser receives very high volumes of exhaust gas (or moisture in the exhaust gas), or if support burners do not operate effectively.

If the level of VOC is too high then the oxidiser temperature may increase beyond limits for acceptable operation, which can lead to overloading of the oxidiser.

5.2 Selection

The selection of a suitable CEMS for a specific process is critical for achieving representative data of adequate quality. The following criteria should be considered when selecting CEMS on a particular site or process:

5.2.1 Certified CEMS

There are a number of certification schemes around the world such as TUV and MCERTS. These schemes certify CEMS in accordance with EN 15267-3[8] (Performance criteria and test procedures for automated measuring systems for monitoring emissions from stationary sources). More information can be found in Section 10.1.

Industrial processes that are required to use certified CEMS often differ in their requirements, some flexibility is allowed in the selection of the appropriate sampling system use with the CEMS. However, the installed CEMS must not deviate from the type of sampling system, as used in the certification process, and described on the certificate, e.g. MCERTS or TUV certificates[9], such that it no longer meets the required performance specifications.

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[8] Available here : https://shop.standards.ie/en-ie/standards/i-s-en-15267-3-2007-869013_saig_nsai_nsai_2066519/

[9] CEM certification schemes include the Environment Agency's Monitoring Certification scheme (MCERTS) and the German TUV/UBA certification scheme, although other schemes may be available.

Allowable deviations include:

- A different length of sampling line to that which was tested;
- A different brand or model of sampling system, so long as there is evidence from third- party testing, or witnessed testing that the alternative components meet the required performance specifications, and have been tested on analogous systems. For example: an MCERTs certified permeation dryer[10] may replace an existing permeation dryer, however, a different dryer technology (for example a chiller-dryer) would not be accepted, unless its performance could be proved to be equivalent to the original, either through MCERTS testing or witness test data.
- Additional manifolds and heated valves used to allow more than one analyser to share a sampling system.

If there are more significant changes to the CEMS' sampling system, such that it could affect the quality of the data, the CEMS would no longer remain certified.

5.2.2 Suitability

The CEMS should be suitable for monitoring the determinands (pollutants) specified in the Licence or permit, some regulated processes require continuous monitoring to be certified, e.g. IED.

On processes that do not require this level of evaluation and certification, proven performance on similar processes can provide evidence of suitability.

5.2.3 Key performance Characteristics

The key CEMS performance characteristics against which a CEMS will be assessed by a combination of laboratory and field testing to demonstrate suitability include:

- lack-of-fit (linearity);
- cross-sensitivity to likely components of the stack gas, other than the determinand;
- influence of sample pressure and sample temperature;
- response time;
- detection limit (repeatability at zero);
- repeatability at span;
- influence of ambient conditions on zero and span readings;
- performance and accuracy under field conditions;
- reproducibility under field conditions;
- availability and maintenance interval under field conditions;
- time-dependent zero and span drift under field conditions;
- susceptibility to physical disturbances;
- design features.

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[10] A permeation dryer is a device in which the sampled gas passes through a tube with walls that are permeable to water molecules. There is a flow of dried air flowing outside this permeable membrane and the water molecules move from the sample gas into the air flow.
A chiller-dryer drops the temperature of the sample causing water molecules to condense. The condensate is collected and removed as quickly as possible to avoid the loss of soluble components.

5.2.4 Ranges

Ideally, the CEMS should be certified for a range that is suitable for the application. Generally, CEMS with lower certified baseline ranges will perform satisfactorily at higher ranges – a lower certified range generally indicates better CEMS performance.

Instrument operating ranges are different to certification ranges. These should cover the range of emissions from the process to ensure that all emissions data is captured, i.e. up to and beyond any emissions limit value (ELV) in order to consider potential ELV breaches. If the CEMS consistently goes over range then re-ranging must be considered to ensure that all data is captured, and the range is not influencing the reported data.

5.2.5 Stack gas conditions

The operator should ensure that specific site conditions (for example high moisture, high dust levels) do not negate the performance of the CEMS to below required standards. The stack conditions have a significant impact on the performance and operational life of the CEMS. Consequently, the design of the CEMS is critical, and may include heated filters, heated lines, filtration systems) so that it operates effectively at the process normal operating conditions. Suppliers should request details of the conditions of measurement, both in stack and ambient environment, to enable them to ensure that their system can operate in the required conditions.

5.2.6 Proven suitability - Validation

The operator is recommended to ensure that the intended CEMS is proven on comparable installations. Also, once a new CEMS has been installed, its outputs should be compared against reference methods, to demonstrate that the CEMS is providing representative data.

CEMS should include the means to allow operators, test laboratories, or suppliers, to perform zero, span, and linearity tests, once the CEMS have been installed.

5.2.7 Special provisions for particulate monitors

Generally, particulate monitors may be sensitive to changes in flow rate, particle size distribution, and changes in particle shape. Therefore, the operator should determine that the expected variation in process and stack conditions does not impact the integrity of the monitoring data.

5.3 CEMS Design

System design is an important part of a CEMS, to ensure the quality of the data provided by the CEMS is representative of the process. An extractive system provides an opportunity to condition the sample, prior to analysis. This conditioning can eliminate substances that can influence the analysis, e.g. moisture removal when analysis is undertaken by Infrared detection (IR), as moisture has a broad absorbance, which interferes with a large number of components. If system design does not reflect the actual stack and process operating conditions, then these factors can adversely affect the quality of data provided by the CEMS.

The following sections describe the components that make up a CEMS.

5.3.1 Enclosures

One important aspect of CEMS design is the enclosure in which the CEMS is housed. This provides protection, all services required for operation, and safe access. The complexity of the enclosure can vary from a simple cover through to a cabin. The selection of enclosure should consider the CEMS, the location, and the environment that the CEMS will be operating in. The design of the enclosure should consider the operating requirement of the CEMS, and health & safety issues to protect anyone working on the CEMS and the enclosure.

5.3.2 CEMS Components

An extractive CEMS comprises the analyser(s), and additional devices for obtaining a measurement result, including the sampling system.

There are several types of sampling system, and these can include some or all of the following components:

- Filters to remove particulate – in-stack, on the probe outlet, and elsewhere in the system;
- heated sample transport lines, coupled to heated analysers that measure gases in a hot, ‘wet’ (not dry) form;
- Heated lines and chiller-dryers, delivering the sampled gases to the analyser in cooled, dry form;
- Heated lines and permeation-dryer, delivering the sampled gases to the analyser in a dry form;
- Dilution systems (although these are rarely used);
- A stack-mounted probe coupled directly to a dryer, which passes the cooled/dry sample gas, via an unheated line, to an analyser;
- There may be NOx converters to convert NO_2 to NO in cases where the operator needs to monitor total NOx using an analyser, which measures NO alone.

In-situ CEMS techniques employ a “close coupled” analyser and probe, where the analyser is directly connected to the probe installed in-situ at the point of measurement (this can reduce problems associated with sample transport, filtration, and conditioning that may occur with extractive monitoring, especially heated extraction).

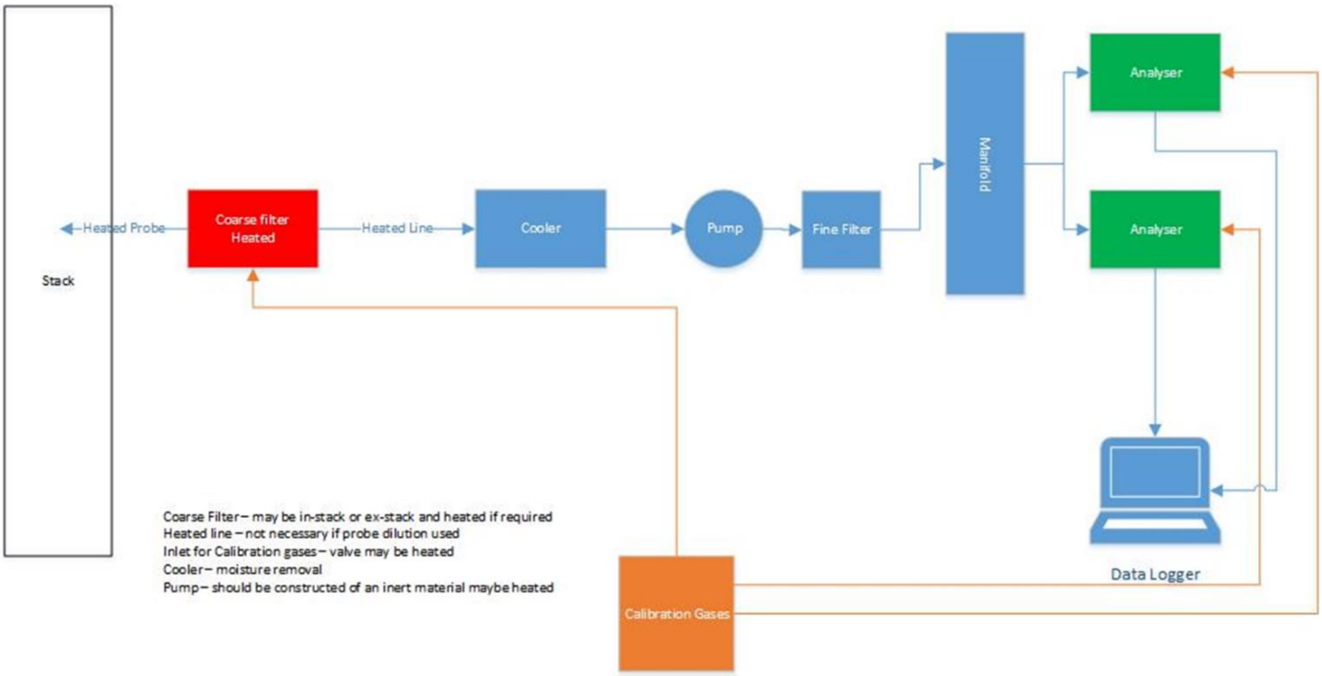
Cross-duct CEMS use the stack or duct as part of the measurement system. A light or other energy source is projected across the stack from one side to the other. Specified target gases or particulate in the exhaust gases absorb some of this energy at specific wavelengths allowing measurement.

There are many variations of these basic forms, and as analysers are typically designed for use with specific types of sampling system, the testing and subsequent certification will specify the CEMS components which were assessed.

Although a number of processes are not required to adopt/install certified CEMS, certification does provide useful information on the performance, capability, and applicability of a CEMS relative to a process.

A CEMS for gaseous components comprises a sample probe, filter, sample transport system, usually a conditioning unit (e.g. cooler which will remove particulates, mists and water vapour from a gas stream without the loss of analyte gases), analytical unit, and a data handling system. All components of which have an impact on the quality of measurement. The conditioning unit is required to ensure that the impact of interfering substances (such as water when using infrared detection) are reduced to a minimum, without reducing the accuracy and precision of the measurement made. A typical CEMS set up is illustrated below in **Error! Reference source not found.** and Figure 7.

Figure 6 - Typical CEMS Set up Illustration



Coarse Filter – may be in-stack or ex-stack and heated if required
Heated line – not necessary if probe dilution used
Inlet for Calibration gases – valve may be heated
Cooler – moisture removal
Pump – should be constructed of an inert material maybe heated

Figure 7 - Typical CEMS arrangement[11]

5.3.3 Sample transport and conditioning

The control of the gas sample in any sample system is critical to ensure that the sample analysed is the same as that taken from the stack.

The systems can include heated sample lines and probes, and pump control. The management of the system is important to avoid sample transformation, to prevent blockages, and any damage to analytical hardware. Automation of CEMS is utilised in some systems, so that if a heated filter or line fails, moisture is detected, or there is an increase in pressure or decrease in flow, then the system goes into a self-cleaning, purge mode, and alarm mode. These systems are designed to maintain operation and the quality of data.

Heating of these components prevents condensation, and possible loss of soluble components, e.g. HCl and VOC’s during transport from the probe and heated line, to the analysis stage.

Maintenance of sample transport and conditioning systems is critical to ensure that each of the components are operating correctly, and there are no leaks in the system.

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[11] Courtesy of SICK UK

Collection and initial conditioning of sample occurs at the sampling probe:

- Probe and heated filter:
  - can become blocked by particulate, which restricts the flow to the analysers;
  - leaks can occur at joints/seals, or due to corrosion. If these are external to the stack, these will result in air being drawn into the system, diluting the sample, making it non-representative of the process;
  - heating can fail, which can lead to condensation at the filter or filter housing. This can result in blockage, and the loss of soluble components, such as acid gases, which can lead to corrosion within the filter.

In extractive CEMS, the collected sample is usually further conditioned in some way, before it is analysed. It is important that any conditioning carried out to make the gas compatible with the analysis method does not alter the substance being monitored.

This conditioning usually occurs:
- during transport to the analysis stage;
- just before analysis.

Some examples of sample conditioning during the extractive monitoring of gases include:
- using a particulate filter in the sampling probe, prior to the analyser. This prevents particulate matter depositing further downstream in the heated lines, and also prevents particles from entering the analyser, where they can influence the analysis by reflecting light from reaching the detector and depositing on internal surfaces. **Error! Reference source not found.** is an e xample of a heated probe assembly. This is made up of a probe and a heated filter to remove PM, before transport via heated line. It is best practice to inject zero and calibration gases into these assemblies.

Figure 8 - Typical Heated sample Probe[12]

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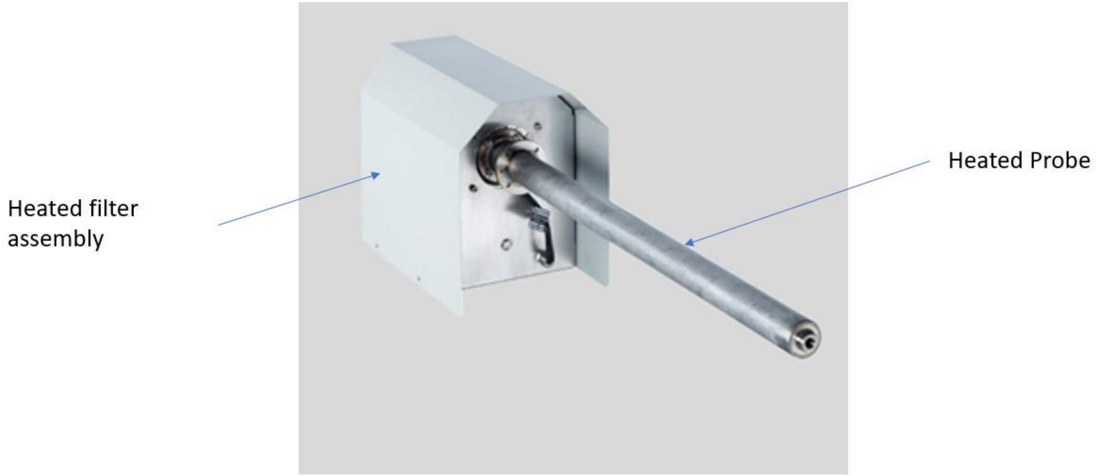
[12] Courtesy of SICK UK



- a heated sample line to prevent condensation during transport from the probe to the analysis stage. Condensation can result in the loss of soluble components, such as HCl, SO_2, and potentially semi-volatile organic compounds.
- system to remove moisture from the sample, using for example, a cooling system or permeation drier. Figure 9 shows an example of a cooler and condensate pump system that removes moisture from a sampled gas stream.
- dynamic system to dilute the sample by a known factor to below its dew point.

Figure 9 - Typical Gas conditioning unit - cooler and pump system[13]

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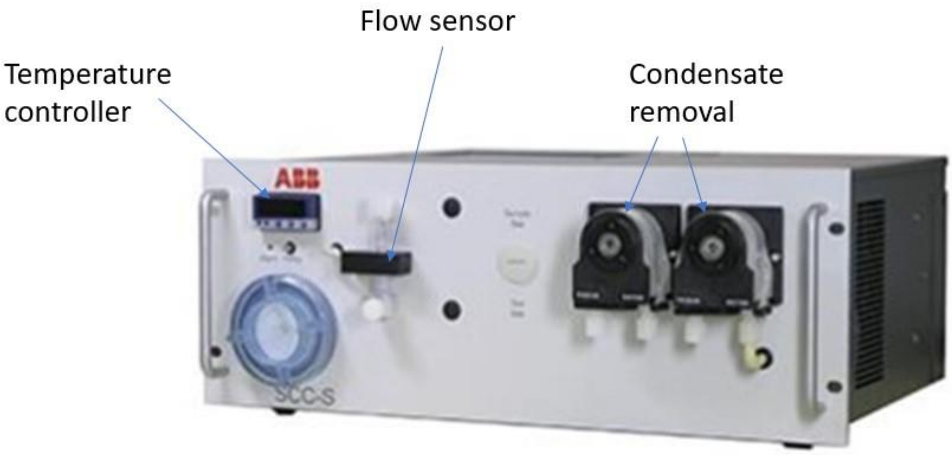
[13] Courtesy of ABB



5.3.4 Sample pumps

Sample pumps need to be constructed of inert materials, heated if necessary, and leak-free.

5.3.5 Manifold

Manifolds and automatic valves are used on the CEMS system, to allow more than one individual analyser to share a sampling system, to introduce calibration gases, and to backflush components to purge moisture or clean filters.

5.3.6 Summary of CEMS components

The typical sampling train requirements for extractive and in-situ CEMS are shown in Table 3.

Further information on the principles of CEMS measurement can be found in Section 6, Appendix 2, and Appendix 3, including applicable technologies of the CEMS (e.g. FTIR, NDIR, etc.), and what pollutants would be monitored, according to the type of process.

CEMS type	Parameters that can be monitored	Typical Sampling Train Components	Typical Corrections for Compliance	Typical Corrections for Mass Emission
Extractive Dry measurement	CO_2, CO, HCl, HF, H_2O, NO/NO_2, O_2, SO_2,	Sampling probe (can be heated) Gas conditioning systems Pumps Manifold/Connections Sample lines (can be heated) Filters NOx converter (if applicable)	Reference Oxygen *(O_2 and moisture corrections only needed in combustion processes and when the licence requires)*	Ensure that the measured pollutant concentration and the measured flow rate are at the same conditions, i.e. both dry, STP or both wet STP
Extractive	PM	Isokinetic sampling system heated	Pressure Temperature Moisture *The above may involve correction at the point of* ***measurement*** *which may be different to that in stack* Reference Oxygen *(O_2 and moisture corrections only needed in combustion processes and when the licence requires so)*	
Extractive Wet	CO_2, CO, HCl, HF, H_2O, NO/NO_2, O_2, SO_2, TVOC	Sampling probe (can be heated) Gas conditioning systems Pumps Manifold/Connections Sample lines (can be heated) Filters NOx converter (if applicable)	Moisture Reference Oxygen *(O_2 and moisture corrections only needed in combustion processes and when the licence requires so)*	
In-situ (Cross stack)	PM	Source and detector mounted on stack Air purges to keep source and detector windows clear	Moisture Temperature Pressure Reference Oxygen *(O_2 and moisture corrections only needed in combustion processes and when the licence requires so)*	
In-situ (Cross stack)	CO_2, CO, HCl, HF, H_2O, NO/NO_2, O_2, SO_2, TVOC PM Flow/velocity, stack temperature, stack pressure	Source and detector mounted on stack Air purges to keep source and detector windows clear	Moisture Temperature Pressure Reference Oxygen *(O_2 and moisture corrections only needed in combustion processes and when the licence requires so)*	

Table 3 - Typical sampling system requirements

5.4 Installation and Monitoring Location

Key points for the installation and monitoring location:

- Critical in ensuring data is representative;
- EPA Guidance AG1 - relating to location of Sample plane and Sampling points;
- Location requirements for PM measurement in EN 13284-1;
- Sampling profile criteria and assessment in EN 15259;
- Ports used for CEMS installations are in addition to the ports used for periodic monitoring, but should be approximately 1 m away for the sample plane used for periodic monitoring.

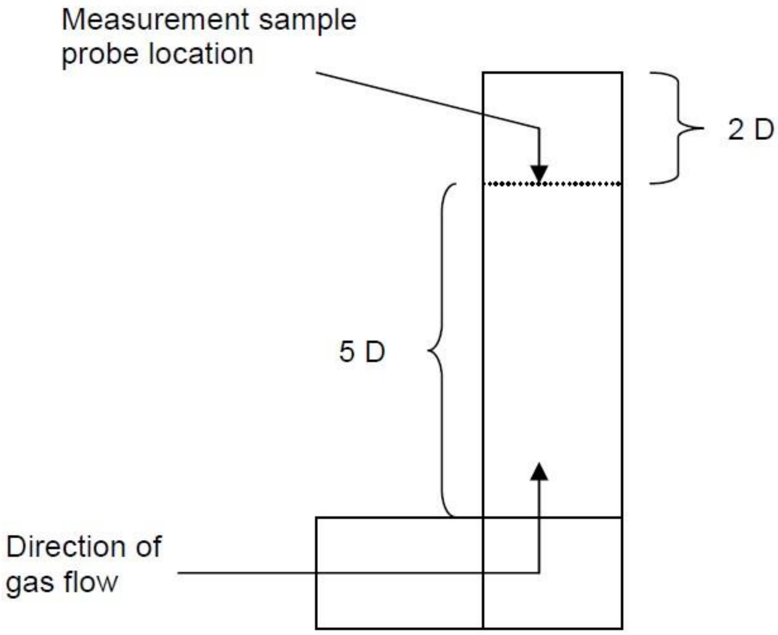
The installation of a CEMS has an influence on the quality of data produced, and also on the capability of the system to provide data representative of the process monitored. Consequently, there are standards supporting the location of the sample position, at which the CEMS collects/measures to ensure that the measurement is representative of the process (further details on this are provided below). This is critical, and as such should be adopted for all CEMS installations. These criteria are also adopted for periodic measurements, so should be relatively easily addressed for the use of CEMS. Note that periodic measurements are used to assess CEMS performance, so CEMS installation must not impact ability to undertake periodic measurements (for example blocking access to sampling ports or creating obstructions within the sampling plane), and periodic measurements probes must not affect operation of CEMS.

Stack emission measurements should be carried out at suitable locations, which have appropriate sampling ports and platforms. Positioning of sample locations to ensure representative sampling is more complex for sampling of particulate-based emissions (such as dust, metals, dioxins and furans), than for gases, because the distribution of gases in a stack tends to be much more homogeneous.

Standards suggest that sampling criteria is likely to be met when the following criteria are met:

- The sample plane positioned within a straight (preferably vertical) duct, of at least seven hydraulic duct diameters;
- At length of five hydraulic duct diameters from the entry into the straight section, and at least 2 hydraulic diameters from the exit of the duct/stack.

Figure 10 - Sample plane location



Where:

D = Hydraulic duct diameter

$$Hydraulic\ Duct\ Dia\ (m) = 4 \times \frac{Cross\ Sectional\ Area\ (m^2)}{Perimeter\ (m^2)}$$

The positioning of sampling locations for measuring gaseous species is usually straightforward. It will generally be sufficient to confirm that the gases are homogeneously distributed in the stack. The standard EN 15259 describes a procedure to determine whether the sample will be representative

- EN 15259 Air quality - Measurement of stationary source emissions - Requirements for measurement sections and sites and for the measurement objective, plan and report

Licence holders should employ an accredited test laboratory to confirm that CEMS probes are installed at the correct location, as confirmed by a homogeneity test, as described in EN 15259. This procedure involves taking grid measurements of the stack-gas at centres of equal area across the sampling plane, and comparing the results to a fixed reference point within the sampling plane.

The requirements described in EN 13284-2 should be considered on ducts where particulates and flow are required to be monitored. Further information is given in AG1.

- EN 13284-1:2017 Stationary source emissions - Determination of low range mass concentration of dust - Part 2: Quality assurance of automated measuring systems

Permanently installed CEMS are usually restricted to sampling at a single point, or along a single diameter/path. These sampling points or lines must be located, so that a representative sample of the pollutant is obtained. They must be positioned so as not to obstruct or affect (or be affected by), sampling probes used to perform periodic measurements.

The CEMS port should be positioned as close as possible to the locations to be used for their calibration (parallel and/or periodic measurements), but far enough away, so that they are not affected by sampling probes used for periodic monitoring; it is preferable for the CEMS to be downstream of the sample location used for periodic monitoring. EN 15259 has further information on the requirements for the CEMS port location.

Other location requirements for CEMS include:
- Being downstream from any abatement system;
- Being downstream from any merging ducts;
- Each CEMS should monitor a single stack/duct;
- As far from the final exhaust as practicable.

The installation of the CEMS should include appropriate protection for the system by means of enclosures, cabins, and shelters. When designing a platform for CEMS, access and facilities are required to enable:
- Calibration by periodic monitoring (where applicable), including space for probe and filter disassembly to allow for leak checks.
- Routine maintenance and operational functional checks, such as span and zero checks to be carried out (as required by the maintenance interval on the CEMS certificate, or the CEMS maintenance manual).

Non-compliant sample locations

In some circumstances, it may be difficult to follow the requirements for a representative position because of the sample location. There may be:

- limited straight lengths of duct/stack, to ensure that there is a homogenous profile;
- a non-homogenous profile at the sample plane, i.e. the profile does not meet the acceptance criteria for flow;

If it is not possible to relocate the plane to a suitable position, standard requirements for gaseous sampling is to undertake multiple point sampling across the profile. This is not possible for a fixed-point sampling system. There are options that should be considered, both of which start with the profile characterised by an ISO 17025-accredited monitoring contractor.

- Select a sampling point in the profile that is close to the average for the profile;
- Generate a calibration function for the CEMS relative to the whole profile, using reference methods;
- Consider the use of cross duct methodology.

5.5 Calibration

The following is a summary of the approaches that can be used in the calibration of CEMS:

- Calibration using calibration gases;
- Calibration using surrogates, e.g., diffraction gratings[14];
- Calibration against standard reference methods, e.g., used in accordance with the requirements of EN 14181[15] and ISO 10155[16] and best practice.

It should be noted that the requirements of EN 14181[17] are only mandatory for CEMS installed on plant governed by Chapters 3 & 4 of the IED, but may be considered part of BAT for IED Chapter 2 installations - for example EN14181 is mentioned for the continuous monitoring of TVOC in the BAT Conclusions for surface treatment with organic solvents.

5.5.1 Gaseous Components

5.5.1.1 Calibration

For calibrating CEMS without applying EN14181, the following provisions and steps represent best practise, ensuring that continuous data is accurate and compliant:

- Calibration gases (or surrogates where appropriate) used for calibrating (spanning) CEMS should be traceable[18]. In terms of calibration (span) gas concentrations, there are no firm rules on the actual concentrations; a recommended starting point is to use a span gas, which has a concentration of 80% to 100% of the pollutant’s short-term ELV. Alternatively, it is good practise to use a span gas that has a concentration of approximately 80% of the operating range that includes the relevant pollutant’s emission limit value. It should be noted that the higher the concentration, the more sensitive the span check will be to changes, whether these are random variations or systematic changes due to actual drift.
- There are three types of gas standards that are commonly used for the calibration of CEMS: unaccredited, ISO 6141 and ISO 17025. ISO 6141 defines the requirements for certificates disclosing the composition of pure gases and gas mixtures. Whereas ISO 17025 is the recognition of the process used to determine the composition, and hence data used within the certificate.

  Unaccredited gases should be avoided where possible (but note that not all components may be available to accredited standards). Site gases would normally be ISO 6141, whereas functional test gases and Test house calibration gases are ISO 17025. The concentrations used in each of the areas defined above are likely to be different.

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[14] Spectrophotometric methods are based on the identification of an element or compound by observing the characteristics of its absorption or emission of electromagnetic radiation (including InfraRed & Ultraviolet measurement principles). For dispersive CEM instruments, the radiation source has a wide spectrum and the band of interest (i.e. pollutant) can be selected by means of a diffraction grating.

[15] EN 14181 : Stationary source emissions. Quality assurance of automated measuring systems https://shop.standards.ie/en-ie/standards/i-s-en-14181-2014-861270_saig_nsai_nsai_2049041/

[16] ISO 10155 Stationary Source Emissions - Automated Monitoring of Mass Concentrations of Particles - Performance Characteristics, Test Methods and Specifications https://www.iso.org/standard/18150.html

[17] The EN1481 Standard provides a consistent approach for ensuring a CEMS is providing data of sufficient quality but may not be appropriate for all sites.

[18] Traceability should be according to ISO/IEC 17025 Testing and calibration laboratories: https://www.iso.org/ISO-IEC-17025-testing-and-calibration-laboratories.html

- The whole CEMS (including heated lines) should be checked using zero (typically Nitrogen) and span gases, in order to ensure the integrity of the system (no leaks). Zero checks ensure the CEMS is reading zero when there is no pollutant concentration within the CEMS.
- Initial span calibrations should be set at the pollutant concentration stated on the calibration gas cylinder certificate.
- Zero and span checks should be performed on a regular basis by the licensee or service engineer/manufacturer, to access drift of the CEMS, and therefore that the data quality is valid. **Ongoing calibrations should be on a regular basis, between 6 and 12 months, using calibration gases accredited to ISO17025, and carried out by a specialist service engineer/manufacturer**. A calibration report shall be produced by the specialist service engineer/manufacturer, detailing the results and performance of the CEMS.
- Maintenance and component checks should be carried out at defined intervals on a periodic basis. These checks should include the following components:
    - Sample probe;
    - Sampling line components;
    - Analyser sample cells;
    - Sample pumps;
    - Gas conditioning units;
    - Calibration control system.

5.5.1.2 Zero and Span Checks

These checks should be performed by the licensee, or service engineer/manufacturer, to ensure acceptable drift of the CEMS, and therefore that the data quality is valid. The period of checks can range from weekly to monthly. However, for periods longer than a month, the stability must be demonstrated with check data. On installation of a new CEMS, zero and span checking should start weekly, and then the period extended.

Importantly these checks do not involve any adjustment to the CEMS.

Zero and Span checks involve the injection of:

- Zero gas, until a stable reading is obtained, and the value attained recorded; followed by:
- Span gas, until a stable reading is achieved, and the value attained recorded.

The difference from the calibration gas used to set the analyser, and the values recorded during these checks is the drift. If this value is less than 2%, then no action is required. However, if the drift is greater than 2%, then the unit should be recalibrated, using the traceable calibration gas. The assessment of drift is further explained in Section 9.9.8.

5.5.2 Calibration of Particle Measurements

For the measurement of the mass concentration of particulate material (PM), it is essential that the device be calibrated on the process being measured. This is undertaken using a standard multipoint gravimetric reference method (for example EN13284-1), to correlate the output of the device with the obtained results. Variation in concentration across the sample plane is accounted for if multiple points are sampled.

PM is measured using a surrogate, such as light, and has a variable response to different particle physical characteristics, this calibration must be undertaken in the process. EN 13284-2 describes the quality assurance procedures for CEMS for the determination of particulate in flue gases.

This is typically undertaken annually.

5.6 Responsibilities

The operator is responsible for installing and operating CEMS that are fit for purpose, and that also fulfils the requirements set out in their licence.

The operator must ensure that the measurement equipment is suitable for the environment in which it is to be used, and regularly maintained and calibrated, so that it provides data that is suitable for assessing compliance, with regulatory requirements. The ongoing calibration and maintenance provisions of CEMS instruments require co-operation of a number of different parties. The following list clarifies the roles and duties of each stakeholder in the calibration and maintenance process:

- Suppliers and Manufacturers of CEMS:
    - Providing certification (certificates) for CEMS (where appropriate);
    - Appropriate and safe installing of a CEMS;
    - Co-operation with the plant operator calibration tests to devise an applicable test plan, and ensure a spread of emission concentrations (if possible);
    - Annual Service.
- Test Houses/Laboratories:
    - Maintenance of accredited Standard Reference Methods or other relevant tests for calibration methods;
    - Sampling or auditing the test results by other parties (if required);
- Industrial Plants / Process Operators:
    - Maintaining the CEMS in accordance with manufacturers' instructions and local procedures;
    - Performing ongoing calibration at defined intervals using calibration gases, as per the CEMS certificate maintenance interval, or as scheduled in the CEMS maintenance manual;
    - Providing reporting of compliance data, ongoing calibration to regulators;
- EPA:
    - Assessing operator compliance;
    - Assessing testing reports and organisations;
    - Providing guidance on relevant standards to use.

6 Principles of CEMS Measurement

6.1 Overview

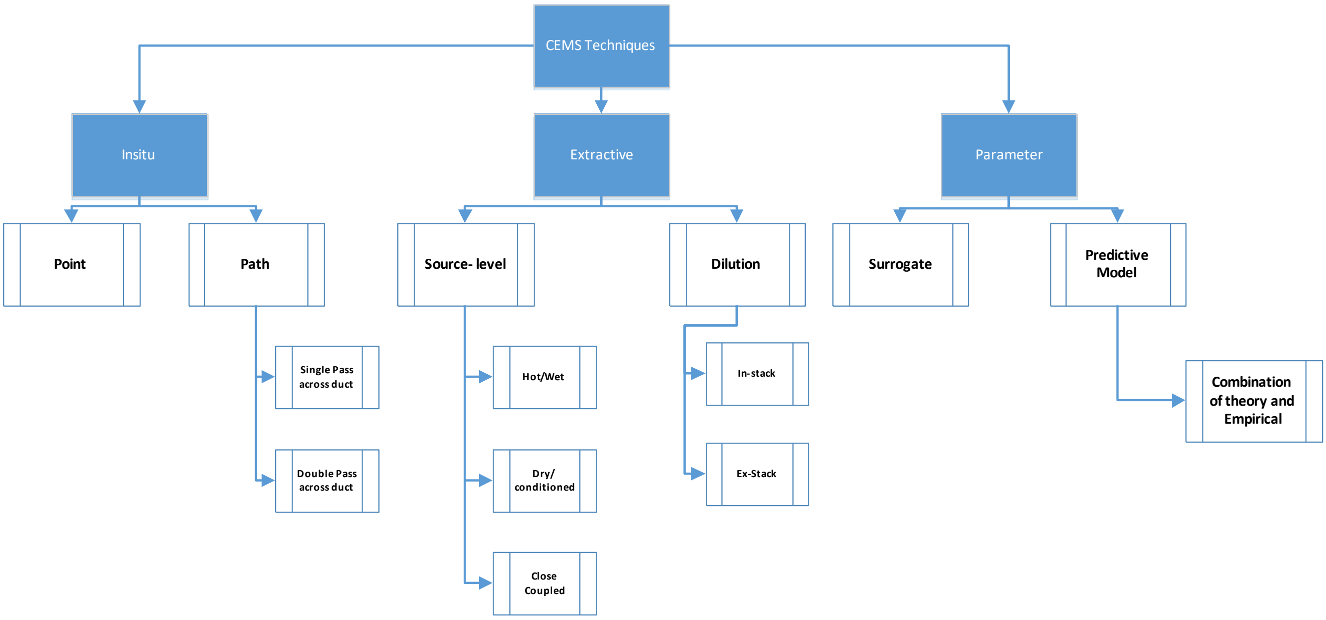
Descriptions of the detection principles utilise in CEMS are provided in Appendix 2 and Appendix 3.

Approaches to determining the presence and quantification of a species/pollutant utilise:

- the loss of energy, e.g. in the absorption of infrared radiation when measuring CO;
- the increase in parameter, such as a current as in an FID (TVOC) and Zirconia based analyser (O_2).

The common feature is that there is a relationship between the measured parameter, and the response of the detection method, and that this relationship can be quantified.
There are a number of techniques and configurations of CEMS that employ the various detection principles to measure various determinands in a CEMS. These are shown in Figure 11.

Figure 11 - CEMS Techniques/Configurations



The selection of the detection principle and system configuration is dependent on a number of factors:

- Process and the regulatory requirements;
- The physical characteristics of the gas stream being measured
  - Moisture content – will often determine the suitable detection principle, system configuration/design;
  - Particulate content –
    - determine the design of filtering prior to gaseous analysis
    - type of suitable PM analyser configuration;
  - Temperature – determine the materials of construction;
  - Pressure – Determines how the system is connected/mounted onto the duct, and the systems used to obtain a sample;
  - Presence of corrosive components such as HCl;

- Type and proximity to abatement equipment;
- Concentration of component to be measured.

All of these and other factors should be addressed as part of the supplier submission. There should be a system design phase, where the CEMS supplier gathers information about the process to be monitored. This requires input from the operator. Some suppliers will require a questionnaire about the process to be completed.

6.2 Particulate Monitoring

Particulate measurement is proportional to the impact on light, radiation, or charge that results from the presence of dust in a duct.

Key points for particulate CEMS:

- CEMS must be suitable for the application, i.e. for process conditions and characteristics of the particulate being measured;
- Certified CEMS may be used;
- All PM CEMS must be installed in a suitable location, which meets the requirements of EN 15259, EN 13284, and EPA guidance Document AG1;
- All CEMS must be calibrated on the process, using a reference method such as EN13284;
- When the particle size present in a gas stream significantly changes, the calibration function may no longer be applicable, where instrument response is dependent on size. An example is bag filter failure when larger particles can pass through the system.
- Zero and span checks must be incorporated into the CEMS, using surrogate approaches. For example, either internal reflections, application of a fixed charge/current, i.e. checks of the optics and electronics. Not to be confused with a zero-span check of a gaseous CEMS, where the component is measured. **These are checks ensure that the CEMS is operating correctly, and within acceptable limits;**
- Linearity checks can be undertaken using diffraction gratings that simulate loss of light across the measurement range;
- Staff involved with the CEMS must be suitable trained;
- Maintenance and servicing must be undertaken in accordance with manufacturers' requirements.

Table 4 provides a summary of factors that influence the use of different PM monitoring technologies.

Measurement Technology		Stack Diameter (m)	Concentration mg m^{-3}		Filter Type	Dry	Humid	Wet Droplets	Velocity dependant	Process
			Min	Max						
Probe Electrification	Charge induction (AC)	>0.5	0.1	1000	Bag, Cyclone, Scrubber	Y	Y	N	N 8-20ms^{-1}	Incineration Metals (e.g. Steel/Aluminium) Minerals (e.g. Cement/Gypsum) Chemicals (e.g. Detergent/Carbon Black) Power Generation Plant (e.g. Coal/Biomass)
	Combination AC & DC	0.2 – 2	1	1000	Bag, Cyclone	Y	Y	N	Y	Incineration Metals (e.g. Steel/Aluminium) Minerals (e.g. Cement/Gypsum) Chemicals (e.g. Detergent/Carbon Black) Power Generation Plant (e.g. Coal/Biomass)
Transmissometer	Opacity	2 - 10	30	1000	EP	Y	Y	N	N	Incineration Metals (e.g. Steel/Aluminium) Minerals (e.g. Cement/Gypsum) Chemicals (e.g. Refinery / Rubber) Power Generation Plant (e.g. Coal/Biomass)
Scattered Light	Forward		<0.1	300	Bag, cyclone, EP	Y	Y	N	N	Power, Cement and Metals smelting, and in processes without filtration
	Back		10	500	Bag, Cyclone, EP	Y	Y	N	N	Incineration Metals (e.g. Steel/Aluminium) Minerals (e.g. Cement/Gypsum) Chemicals (e.g. TiO2 / Coating Powder) Power Generation Plant (e.g. Coal/Biomass)
Extractive	Above	Independ						Y		Power Generation Plant, e.g. Coal/Biomass Incineration Metals e.g. Steel/Aluminium Minerals e.g. Cement/Gypsum Chemicals e.g. Detergent / Carbon Black Fertiliser Pulp and Paper

Table 4 - Summary of PM technologies and applications

6.3 Gaseous Components

The measurement of gaseous components can be undertaken using a number of different technologies and configurations. The overall objective is to undertake a measurement that is representative of the process being monitored. Also, that any measurement undertaken is of sufficient quality to ensure confidence in the data produced.

Key points for gaseous CEMS:

- Selection of a suitable CEMS (detection principle, configuration and system design) for the process is critical. This is achieved by:
    - Understanding the conditions and process to be monitored, e.g. moisture content, PM, temperature, and presence of corrosive gases;
    - use of CEMS certifications (MCERTS or TUV) as a guide;
    - Experience of other operators in the same sector;
    - Information from instrument suppliers/manufacturers.
- CEMS Must be installed in suitable location that meets the requirements of EN 15259;
- All CEMS must be calibrated using traceable calibration gases, in accordance with the manufacturers' requirements, and usually a value of approximately 80% - 100% of the ELV;
- The whole system from probe to analyser should be checked regularly by injecting zero and span gases at the probe, i.e. checking for leaks and system losses;
- Regular checks of zero and span points should be undertaken. **These are checks and do not require intervention unless they indicate that recalibration is required. They demonstrate that the system is operating correctly, and within acceptable limits;**
- All interventions must be undertaken by competent personnel;
- Annual servicing and preventative maintenance must be undertaken by a competent person.

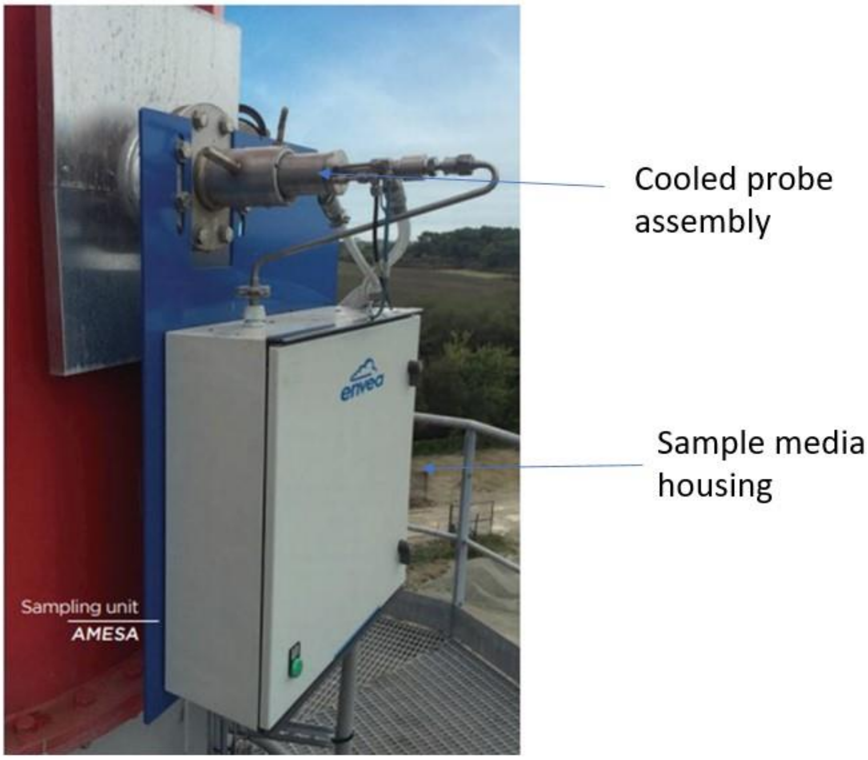
6.4 Continuous Samplers

These devices are not CEMS, as they do not provide data on a real time basis. However, they do enable particulate samples to be collected that provide a time average over the period of process operation. These systems have been used for the measurement of emissions of pollutants, such as dioxins and furans, and metals.

The systems are designed to sample isokinetically, by monitoring the flow at the sample point, and adjusting the sampling rate to maintain isokinetic conditions. They also are capable of operating over sampling periods of days to weeks, up to a month in duration. The sample is collected on a suitable media, which is then later analysed to provide a result. Consequently, the data is available retrospectively. However, it can demonstrate the continued long-term compliance of a process with emission limit values over longer periods than the short-term measurements used during periodic compliance monitoring.

These systems do not fully comply with the requirements of the relevant standard methods, e.g. EN1948 for Dioxins & Furans, as they only sample at one or two locations, and not the multiple points required. An example is shown in Figure 12.

Figure 12 - Example of a Continuous Sampler



6.5 Flow

Key points for CEMS including flow monitoring:

- Measurements made in accordance with EN 16911;
- Flow CEMS installed in locations that meet the criteria given in EN 16911 and EN 15259;
- Measurement of moisture, temperature, and pressure required, to correct volumes to STP (0°C, 101.3kPa) and dry gas;
- Measurement of Oxygen required, if correction to reference oxygen is required.

Emission limit values are usually reported on a mass concentration basis. The measuring instruments used for gas concentration produce output signals for concentration values in ppm or mg/m³. These measurements are concentrations under measurement conditions on a wet or dry basis.

To determine the mass emission rate, the referenced concentration is multiplied by the gas flow value. It should be noted that all flow monitors principally measure at stack conditions - on a wet basis, and at stack temperature and pressure; the gas flow must be standardised to the same conditions as the concentration data, before it can be used to calculate an emission rate.

Flue gas flow may be determined by direct measurement, and standards relating to the flow measurement include EN 15259 and EN ISO 16911-2[19]. If there are no flow monitors, flow can be calculated using process throughput parameters and emissions factors (including input material flows, input airflow and concentration of oxygen and other gases), depending on the type of process. This approach can be applied to processes other than power plant, such as chemical processes, where the volumes involved are known, and the reactions understood. EPA Guidance Note AG10 outlines the requirements for using this calculation method, based on energy consumption using Annex E of EN 16911-1.

The following monitoring techniques are currently used in stacks and ducts:

- Ultrasonic flow monitor;
- Pitot tubes – with differential pressure measurement;
- Averaging differential pressure probes;
- Thermal sensing;
- Infra-red cross-correlation;
- Vortex shedding flow meter.

The most common types of flow monitors used are ultrasonic, pitot, and averaging pitot.

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[19] BS EN ISO 16911-2:2013. Stationary source emissions. Manual and automatic determination of velocity and volume flow rate in ducts - Automated measuring systems https://www.iso.org/standard/57948.html

7 Appropriate Technologies

Table 5 provides a summary of technologies that are available to measure a number of particular determinants.

A summary of the detection principles is given in Appendix 2 and Appendix 3. The configurations in which they can be used, comments about its use, and typical processes on which the systems are used. This should not be taken as a recommendation or guarantee that a system will operate without issue on a process. The CEMS should be selected by an operator, in consultation with suppliers, other operators, other sources of information and the regulator.

Summary of points to consider when purchasing a CEMS:

- Devise a specification for the system, which should include:
    - Process description- typical emission concentrations, flue gas conditions, duct size;
    - Measurement requirements, as per licence requirements;
    - Describe the location;
    - Data collection and reporting requirements (to meet licence reporting requirements). Consider if there are any process supervision systems that could make use of the data, e.g. Bag failure warning, indication of process efficiency. Consider how to integrate this data;
    - Servicing and maintenance requirements;
    - Response to break downs – consider CEMS availability requirements. Will the process need to shut down if the CEMS not operating?
- Gather background information. What systems are used on similar processes? What systems have approval.

	B attenuation	Chemiluminescence	Contact Charge transfer	Contact Acoustical	Conductivity	Continuous Sampling	Differential absorption Spectroscopy	Derivative spectroscopy	Electrodynamic	Electrochemical Cells	Flame photometric	Flame ionisation	FTIR	Gas Chromatography	Gas Filter Correlation	High T electrochemical	Ion Mobility spectrometry	Light Scattering	Loaded Oscillator	Luft Detector (NDIR)	Mass Spectrometry	NDUV	Opacity	Paramagnetic analyser	Photo acoustic detector	Photo ionisation	Potentiometric analysis	Scintillation	Simple NDIR	Tuneable Diode :Laser	Ultraviolet florescence	Zirconia Sensor
TPM Ex																		x					x									
TPM In			x						x									x	x				x					x				
CO Ex							x	x		x			x		x										x			x	x			
CO In																														x		
CO$_2$ Ex													x		x										x			x	x			
CO$_2$ In							x																							x		
O$_2$ Ex								x		x														x								x
O$_2$ In																														x		
HCl Ex					x		x	x					x		x		x										x		x			
HCl In																														x		
HF Ex							x	x					x		x		x										x					
HF In																														x		
Hg Ex																																
Hg In																																
NO$_x$ Ex		x					x	x		x			x									x						x	x			

	B attenuation	Chemiluminescence	Contact Charge transfer	Contact Acoustical	Conductivity	Continuous Sampling	Differential absorption Spectroscopy	Derivative spectroscopy	Electrodynamic	Electrochemical Cells	Flame photometric	Flame ionisation	FTIR	Gas Chromatography	Gas Filter Correlation	High T electrochemical	Ion Mobility spectrometry	Light Scattering	Loaded Oscillator	Luft Detector (NDIR)	Mass Spectrometry	NDUV	Opacity	Paramagnetic analyser	Photo acoustic detector	Photo ionisation	Potentiometric analysis	Scintillation	Simple NDIR	Tuneable Diode :Laser	Ultraviolet florescence	Zirconia Sensor
NO_x In																																
H_2O Ex													x																			
H_2 O In																														x		
NH_3 Ext													x																			
NH_3 In																														x		
SO_2 Ex					x		x			x			x		x							x						x	x		x	
SO_2 In																																
Total VOC's Ext										x		x		x			x				x					x						
Total VOC's In										x		x		x			x				x					x						
Individual VOC's Ext													x	x	x										x				x			
Individual VOC's In													x	x	x										x				x			
Dioxins/Furans Ext						x																										
Mercury/Metals Ext						x																										

Table 5 - Applicable technologies for each component

Ext- Extractive, In- situ

8 Measurements for standardisation

Peripheral measurements are needed to correct or standardise the emission concentrations of pollutants, to standard reference conditions, to allow comparison with the emission limit value (ELV). The EPA licence will define the reference conditions required for reporting purposes. Standardisation to reference conditions is used to align measured concentrations to:

- Standard temperature and pressure 'STP', 0°C, 1 atmosphere (273.15K, 101.325kPa);
- Either dry, or 'as measured' moisture level;
- A reference, or 'as measured' oxygen content.

See Section 9.9 for details of corrections to reference conditions.

The requirement to correct measured concentrations to reference conditions may require additional sensors to be installed, and incorporated into the system.

The measurement data used for the correction of concentrations to reference conditions should come from the point of measurement/analysis, i.e.:

- The measured stack temperature, pressure, moisture, and oxygen, if an in-situ device;
- The measured temperature, pressure, moisture, and oxygen in the extraction loop, for an extractive PM monitor;
- Extractive dry analysers are usually calibrated using calibration gases that are certified at reference conditions of temperature and pressure. Also, the measurement is made dry, so it is needed to correct for moisture. Consequently, the only correction to be made is that of oxygen, if required by the licence.

  Note that some calibrations gases mass concentrations are certified at 25°C or 15°C, rather than 0°C. In this case, temperature correction is required.

8.1 Oxygen

For most non-combustion activities, oxygen standardisation is not required, because the pollutants are present in a discharge which is largely air. However, in combustion processes, oxygen standardisation is undertaken, because it allows normalisation of concentrations to a specific amount of dilution, or excess air in the flue gases. Standardisation to a fixed oxygen concentration allows comparison with an emission limit value, or between different plant.

Oxygen measurements are always required on combustion activities to allow this standardisation. Depending on the combustion process, the oxygen reference used can differ, and must be appropriate to the process in question. The normal running conditions of the process, the technology, as well as the type of fuel used, will determine the typical level of oxygen for standardization, for example:

- A gas fired, or liquid fuel boiler would use a 3% oxygen reference;
- Solid fuels use 6% (biomass may be 6, 10 or 11%);
- Waste incineration processes use 11%;

- Gas turbines use 15%.

Oxygen corrections are not required on processes such as chemical, casting, or petrol storage, i.e. processes that do not involve combustion.

8.2 Moisture

The presence of moisture occupies space that would, without moisture, be occupied by other gases. Therefore, the higher the moisture content of the stack gas, the higher the pollutant concentration, after it has been converted to a dry basis.

Water vapour concentration measurement is usually required when measuring pollutant concentrations on a wet basis.

Reference conditions are typically 0% moisture (dry), or at stack moisture levels.

8.3 Temperature & Pressure

Temperature affects an emissions concentration reading, due to the influence of temperature on gas volume. When measurements are made on a volume basis (for example CEMS measurement of gases), the changes in volume happen to both the measured gas, and the diluent gas, so a correction is not needed. However, concentrations are typically expressed on a mass per unit volume basis, and the temperature is usually standardised, so that volumes are on a consistent basis. Temperature and pressure of the flue gases is important to ensure that exhaust gas flow measurements can be adjusted to reference conditions (typically 273.15 K or 0°C, and 101.325 kPa).

9 Data

This section considers:

- Data collection;
- Verification of data;
- Valid data;
- Availability;
- Data Storage;
- Alarms/interlocks and;
- Calculations.

Typically, one-minute average data are used as the building blocks to derive other averages, e.g., half-hourly mean values for each required species/parameter. If the data is required to be at a specific reference condition, the half hourly mean values shall be converted to these conditions. The values are then stored along with the plant specific operating signals, i.e. plant status. These averages are then used to calculate for each calendar day, a daily mean value, related to the daily operating time, and any other average period required which should be stored. A facility complies with requirements, if the emission limits established in the licence or permit are not exceeded. If limits are exceeded, there is a requirement to report to the EPA immediately. Measurement results shall be kept on file by the operator for seven years.

Collecting and manipulating the data is a critical step in demonstrating compliance. Selection and installation of a Data Acquisition and Handling Systems (DAHS) enables data to be collected, manipulated, and reported effectively.

9.1 Data Acquisition and Handling Systems

DAHS are available in a wide range of complexities. The selection of DAHS is dependent on the requirements for data, data manipulation, integration with plant processes, and reporting requirements needed to demonstrate compliance.

There are a number of DAHS that have been certified under the MCERTS and TUV schemes. These have used a performance specification[20] and, more recently, EN standards.

- EN 17255-1 Stationary source emissions - Data acquisition and handling systems - Part 1: Specification of requirements for the handling and reporting of data
- EN 17255-2:2020 Stationary source emissions. Data acquisition and handling systems. Part 2 Specification of requirements on data acquisition and handling system

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[20] *Quality and Performance Standards for Environmental Data Management Software, Environment Agency Version 4 December 2017*

- EN 17255-3. Stationary source emissions. Data acquisition and handling systems. Part 3. Specification of requirements for the performance test of data acquisition and handling systems – Currently a draft

The EN 17255 suite of standards has been produced to support EN 14181, because the DAHS component of a CEMS had not been included in EN14181.

Some data handling systems can be very sophisticated (Figure 13), and are not necessarily appropriate for a smaller low risk process or facility, when a more basic system may be more appropriate. The licence requirements should be used to select an appropriate system. This will define:

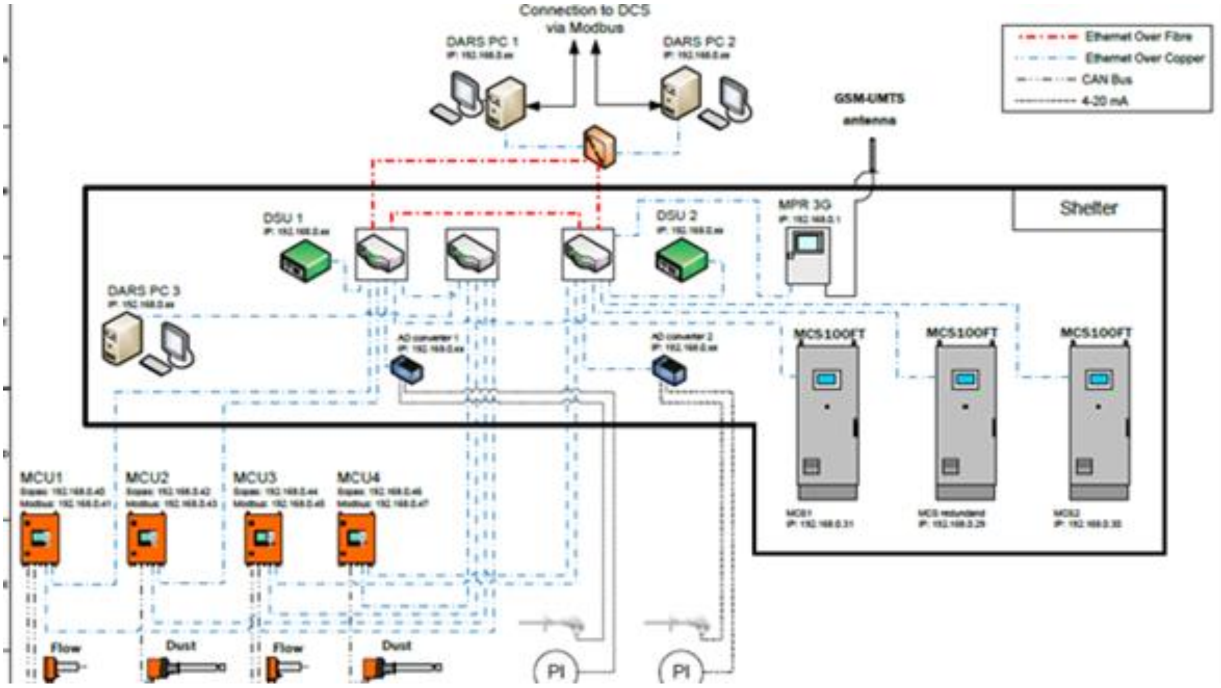
- Number of components to be recorded;
- Averaging periods, e.g. 30 mins, hourly and daily;
- Data corrections, e.g. conversions from ppm to mg m^{-3}, correction to reference conditions of temperature, pressure, moisture and oxygen where applicable (calculations can be found in Section 9).

Some packages can be configured by the operator, but it is recommended that this is done by the supplier, in conjunction with the operator. In addition, training shall be provided to staff, so that they can collect data, understand data processing steps, and production of reports.

DAHS must be used to collect and undertake the calculations required to demonstrate compliance. The selection of an appropriate system is the responsibility of the licence holder.

MCERTS and TUV Certifications include DAHS systems, and can be used to identify these systems that are designed to collect data in the manner required by EU directives. Figure 13 is an example of a complex CEMS and DAHS.

Figure 13 - An example of a complex DAHS[21]



9.2 Data Collection

The collection of data is critical to demonstrate the compliance of a regulated process. The basis of all of the regulatory requirements is one-minute averages. However, to ensure that these one-minute averages are statistically correct, a minimum sampling period of 1 reading every 10 seconds is required. Quicker sampling rates are acceptable.[22]

Consequently, the minimum number of data points that make up a one-minute average is 6. However, most DAHS are capable of collecting data at far higher rates than this, and consequently give the opportunity to collect up to a maximum of 30 data points in one minute.

9.3 Verification of Data

Verification of data during installation and operation is critical to ensure representative data. There are opportunities when the data on the analyser panel should be checked with data being collected. This is particularly necessary on older systems, which use analogue to digital converters. This should be done during commissioning, after any change to the CEMS or DAHS, and at regular intervals, to confirm that the data is correct. This comparison should be undertaken by the instrument supplier, or a certified testing organisation.

The data collected should be checked through from the raw data taken directly from the analyser, through to the final data. This should then be used to check the outputs from the DAHS. This can then be compared with the data reported by the DAHS. The steps of typical calculations used are given in section 8.5.

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[21] Courtesy of Envirosoft UK

[22] EN 17255 Stationary source emissions – Data acquisition and handling systems - Part 2: Specification of requirements on data acquisition and handling

The DAHS calculation steps in sequence should be documented, and be available for review by the EPA during site inspections. The calculations should be in order from raw data through to reported values:

- Collection of one-minute average (minimum data point every 10 seconds) raw data (as measured, without correction to STP dry reference oxygen). This should be un-editable. All subsequent data manipulations should be done on a copy of this data;
- Calculation of corrected values, i.e. to STP dry;
- Correction of STP dry values to reference oxygen if required;
- Determination of averages, i.e. 30min, hourly, and or daily.

9.4 Data availability

Data availability required from a CEMS is typically 95%, this means that for 95% of the time that the plant is operating, the CEMS must be collecting data. However, based on a risk-based assessment, this may be extended with the agreement of the EPA. The IED and other directive specifies availability requirements for CEMS. For a daily average value to be valid, an operator may discard no more than five half hourly average values in any day, due to malfunction or maintenance of a CEMS. This includes periods when the CEMS are out of calibration, or conducting zero and span checks. These definitions are used throughout EU directives.

9.5 Valid data

The EPA consider that 20 minutes of data in any given half-hourly, and 40 mins of data in an hourly average period is representative of a half-hour and hourly averages respectively. These are based on what is deemed statistically acceptable for a data set.

Consequently, it is possible to operate the CEMS to include periods of calibration, so that no data is invalidated by span zero checks or calibrations. This then means that daily averages do not need to be invalidated, when there is limited data missing. It is recognised that calibrations or span and zero checks are a critical part of ensuring the quality of data provided.

9.6 Data Security

Data Security is critical from both the operator and regulators point of view. Best practice is that:

- The raw data collected should be securely stored and un-editable, so that this data can always be used to recalculate results;
- Calculations are then undertaken on a copy of the secure data;
- Calculations should be in accordance with the licence requirements;
- Calculations used should be available for review;
- Any changes made to the data should be documented automatically with date and time stamps, so that these changes can be reviewed;
- Limited number of competent people should have access to the DAHS set-up configurations, data, and calculations.

9.7 Data Storage

Under licence conditions, data is required to be kept for seven years. This should include raw, calculated, and reported data. In addition, operational data that is required under the licence and impacts on emissions should be stored. This storage should be secure, and a copy should be retained in another location, in case of loss.

9.8 Alarms and Interlocks

There are number of metadata to accompany emission data from the CEMS that should be recorded with the DAHS. These include:

- CEMS in calibration;
- CEMS fault;
- CEMS maintenance mode;

In addition to these, there may be requirements that define when the process is operational, and that CEMS monitoring must be undertaken, e.g., feed on, temperature, and oxygen. These should be recorded clearly, along with the data, so that it can be seen that the process is on-line, and the CEMS is measuring the process operating.

It is important that all licence conditions relating to CEMS and their use are fully understood. As an example, a licence may require that the process is shutdown, if the CEMS is not operational, or has failed. Consequently, a system, e.g., interlocks must be put in place that prevents operation, until the CEMS is returned to operational status. It is important that any such requirements are clearly understood and considered, during the design of the monitoring system.

The data collected and the DAHS provides an opportunity to monitor the process relative to the licence ELVs, by setting warning and alarm limits. These can be set at a level based on the experience of the operators, in combination with measured data. This combination is useful in that there are some processes that when a certain level is reached, it is not possible to control the process, to avoid a breech. So, by setting the alarm at a level prior to this point, it gives the possibility to control the process prior to this. An example would be to set the alarm level around 80% of the ELV.

9.9 Calculations

The following sections provide the calculations and worked examples commonly used to convert data for measured conditions to those required for reporting.

Note that EPA has published a basic calculation spreadsheet with many of these calculations here : https://www.epa.ie/publications/compliance--enforcement/air/correction-of-concentration--volumetric-flows-calculator.php Also, the EPA has published guidance within Air Guidance Note 2 on calculations and standardisation here: https://www.epa.ie/publications/compliance--enforcement/air/Emission_Monitoring_Guidance_AG2_May2018.pdf (Appendix 3).

9.9.1 mA to either ppm or mg m^{-3}

Some CEMS utilise analogue outputs, e.g., mA, which are related to the concentration being measured. There are typically two ranges of mA used. These are 0-20mA and 4-20mA.

Converting 0-20mA output use the following:

$$Concentration\ (ppm\ or\ mg\ m^{-3}) = \frac{Analyser\ Measurement\ Range}{20} \times mA\ (measured)$$

Converting a 4-20mA output use the following:

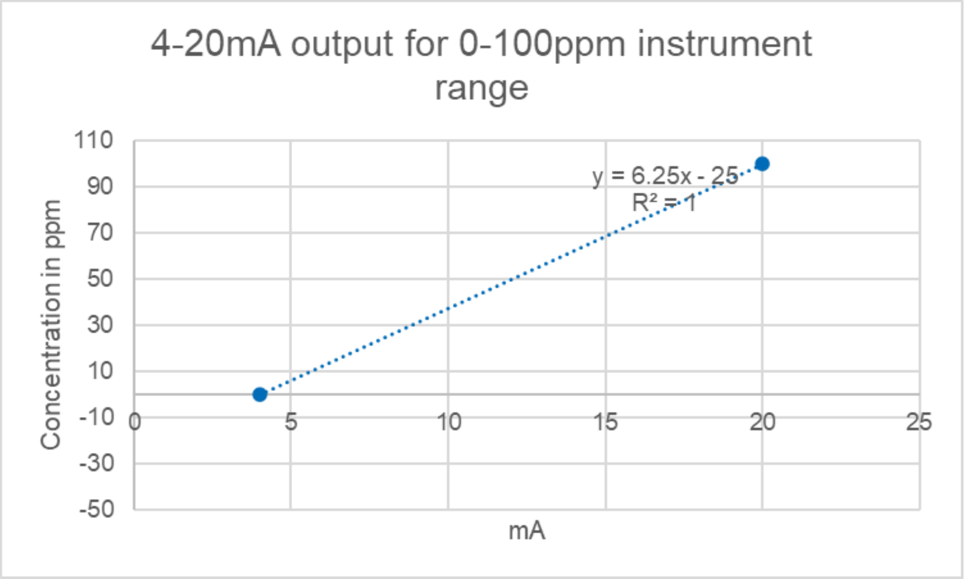
$$Concentration\ (ppm\ or\ mg\ m^{-3}) = \left\{\left(\frac{Analyser\ Measurement\ Range}{20-4}\right) \times (mA\ (measured) - 4)\right\}$$

Example: For an instrument with a measurement range of 0-100 ppm and a mA output of 17 mA, the ppm concentration is:

$$Concentration\ (ppm\ or\ mg\ m^{-3}) = \left\{\left(\frac{100}{20-4}\right) \times (17-4)\right\}$$

$$Concentration\ (ppm) = 81.3$$

Figure 14 - Graph of 4-20mA output



NB, if the analyser is measuring in ppm then this will need to be converted to mg m^{-3}, using the equation in section 9.9.2.

There can be some issues with the use of analogue outputs, especially when.

- these are converted into a digital signal;
- the instrument goes over range. The CEMS may have the capacity to swap ranges to measure higher levels, but the Analogue to digital (A/D) converter does not recognise a change, so any data above the range set on the A/D converter may appear as maximum, or there may be a step change to a lower level. Both of these scenarios mean that the data is not representative of the emission.

9.9.2 ppm to mg m^{-3}

$$Concentration\ mg\ m^{-3} = \frac{concentration\ (ppm) \times molecular\ weight\ (g)}{molar\ volume\ (dm^3)}$$

Applicable for modifying volume/volume gas concentrations to mass/volume concentrations. Conversions from ppm to mg m^{-3} is related to the molecular weight, the molecular weights are given in Table 6 .

Component	Molecular wt. (g)
C_3H_8	44 (36 used if reporting as C)
CO	28
CO_2	44
NO	30 (but typically not used as reported as NO_2)
NO_2	46
HCl	36.5
HF	20
SO_2	64

Table 6 - Common Molecular Weights

For a molar volume of a gas at STP (0°C/273.15K and 101.325 kPa) i.e. reference conditions.

Example: For a measured SO_2 concentration of 100 ppm, the mass concentration is

$$Concentration\ (mg\ m^{-3}) = \frac{100 \text{ x } 64}{22.4}$$

$$Concentration\ (mg\ m^{-3}) = 285.7$$

9.9.3 Temperature Correction

Conversion factor 'Ft' multiplied by a mass concentration at a measured temperature to provide a concentration at reference conditions of 273.15K (0°C).

$$F_t = \frac{T(K)}{273.15}$$

Or

$$F_t = \frac{(T(°C) + 273.15)}{273.15}$$

Note that this is the most common situation, for example for correction of measurement at stack conditions, or correction of a reference measurement from a gas volume meter temperature. The equation can be rewritten more generally for a change from one temperature condition (T1) to a second temperature condition (T2).

$$F_t = \frac{(T1(°C) + 273.15)}{(T2(°C) + \ 273.15)}$$

Example1: For a PM concentration of 100 mg/m^3 measured with a cross-stack CEMS at a stack temperature of 175°C, the mass concentration at STP (0°C, 101.3kPa) is:

$$Concentration\ (mg\ m^{-3})stp = \ Concentration\ (mg\ m^{-3})act\ x\ F_t$$

$$Concentration\ (mg\ m^{-3})stp = \ Concentration\ (mg\ m^{-3})act\ x\ \frac{(T(°C) + 273.15)}{273.15}$$

$$Concentration\ (mg\ m^{-3})stp = \ 100\ x\ \frac{(175 + 273.15)}{273.15}$$

$$Concentration\ (mg\ m^{-3})stp = \ 164.1$$

Example2: For a PM concentration of 100 mg/m^3 at STP (0°C, 101.3kPa) [T1] determined from a reference measurement, the mass concentration at a stack temperature of 175°C [T2] is:

$$Concentration\ (mg\ m^{-3})T2 = \ Concentration\ (mg\ m^{-3})T1\ x\ \frac{(T1(°C) + 273.15)}{(T2(°C) + 273.15)}$$

$$Concentration\ (mg\ m^{-3})T2 = \ 100\ x\ \frac{(0 + 273.15)}{(175 + 273.15)}$$

$$Concentration\ (mg\ m^{-3})T2 = \ 60.9$$

9.9.4 Pressure Correction

Conversion factor 'Fp' multiplied by a mass concentration at a measured pressure to provide a concentration at reference conditions of 101.3 kPa.

$$F_p = \frac{101.325}{p}$$

Note that this is the most common situation, for example for correction of measurement at stack conditions or correction of a reference measurement from a gas volume meter pressure. The equation can be rewritten more generally for a change from one pressure condition (P1) to a second pressure condition (P2).

$$F_p = \frac{(P2)}{(P1)}$$

Example: For a PM concentration of 100 mg m^{-3}, measured with a cross-stack CEMS, at a stack pressure (P1) of 99.5kPa, the mass concentration at Standard Pressure (101.325kPa) (P2) is:

$$Concentration\ (mg\ m^{-3})stp = \ Concentration\ (mg\ m^{-3})act\ x\ F_p$$

$$Concentration\ (mg\ m^{-3})stp = \ Concentration\ (mg\ m^{-3})act\ x\ \frac{P2}{P1}$$

$$Concentration\ (mg\ m^{-3})stp = \ 100\ x\ \frac{101.325}{99.5}$$

$$Concentration\ (mg\ m^{-3})stp = \ 101.8$$

Note that, in most circumstances, the magnitude of a pressure correction is much smaller than the temperature correction.

9.9.5 Moisture Correction

Conversion of a wet gas concentration to a dry gas.

$$Dry\ gas\ concentration = wet\ gas\ concentration \times \left(\frac{100}{(100 - H_2O(\%))}\right)$$

Note that this is the most common situation, for example, for correction of measurement at stack conditions. The equation can also be rewritten for a change from dry conditions to 'wet' gas concentration (for example adjusting a reference measurement to stack moisture conditions).

$$Wet\ gas\ concentration = dry\ gas\ concentration \times \left(\frac{(100 - \ H_2O(\%))}{100}\right)$$

Example: For a PM concentration of 100 mg/m^3, measured with a cross-stack CEMS, reporting data at a stack moisture content of 15% (v/v), the mass concentration at dry condition is:

$$Dry\ gas\ concentration = wet\ gas\ concentration \times \left(\frac{100}{(100 - H_2O(\%))}\right)$$

$$Dry\ gas\ concentration = 100 \times \left(\frac{100}{(100 - 15)}\right)$$

$$Concentration, dry\ (mg\ m^{-3}) = \ 117.6$$

Note that this can also be applied to volume concentrations (ppm).

9.9.6 Oxygen Correction

This is only applicable to combustion activities.

To convert a concentration at a measured (dry) oxygen concentration to a reference oxygen concentration, multiply measured concentration (Dry concentration at measured O_2) by conversion factor 'F_o'.

$$F_O = \frac{21 - O_2\%\ reference\ (Dry)}{21 - O_2 measured (Dry)}$$

$$Concentration\ of\ a\ measurand\ (mg\ m^{-3}) ref O2 = \ Concentration\ (mg\ m^{-3}) mO2\ x\ F_o$$

Note that this is the most common situation, for example for correction of measurement at stack or measured conditions to a reference oxygen level. The equation can also be rewritten for the general case of a change from one oxygen level (Oxy1) to another oxygen level (Oxy2) - for example, adjusting a standardised pollutant measurement at reference conditions to stack oxygen conditions.

$$F_O = \frac{21 - O_{xy2}(\%\ dry)}{21 - O_{xy1}\ (\%\ dry)}$$

Example: For a NOx concentration of 100 mg/m^3 (for a dry gas, expressed as NO_2), measured at a stack oxygen content of 5% (v/v, dry), the mass concentration at a reference concentration of 15% oxygen is:

$$Concentration\ (mg\ m^{-3}) ref O2 = \ Concentration\ (mg\ m^{-3}) mO2\ x \frac{(21 - O_2\%\ reference)}{(21 - O_2 measured)}$$

$$Concentration\ (mg\ m^{-3}) ref O2 = \ 100\ x \frac{(21 - 15)}{(21 - 5)}$$

$$Concentration, 15\%\ O2\ dry\ (mg\ m^{-3}) = 37.5$$

9.9.7 Combined standardisation of data

Typically, several corrections/adjustments will be applied to standardise emission data to a reference condition. A CEMS monitors continuously, and may update data many times per second. Some adjustment to data may be undertaken as it is collected, but in general, standardisation will be undertaken on average data collected over a period of a minute, to help manage data volumes.

Initial data transformations will include conversion of measured parameters to pollutant ppm and/or mg/m^3 concentrations – undertaken by analyser.

9.9.8 Example real world calculations

Expected data management steps for a **gaseous** pollutant:

- Conversion of ppm to mg/m^3;
- Development of 1-minute average, including data status;
- Moisture standardisation (if required);
- Oxygen standardisation (if required).

Example 1: For a VOC CEMS on a chemical activity, measurements are made on undried flue gases, with an ELV as mg C/m^3 at STP (273.15K/0°C, 101.325 kPa), with no correction for moisture content. The CEMS is calibrated against a propane standard gas, and gives VOC measurements as ppm (propane equivalents).

Pollutant	Measurement reported by CEMS	ELV condition	ppm to mg/m^3	Moisture correction needed	Oxygen correction needed	Temperature and pressure correction needed
VOC	ppm (propane equivalent) from measurement and sampling system with no drying	mg C/m^3 STP (273.15 K, 101.325 kPa),	Y	N	N	N

Note that, assuming ideal gas behaviour, a ppm volume concentration does not change with temperature or pressure (that is the ppm volume concentration value at STP is the same as at the measurement or stack temperature and pressure).

To calculate the mass concentration from the ppm (propane equivalent) measured concentration [VOCm], the following conversion is used

$$Concentration\ (mgC\ m^{-3}) = \frac{[\mathrm{VOCm}]\ \mathrm{x}\ 36}{22.4}$$

$$Concentration\ (mgC\ m^{-3}) = [VOCm]\ x\ 1.607$$

No moisture or oxygen standardisation is needed for comparison with the ELV, so no further standardisation of measured data is needed (and note that the CEMS may be configured to make the conversion to a mass basis). Data will require averaging and identification, and screening of valid monitoring data (for example from CEMS status flags). All data operations, including CEMS configurations should be detailed in a CEMS data handling procedure.

Example2a: For a NOx CEMS on a cement kiln, an extractive CEMS is applied which makes measurements on un-dried flue gases with an ELV as mg NO_2 m^{-3} at STP (273.15K/0°C, 101.325 kPa), for a dry flue gas at an oxygen content of 10%. In this CEMS there are separate measurement channels for NO and NO_2 which are summed to provide a NOx output (NO and NO_2 are also reported separately) and also measurement of moisture and oxygen.

Pollutant	Measurement reported by CEMS	ELV condition	ppm to mg/m^3	Moisture correction needed	Oxygen correction needed	Temperature and pressure correction needed
NOx	ppm (NOx) from measurement and sampling system with no drying	mg NOx (as NO_2)/m^3 dry gas at 10% O_2 and STP (273.15 K, 101.325 kPa).	Y	Y	Y	N

Note that, assuming ideal gas behaviour, a ppm volume concentration does not change with temperature or pressure (that is the ppm volume concentration value at STP is the same as at the measurement or stack temperature and pressure).

To calculate the mass concentration from the ppm measured concentration [NOxm], the following conversion is used (46 is the molecular weight of NO_2).

$$Concentration\ (mg\ NO2\ m^{-3}) = \frac{[\text{NOxm}]\text{ x }46}{22.4}$$

$$Concentration\ (mg\ NO2\ m^{-3}) = [NOxm]\ x\ 2.05$$

Moisture and oxygen standardisation are needed for comparison with the ELV, so the measured moisture [H_2Om] (% v/v wet) and oxygen content [O_2m] (% v/v dry) will be applied – typically the oxygen standardisation is undertaken on the 1-minute average data, but note that the CEMS may be configured to make the calculations to standardise to reference conditions. The overall standardisation (including moisture, oxygen, and ppm to mass concentration) is provided below. Note that oxygen may require correction to dry condition, if measurement is of undried sample (but this may also be undertaken internally by the CEMS).

$$\begin{aligned}&Standardised\ dry\ gas\ concentration\ (mg\ NO2\ m^{-3})\\&= [NOxm] \times 2.05 \times \left(\frac{100}{(100-[H_2Om])}\right) \times \left(\frac{(21-10)}{(21-[O_2m])}\right)\end{aligned}$$

Data will also require averaging and identification and screening of valid monitoring data (for example from CEMS status flags). All data operations, including CEMS configurations, should be detailed in a CEMS data handling procedure.

Example2b: As for 2a, but with separate reporting for NOx components. For a NOx CEMS on a cement kiln, an extractive CEMS is applied, which makes measurements on un-dried flue gases with an ELV as mg NO_2 m^{-3} at STP (273.15K/0°C, 101.325 kPa) for a dry flue gas at an oxygen content of 10%. In this CEMS there are separate measurement channels for NO and NO_2, which are summed to provide a NOx output, and are also reported separately, and also measurement of moisture and oxygen.

Pollutant	Measurement reported by CEMS	ELV condition	ppm to mg/m³	Moisture correction needed	Oxygen correction needed	Temperature and pressure correction needed
NOx	ppm (NO and NO_2) from measurement and sampling system with no drying	mg NOx (as NO_2)/m^3 dry gas at 10% O_2 and STP (273.15 K, 101.325 kPa).	Y	Y	Y	N

Note that, assuming ideal gas behaviour, a ppm volume concentration does not change with temperature or pressure (that is the ppm volume concentration value at STP is the same as at the measurement or stack temperature and pressure).

To calculate the mass concentration from the ppm measured concentration [NOm] and [NO_2]m, the following conversion is used (46 is the molecular weight of NO_2).

$$Concentration\ NO\ (mg\ NO2\ m^{-3}) = \frac{[\mathrm{NOm}]\ \mathrm{x}\ 46}{22.4}$$

$$Concentration\ NO2\ (mg\ NO2\ m^{-3}) = \frac{[\mathrm{NO2m}]\ \mathrm{x}\ 46}{22.4}$$

$$Concentration\ NOx\ (mg\ NO2\ m^{-3}) = ([NOm] + [NOxm])\ x\ 2.05$$

Moisture and oxygen standardisation are needed for comparison with the ELV, so the measured moisture [H_2Om] (% v/v wet) and oxygen content [O_2m] (% v/v dry) will be applied – typically the oxygen standardisation is undertaken on the 1-minute average data, but note that the CEMS may be configured to make the calculations to standardise to reference conditions. The overall standardisation (including moisture, oxygen, and ppm to mass concentration) is provided below. Note that oxygen may require correction to dry condition, if measurement is of undried sample (but this may also be undertaken internally by the CEMS).

$$Standardised\ dry\ gas\ concentration\ (mg\ NO2\ m^{-3}) = ([NOm] + [NOxm]) \times 2.05 \times \left(\frac{100}{(100 - [H_2Om])}\right) \times \left(\frac{(21 - 10)}{(21 - [O_2m])}\right)$$

Data will also require averaging and identification, and screening of valid monitoring data (for example from CEMS status flags). All data operations, including CEMS configurations should be detailed in a CEMS data handling procedure.

Example2c: As for 2a but with separate reporting for NOx components and measured on a dry basis. For a NOx CEMS on a cement kiln, an extractive CEMS is applied which makes measurements on **dry basis** with an **ELV as mg NO_2 m^{-3} at STP (273.15K/0°C, 101.325 kPa), dry, and at a reference oxygen content of 10%.** In this CEMS there are separate measurement channels for NO and NO_2, which are summed to provide a NOx output, and are also reported separately, and also measurement of moisture and oxygen.

Measured NO = 201 mg/m3
Measured NO_2= 10 mg/m3
Measured O_2 = 12%

Pollutant	Measurement reported by CEMS	ELV condition	ppm to mg/m^3	Moisture correction needed	Oxygen correction needed	Temperature and pressure correction needed
NOx	mg/m3 (NO and NO_2) from measurement and sampling system for a dry gas	mg NOx (as NO_2)/m^3 dry gas at 10% O_2 and STP (273.15 K, 101.325 kPa).	N	N	Y	N

To calculate the mass concentration from the ppm measured concentration [NOm] and [NO_2]m, the following conversion is used (30 is the molecular weight of NO and 46 is the molecular weight of NO_2):

Converting NO to as NO_2

$$Concentration\ mg\ m^{-3}\ of\ NO\ as\ NO_2 = 201 \times \frac{46}{30} = 308.2\ mgm^{-3}$$

Consequently, the measured NO_X as NO_2 is

$$Concentration\ NOx\ (mg\ NO2\ m^{-3}) = ([NOm\ as\ NO2] + [NO2m])$$

$$Concentration\ of\ NO_X as\ NO_2 = 308.2 + 10 = 318.2\ mg\ m^{-3}\ STP\ DRY$$

For comparison with the ELV, the measurements were on a dry sample gas, so no moisture standardisation is needed. However, oxygen standardisation is required, so the measured oxygen content [O_2m] (% v/v dry) will be applied – typically the oxygen standardisation is undertaken on the 1-minute average data, but note that the CEMS may be configured to make the calculations to standardise to reference conditions. The standardisation is provided below.

Note that oxygen would require correction to dry condition if measured wet (but this may also be undertaken internally by the CEMS).

$$Standardised\ dry\ gas\ concentration\ (mg\ NO2\ m^{-3})\ at\ 10\%\ O_2 = ([NO_X] \times \left(\frac{(21-10)}{(21-[O_2m])}\right)$$

O_2 measured = 12%

$$Concentration\ of\ NO_X as\ NO_2\ mg\ m^{-3} = 318.2 \times \left(\frac{11}{21-12}\right) = 388.9\ mg\ m^{-3}\ \text{STP dry at 10\% } O_2$$

Data will also require averaging and identification, and screening of valid monitoring data (for example from CEMS status flags). All data operations, including CEMS configurations should be detailed in a CEMS data handling procedure.

Example 3: For a PM CEMS on a cement mill, an in-situ instrument is applied, which makes measurements on flue gases, with an ELV as mg m^{-3} at STP (273.15K/0°C, 101.325 kPa) without correction for moisture or oxygen content. In this CEMS, the concentration data are measured at duct/stack conditions.

Pollutant	Measurement reported by CEMS	ELV condition	ppm to mg/m^3	Moisture correction needed	Oxygen correction needed	Temperature and pressure correction needed
PM	mg m^{-3} at stack temperature, pressure and moisture content	mg PM m^{-3} wet gas at STP (273.15 K, 101.325 kPa). No correction for moisture or oxygen.	N	N	N	Y

The adjustment may be undertaken within the CEMS, if it incorporates temperature and pressure measurement. For a measured PM concentration [PMm] of 41 mg m^{-3} and a stack temperature of 35°C and a stack pressure of 99.7 kPa, a temperature and pressure standardisation to STP is required.

$$F_t = \frac{(T(°C) + 273.15)}{273.15}$$

$$F_t = \frac{(35 + 273.15)}{273.15}$$

$$F_t = 1.128$$

$$F_p = \frac{101.325}{p}$$

$$F_p = \frac{101.325}{99.7}$$

$$F_p = 1.016$$

$$Standardised\ dry\ gas\ concentration\ (mg\ PM\ m^{-3}) = [PMm]x\ F_t\ x\ F_p$$

$$Standardised\ wet\ (as\ measured)\ gas\ concentration\ (mg\ PM\ m^{-3}) = 41\ x\ 1.128\ x\ 1.016$$

$$Standardised\ wet\ (as\ measured)\ gas\ concentration\ (mg\ PM\ m^{-3}) = 47$$

When calibrating PM monitors, the standard reference method determines the concentration as a dry measurement. **It is important that calibration data and response from the analyser are in the same condition and this is clearly stated, i.e., either both as measured (wet) or dry.**

Data will also require averaging and identification and screening of valid monitoring data (for example from CEMS status flags). All data operations, including CEMS configurations should be detailed in a CEMS data handling procedure.

9.9.9 Typical Scenarios, and the applicable corrections

For extractive CEMS, the calibration applies to each component measured, providing the result in either mg m^{-3} or %, at STP dry. The data would still need to be corrected for any required reference oxygen conditions.

In-situ measurement, where the duct is the measurement cell, would require correction for pressure and temperature, unless the device made these corrections as part of its measurement. A correction would have to be made for any reference oxygen required, after the concentration had been calculated.

The following are scenarios that define the steps that need to be undertaken to get to the required emission concentration. The calculations for each step are given in the following sections.

- In-situ CEMS Measurement of mA
    - Conversion to ppm, or;
    - Conversion to mg m^{-3}.
- In-Situ CEMS Measurement of ppm
    - Conversion to mgm^{-3}

    - Correction for stack Moisture to dry;
    - Correction for Stack Temperature to 273.15K (0°C);
    - Correction for Stack Pressure;
    - Correction to Reference oxygen if required.
- In-Situ CEMS Measurement of mg m^{-3} without CEMS pressure and temperature correction
    - Correction for stack Moisture to dry;
    - Correction for Stack Temperature to 273.15K (0°C);
    - Correction for Stack Pressure;
    - Correction for reference oxygen if required.
- In-Situ CEMS Measurement of mg m^{-3} with CEMS pressure and temperature correction
    - Correction for stack moisture;
    - Correction to reference oxygen if required;
- Extractive CEMS Measurement of mA
    - Conversion to ppm;
    - Correction for measured Moisture to dry if required;
    - Conversion to mg m^{-3};
    - Correction for reference oxygen if required;
- Extractive CEMS Measurement of ppm
    - Conversion to mg m^{-3};
    - Correction for measured Moisture to dry if required;
    - Correction for reference oxygen if required.

9.9.10 Assessment of Drift

EPA guidance AG3 describes the process of on-going control as required in EN 14181, i.e. QAL 3 and the use of control charts e.g. CUSUM or Shewhart. These are used to assess total drift, and to prompt action if a significant drift is observed.

This assessment should also be used for process not requiring the use of EN14181, as drift is a fundamental parameter impacting on the performance of a CEMS, and provides a good indication that the data being produced is acceptable.

The information used for these assessments are span and zero drift checks, i.e. recording the results of the injection of zero and span gases. The important aspect of this is that no calibration or change is made to the analyser. The results are only recorded, and the differences used to assess the acceptability of the data.

Drift is one of the factors that is used to define the performance of a CEMS. If an assessment of drift shows that the CEMS is outside the acceptance drift criteria given in **Error! Reference source not found.**, the analyser should be recalibrated using the calibration gases used to initially calibrate it, or gases of know concentration, in accordance with the manufacturers procedures. This can either be undertaken by trained staff or the instrument supplier.

The standard EN 15267 provide performance criteria for certification/evaluation of CEMS. One of these criteria are the maximum zero and span drifts allowed in the field under assessment. These are shown in Table 7. This provides an allowable drift (as a percentage of certification range), before intervention should be made, i.e. recalibrate to eliminate the drift.

- EN 15267-1:2009 Air quality. Certification of automated measuring systems General principles
- EN 15267-2:2009 Air Quality. Certification Of Automated Measuring Systems. Initial Assessment Of The AMS Manufacturer's Quality Management System And Post Certification Surveillance For The Manufacturing Process
- BS EN 15267-3:2007 Air Quality. Certification Of Automated Measuring Systems. Performance Criteria And Test Procedures For Automated Measuring Systems For Monitoring Emissions From Stationary Sources
- BS EN 15267-4:2017 Air Quality. Certification Of Automated Measuring Systems. Performance Criteria And Test Procedures For Automated Measuring Systems For Periodic Measurements Of Emissions From Stationary Sources

The following approaches to evaluate the data can be adopted:

- Calculation – determine the difference between calibrated value and check value, and assess if less than or greater than 2%, i.e., the point at which action should be taken;
- Control charts – Shewart charts as described in AG3;

Pollutant	Zero Drift	Span Drift
Gaseous except Oxygen	≤ 3.0%	≤3.0%
Oxygen	≤0.2%	≤0.2%
Particulate Material	≤ 3.0%	≤3.0%

Table 7 - Allowed drift performance criteria

The values are expressed as percentage of **range.**

Using an assessment of drift would enable an operator to be confident that their CEMS is providing reliable data.

An outline procedure to monitor the performance using drift assessment is given below:

Gaseous species drift procedure

- Inject zero gas and Span gas once per week;
- Calculate the allowed drift using the data in **Error! Reference source not found.**;
- Record the concentrations of the zero and span gases used (expected);
- Record the values obtained when stable CEMS readings have been reached (recorded);
- Calculate the difference between the recorded and expected;
- If the difference is less than the allowed drift, then no action;
- If the difference is greater than the allowed drift, then recalibrate the analyser.

Particulate material CEMS usually undertake a check, which does not involve direct measurement of PM. These involve checks of the optics or electronics, either by:

- directing the light directly into the detector, in the case of a double pass system or;

- inputting a known voltage/current in the case of units based on charge measurement. Both of these outputs can be used to assess the drift of the system;

The data produced during these checks can be used as an assessment of drift, in the same manner as that for gaseous measuring CEMS.

This assessment of span and zero drift should be undertaken by;

- The CEMS supplier/manufacturer engineers;
- A trained member of the operator staff;
- Automating the system requiring only that the gases be available at the time of the injections.

9.10 Calculation of 97% percentile

Some regulations define an ELV at the 97% percentile. A percentile (or a centile) is a value below which a given percentage of scores in its frequency distribution falls (exclusive definition), or a score at or below which a given percentage falls (inclusive definition). For example, the 97th percentile is the score value which (exclusive) or at or below which (inclusive) 97% of the scores in the distribution may be found. The 97%centile is calculated from each complete data set usually 30min averages, daily averages and or annual periods.

9.11 CEMS Security

It is recommended that where operators have provided CEMS suppliers with remote access to their CEMS, that this access be controlled by the operator. Also, that any intervention from outside the operation should be logged. This should be part of the management system, and consequently logged either in the system used for access, or manually by the operator. Any changes made, e.g., calibration adjustments, must be recorded.

Access should only be granted by or at the invitation of the operator. This is to enable the operator to ensure and demonstrate data security.

10 Quality Assurance and Quality Control

The philosophy behind EN 14181 and other CEMS QA/QC standards around the world that are used as best practice, are the same, and contain the same or similar requirements. These have been summarised in the following sections. These outline approaches could be utilised where the more complex requirements of EN 14181 are not necessarily appropriate, based on the risk posed by an activity.

10.1 Selection of CEMS

Selection of a CEMS appropriate for use on a particular process is the initial, critical step in ensuring quality and representative data. Certification schemes provide the guidance on this, and are mandatory in some countries for certain processes, but is not required for all sectors. Some examples of Certification Approval schemes which are based on EN standards include:

- UK Environment Agency Monitoring certification scheme MCERTS or;
- Germany UBA/TUV scheme.

Benefits of a certification are;

- Certification demonstrates compliance with regulatory requirements;
- Certification range includes confidence interval of data;
- Certifies a system which includes;
    - Gas handling filter, sample transport;
    - Care is needed to ensure that the same design gas handling system is used, or that any change provides the same performance as the tested system;
    - Analysis;
    - Calibration;
    - On-going control.

Although certification may not be required at every installation, it provides a useful source of information when selecting a CEMS.

Experience of other operators and sites within a sector provides a source of information about experience of CEMS relative to that sector.

CEMS suppliers can have a significant amount of evidence that a CEMS operates in a specific environment, and can provide references and examples of installations.

10.2 CEMS Installation

The location of CEMS has a significant impact on its capability to provide representative data. This is recognised in all guidance and standards relating to the use of CEMS. Consequently, installation should follow standard requirements, e.g. EN 15259. This includes guidance on likely positions that may meet acceptance criteria. However, this is guidance, and the location must be checked to ensure that representative measurements can be made at the location. This is extremely important when a sample is taken from a single point in a duct. It is critical to ensure that the selected point of sampling is representative of the whole duct area, and hence is representative of the total emission. This is one of the reasons for calibration against reference methods used, at multiple points, to relate the whole profile to a single point.

The location must also meet all health & safety requirements, i.e.:

- Safe access and egress;
- Safe procedures of working.

10.3 CEMS QA/QC

- Set-up of system in accordance manufacturer, standard method and accredited procedure requirements;
- Calibration.
    - Calibration to check for drift using traceable certified calibration gases to ISO 17025 on known uncertainty +/- 2%;
    - Calibration and zero gas injection into
        - Analyser;
        - Probe – system calibration
            - Leak checking;
- Calibration Checks at the end of test period
    - Verifies acceptability of data there should be defined criteria based on drift;
    - Recording of issues during testing.

Failures of system components, such as heated lines, etc. can have an impact on the data collected.

10.3.1 Calibration against reference materials

All CEMS should be calibrated against a reference material, certified to ISO 17025 of known error. This includes calibration gases. The selection of the calibration materials should follow recommendations from the CEMS supplier, i.e., component and concentration. The selection of concentration is usually based around a percentage of the measuring range, used for a specific process. However, the emission limit value should be considered, as this is point of interest when demonstrating compliance.

There are systems that have internal filters, usually diffraction gratings, that can be used to regularly check the calibration of the system. These gratings produce a response equivalent to a concentration. The characteristics of the filters will not change, so should produce the same response each time it is used. These systems should be checked against certified gases to give traceability. The internal filters provide a mechanism to undertake internal analyser checks, without the use of gas, but do not check the whole CEMS.

10.3.2 Checking against Standard reference methods (SRM)

EN 14181 and the USEPA RATA tests both require tests to be undertaken against reference materials. USEPA RATA tests are used to confirm drift characteristics. This also provides an approach to check the performance of a CEMS operating outside the requirements of EN14181. So, by undertaking reference method tests, and then comparing the data collected within a corresponding period from the CEMS, confidence can be gained in the operation of the CEMS.

In addition to checking the continued functionality of a CEMS, checking (rather than adjusting) of instrument span and zeros against reference materials provides a means of on-going monitoring of a CEMS. This demonstrates that its operation is within acceptable levels, and that the data produced is therefore capable of demonstrating compliance.

This activity enables calibrations to be undertaken when needed, and can be planned on the basis of the drift data collected during span and zero checking.

Parallel monitoring between the CEMS and the standard reference method (SRM), on an annual basis is best practise, in order to fully calibrate the CEMS, and to ensure the continuing validity of the CEMS data. Any other data collected throughout the year by using reference methods can be used to check the CEMS output, by comparing the CEMS data with the reference method value.

10.4 Site QA/QC CEMS Servicing and maintenance

Servicing and maintenance are a critical part of operating a CEMS. All systems will have a recommended service schedule that should be adhered to. This will pick up deterioration in both the fabric and operation of the unit, and return it to specification. This goes a significant way to prevent issues. There will be a level of maintenance that may be required between typically annual servicing and maintenance, and this may include actions such as changing and/or cleaning filters. Importantly, any work on the CEMS should be undertaken by competent people, i.e. trained staff, or the instrument/supplier service engineers

Servicing and Spares

There should be a servicing and maintenance plan agreed with the equipment supplier, which will include:

- Preventative servicing and maintenance, which should be undertaken to reduce the amount of downtime experienced;
- An annual leak check of the entire sampling train (which could be performed during annual shutdown). This should also be undertaken when component parts of the CEMS are separated, and prior to the CEMS being used to monitor process emissions;
- Span and Zero Checks should be undertaken using assessment of drift, as an indicator of when intervention is required, e.g. recalibration. As an option, the EN14181 QAL3 procedure and control charts, e.g. Shewart can be used;
- Annual parallel monitoring by accredited contractors.

Records

- A record of any servicing and maintenance should be kept. A service/calibration report shall include:
    - Commentary on the equipment condition, before and after service/calibration;
    - Details of the ISO 17025 calibration gases used;
    - Concentrations of parameters before and after calibration (calibration records);
    - Date of last calibration;
    - Date of service/calibration;
    - Name and signature of personnel performing service/calibration.
- Records of personnel working on the CEMS should be kept;
- Any intervention or work undertaken on the CEMS should be recorded;
- All equipment used should be identified;
- Calibration records should be available;
- Calibration gases (accredited to ISO 17025) should have certificates of analysis;
- Condition of equipment should be recorded;
- A record should be available of an annual leak check through the entire sampling system (to be carried out during annual shutdown);
- A report of any checks against a SRM test.

Training

- Any site personnel working on the CEMS should be trained and competent;

Health & Safety

- There should be safe and permanent access to the CEMS location;
- There should be risk assessment in place, for work undertaken on the CEMS.

11 Example Sector Specific CEMS Monitoring

In this section typical applications are used as examples to illustrate and discuss best practice as applied to the CEMS, data capture and reporting for IE and IPC licences, and VOC permits.

The steps to follow when required to install a CEMS are:

Step 1 – Selection of the CEMS;
Step 2 – Selection of Sampling location.

The objective is to position the CEMS so that it is measuring a sample that is representative of the process emissions. The following standards should be followed.

EN 15259;
EN 13284.

When selecting a sampling location there are a number of standards, and guidance that should be considered.

Step 3 – Installation;
Step 4 – Verification of installation;
Step 5 - Calibration of CEMS;
Step 6 – On going control.

11.1 IED

11.1.1 Cement manufacture

11.1.1.1 Regulatory requirements

The requirements on the operator will be set out in the IE licence, which will be based on the BAT Conclusions published in 2013, for production of cement, lime and magnesium oxide[23]. If waste is used as a fuel in the cement kiln, then the requirements of IED Chapter IV also apply. For cement production using a kiln, continuous monitoring of dust (PM), NOx, SOx, CO and (if SNCR is applied for NOx control) NH_3 is part of BAT for monitoring. Also, continuous or periodic monitoring for HCl, HF and TOC are is required. Emission concentrations from cement kilns are standardised to STP (0°C, 101.3kPa), a dry gas, and 10% O_2.

For cement mills and other sources, BAT requires continuous or periodic monitoring for dust (PM), and emission concentrations are standardised to STP (0°C, 101.3kPa) without correction for moisture or O_2 content.

A licence may specify that:

- No 24 hour mean value from continuous monitoring shall exceed the emission limit value;

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[23] Available here : https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013D0163&from=EN

- The appropriate installation and functioning of the automated monitoring equipment for emissions to air shall be subject to an annual surveillance test. Calibration shall be carried out by means of parallel measurements, with reference methods at least once every three years.

11.1.1.2 Appropriate CEMS

Emission concentrations consistent with BAT AELs are (broadly) similar to emission concentrations at energy and incineration plant, so CEMS certified to MCERTs or TUV requirements with suitable pollutant coverage and measuring ranges should be applicable to cement kilns and mills.

11.1.1.3 Operational Practices

The steps required to achieve reliable data are:

1. Selection of the CEMS – use type-approval and manufacturers' literature as a guide to compliance with BAT requirements, check with other operators/trade associations for solutions elsewhere;
2. Selection of Sampling location – the objective is to position the CEMS, so that it is measuring a sample that is representative of the process emissions. Use of EN standards (EN15259, EN13283-1) can provide best practise;
3. Installation – does it meet the location requirements and manufacturers' guidance, are there additional requirements for weather or local dust sources;
4. Verification of installation – checks to assure that CEMS is functioning, and responding as expected, initial calibration checks;
5. Ongoing control – management, checking, and maintenance processes in place to assure data quality.

11.1.1.4 Calibration

The CEMS should be calibrated in accordance with EN 14181 requirements, i.e. against standard reference methods.

11.2 IPC

11.2.1 Pharmaceutical

The Pharmaceutical sector BAT describes emissions to air as including VOC's, inorganics, combustion by-products, and particulates. The continuous measurement of TOC, HCl, CO, SO_2, NO_X and Particulates can be required, where applicable.

11.2.1.1 Regulatory requirements

Continuous Monitoring data: Requirements

- No 24 hour mean value shall exceed the emission limit value;
- 97% of all 30-minute mean values taken continuously over an annual period shall not exceed 1.2 times the emission limit value;
- No 30-minute mean value shall exceed twice the emission limit value.

The concentration limits for emissions to atmosphere specified in this licence shall be based on gas volumes under standard conditions of Temperature 273.15K, Pressure 101.325 kPa (no correction for oxygen or water content) for non-combustion gases. Emission limit values are given in Table 8.

Parameter	ELV (mg m^{-3})
Total Particulate	1
Total Volatile Organic Carbon	20

Table 8 - VOC emission limit values

There is also a requirement for the continuous measurement of differential pressure across HEPA filters

11.2.1.2 Appropriate CEMS

Particulate material

The ELV of 1 mg/m^3 suggests that probe electrification and forward scatter would be suitable technologies for this process. The emission point is after a bag filter at 80°C. There are other factors that need to be considered, such as the zone classification, i.e., is there a CEMS that has the correct rating for deployment into the area? Is there a way of extracting the sample to a safer place to then analyse the system?

Selected a forward scattering CEMS with a digital output in mg m^{-3}

Correction for temperature and pressure are required, so pressure and temperature sensors need to be installed.

Volatile organic carbon

The requirement is for total VOC's and the most appropriate technology to provide a measure of TVOC is a flame ionisation detector (FID). To ensure that the sample is representative of the emission, a heated particulate filter and heated transport lines should be used.

If speciated VOC's were required, then CEMS such as

- FTIR - can be configured with a library suitable for the process;
- Gas Chromatograph FID, can be used

Selected an FID with digital output in mg m^{-3}

Differential pressure Measurement

A pressure sensor may be installed to measure the pressure drop across the bag house.

Data Acquisition and Handling system

A multi-channel data logging system should be used and configured to collect data from the PM CEMS, temperature sensor, pressure, VOC CEMS, and the differential pressure sensor across the bag filters.

The unit should also collect function signals from each of the sensors to demonstrate that the unit is operational.

The DAHS stores raw data, then produces corrected data, 24-hour averages, 30 min averages. The unit then calculates the exceedances, and reports these in an agreed format, and alarms the control room that an exceedance has occurred.

11.2.1.3 Calibration

The PM monitor is calibrated against EN 13284 annually. The daily internal zero and up-scale checks are monitored to show that the unit is operating correctly.

The FID is calibrated using propane at 18 mg m-3. The unit is checked (i.e., no adjustment is made) against this, and a zero gas, on a weekly basis. This data is used to calculate the drift, when this reaches ±2%, the unit is recalibrated. This is done by trained staff on site, and by the supplier’s engineers.

11.2.1.4 Operational practices

There is a service contract in place to cover maintenance and repairs to all of the sensors involved in monitoring emissions to the environment

11.3 Petrol Storage

11.3.1 Regulatory requirements

The requirements on the operator will be set out in the permit, and will be based on Directive 94/63/EC on the control of VOC emissions from the storage and distribution of petrol (PVR 1) – see Section 4.4. A VOC or petrol storage permit issued by EPA may specify:

- A Continuous Emission Monitor shall be maintained on the VRU (Vapour Recovery Unit). The monitor shall be calibrated with propane, on a bi-annual basis. A summary of the monitoring results shall be submitted to the Agency by the 1'' February each year. These results shall cover the previous calendar year;
- Data generated by the continuous emission monitor shall be recorded, and retained in digital format, for a period of three years. The data shall be available for inspection by authorised persons of the agency.

Such conditions set out the need to use a CEMS, and to record data provided by the CEMS. Other conditions will set the ELV and requirements around measurement error, limit of detection, and precision (based on the requirements of PVR 1).

11.3.2 Appropriate CEMS

Identification of a suitable CEMS through MCERTs or other emission monitoring certification scheme is unlikely to be possible (such schemes tend to focus on large combustion plant or waste incineration plant, where measurement ranges and emission concentrations are orders of magnitude lower than the ELV for a petrol storage activity). In addition, the CEMS will require equipment, which has been assessed as suitable for use in flammable atmospheres (or with appropriate installation and sample transport to assure that the equipment can be applied safely).

Flammable gas monitors are available and certified for use in flammable atmospheres. Although these may not be the ideal monitoring system for assessing VOC compliance (they may be monitoring a surrogate), they are likely to be a common solution. In this case, the permit holder will need to satisfy the regulator that the minimum requirements specified in the Directive are achieved (Section 4.4). This demonstration of suitability may be from manufacturer's data/specifications (and the systems put in place to monitor and manage the CEMS).

11.3.3 Operational Practices

The measured concentrations and ELV are higher and, the requirements for uncertainty are specified differently to CEMS used to monitor combustion and other activities. However, the steps required to achieve reliable data are the same:

1. Selection of the CEMS – use manufacturers' literature as a guide to compliance with minimum standards, check with other operators/trade associations for solutions elsewhere;
2. Selection of Sampling location – the requirements are the same as for other CEMS. The objective is to position the CEMS, so that it is measuring a sample that is representative of the process emissions. Use of EN standards (EN15259, EN13283-1) can provide best practise;
3. Installation – does it meet the location requirements and manufacturers' guidance, are there additional requirements from potential for flammable atmospheres;
4. Verification of installation – checks to assure that CEMS is functioning and responding as expected, initial calibration checks;
5. On-going control – management, checking, and maintenance processes in place to assure data quality.

11.3.4 Calibration

The CEMS should be calibrated by checking against reference methods on installation, and at regular (annual) intervals.

12 Additional guidance and information for CEMS

In addition to this and other guidance published by the EPA, there is information available from a number of different sources. These include:

- European Commission BAT Conclusions and BAT Reference documents
  IPPC Bureau http://eippcb.jrc.ec.europa.eu/reference/
- National Regulators
  Germany UBA,
  UK
  Defra/Environment Agency/Natural Resources Wales
  https://www.gov.uk/government/collections/monitoring-emissions-to-air-land-and-water-mcerts
  Scottish Environment Protection Agency
  https://www.sepa.org.uk/regulations/pollution-prevention-and-control/guidance/
  Northern Ireland
  https://www.daera-ni.gov.uk/articles/air-emission-monitoring-guidance
  US EPA - Air Emission Measurement Centre (EMC) https://www.epa.gov/emc/emc-performance-specifications
  India, Central Pollution Control Board
  https://cpcb.nic.in/upload/thrust-area/revised-ocems-guidelines-29.08.2018.pdf
- Organisations such as the Source Testing Association in the UK.
- Recognised monitoring Standards IS EN, ISO, national, draft standards and recognised best practice
- Certified CEMS
  UK MCERTS-Certified CEMS https://www.csagroup.org/en-gb/services/mcerts/mcerts-product-certification/mcerts-certified-products/mcerts-certified-products-continuous-emission-monitoring-system-and-transportable-cems/
  Germany TUV-Certified CEMS https://www.qal1.de/en/hersteller/sick.htm

A Appendices

Appendix 1: CEMS Related Standards
Appendix 2: Detection Principles Particulate
Appendix 3: Detection Principles Gases
Appendix 4: CEMS Best Practice Check list

Appendix 1 – CEMS related Standards

Compound	Standard Number	Description
Alternate reference method procedure	CEN/TS 14793:2005	Interlaboratory validation procedure for an alternative method compared to a reference method
Calibration of CEMS	EN 14181:2014	Quality assurance of an AMS
Carbon Monoxide (CO)	EN 15058:2017	Determination of the mass concentration of carbon monoxide (CO). Reference method: non-dispersive infrared spectrometry
CEMS sampling	ISO 10396:2007	Sampling for the automated determination of gas emission concentrations for permanently installed monitoring systems
Flow	EN ISO 16911-1 & 2 :2013	Determination of the volume flowrate of gas streams in ducts. Manual and automated methods
Flow	ISO 10780 1994 (E),	Stationary source emissions- Measurement of velocity and volume flow of gas streams in ducts
Hydrogen Chloride	EN 1911:2010	Manual method of determination of HCl.
Hydrogen Fluoride	ISO 15713:2006	Sampling and determination of gaseous fluoride content
Instrument certification	15267-1:2009	Air quality - Certification of automated measuring systems – Part 1: General principles
Instrument certification	15267-2:2009	Air quality - Certification of automated measuring systems – Part 1: Initial assessment of the AMS manufacturer's quality management system and post certification surveillance for the manufacturing process

Compound	Standard Number	Description
Instrument certification	EN 15267-3:2007	Air quality - Certification of automated measuring systems – Part 3: Performance specifications and test procedures for automated measuring systems for monitoring emissions from stationary sources
Instrument certification (dust monitors)	EN 15859:2010	Air Quality - Certification of automated dust arrestment plant monitors for use on stationary sources - Performance criteria and test procedures
ISO 17025 elaboration	CEN/TS 15675- 2007	Elaboration of ISO17025 for stack emission monitoring
Mercury	EN 13211:2001	Manual method of determination of the concentration of total mercury
Mercury calibration	EN 14884:2005	Determination of total mercury: automated measuring systems
Moisture / water vapour	EN 14790:2017	Determination of the water vapour in ducts
Nitrogen Oxide (NOx)	EN 14792:2017	Determination of mass concentration of nitrogen oxides (NOx). Reference method: Chemiluminescence
Oxygen	EN 14789:2017	Determination of volume concentration of oxygen (O2). Reference method. Paramagnetism
Particulate	ISO 12141:2017	Determination of mass concentration of particulate matter (dust) at low concentrations. Manual gravimetric method

Compound	Standard Number	Description
Particulate / Dust	EN 13284-1:2017	Determination of low range mass concentration of dust. Manual gravimetric method
Particulate calibration	ISO 10155:1995	Automated monitoring of mass concentrations of particles. Performance characteristics, test methods and specifications
Particulate calibration	EN 13284-2:2004	Determination of low range mass concentration of dust. Automated measuring systems
Particulate high range	ISO 9096:2017	Manual determination of mass concentration of particulate matter
Planning	EN 15259:2007	Air Quality – Measurement of stationary source emissions – Requirements for measurement sections and sites and for the measurement objective, plan and report.
Sulphur Dioxide (SO_2)	EN 14791:2017	Determination of mass concentration of sulphur dioxide. Reference method
TOC	EN 12619:2013	Determination of the mass concentration of total gaseous organic carbon. Continuous flame ionization detector method
VOC speciation	CEN/TS 13649:2014	Determination of the mass concentration of individual gaseous organic compounds. Activated carbon and solvent desorption method

Table 9 - CEMS related standards

Appendix 2 – Detection Principles - Particulate

A.2 Particulate measurement

There are a number of detection principles that are used to monitor particulate matter (PM) emissions, and the majority involve the measurement of the impact or influence of particulate material; they do not measure the concentration of the PM directly, as would be the case when measuring a gaseous species. It is this approach that requires PM CEMS to be calibrated on the process being monitored, and the following explains these principles.

As particulate measurement is usually made inside the duct there are a number of considerations that may need to be considered, before data can be reported to any required conditions other than as measured, i.e. temperature, pressure, and moisture.

There are some factors that need to be considered when selecting a PM monitor, and its arrangement/configuration. These include:

- Duct size – a smaller duct may not be suitable for intrusive probe type monitors, due to potential to restrict flow in the duct;
- The presence of water droplets;
- Proximity to abatement systems, specifically:
    - electrostatic precipitators will charge particles and duct walls in the area, which may influence certain types of CEMS detector;
    - wet scrubbers introduce moisture and result in the presence of water droplets.

The physical characteristics of the PM being measured affect the response of all light-based systems, and include size, shape colour, and density. This is the reason that these systems must be calibrated on process using a standard isokinetic gravimetric method, such as EN 13284-1.

Also, the physical characteristics of the gas stream being sampled can impact the measurement, i.e., anything that absorbs, reflects, or deflects the form of light being used will be recorded as dust.

A.2.1 Light Based PM CEMS

Light is used in a number of CEMS, but in different ways, which are described in the following sections. This type of measurement is based on the measurement of the optical transmission of a beam of light, as it passes through the flue gas stream containing gases and particles. The intensity of the beam reaching the detector is reduced by adsorption and scattering (reflection, diffraction, and refraction), the properties of which are dependent on the particles and gases present in the duct. As an example, when there are water droplets and water vapour present in the gas stream, a higher PM reading may be obtained. This is caused by the scattering and adsorption of the light caused by the droplets, i.e., the PM CEMS sees the water droplets as PM.

PM CEMS are usually in-situ, using the duct as the measurement path, and are configured:

- Single beam Opacity– single path of light across the duct from source to detector;
- Single beam/pass transmissometer – single path of light across the duct from source to detector;
- Double Beam/pass transmissometer - light passes across the duct twice by using source and detector on one side and a reflector on the opposite side (Figure 15 - Typical configuration of a Transmissometer).

There are double beam devices that are constructed within a probe configuration. This simplifies installation, as entry into the duct is only needed from one side, and also eliminates some of the alignment issues encountered when the source and detector/reflector are on opposite sides of the duct. However, these units are effectively measuring at a point within a duct. This makes the need for correct location, installation, and process specific calibration critical in obtaining representative data.

A.2.1.1 Opacity

Opacity monitors are the simplest form of transmissometer, and produce an opacity reading as a percentage of the light passing through the duct. They are arranged with a source on one side of the duct, and the detector on the other. The opacity measurement can be considered as similar to the Ringelmann scale used for visual determination of (dark) smoke.

A.2.1.2 Transmissometer – Concentration measurement

A more sophisticated form of opacity meter is the transmissometer that reference an internal reference, zero, and span, with double beam detection, allowing determination of mass concentrations.

Figure 15 - Typical configuration of a Transmissometer

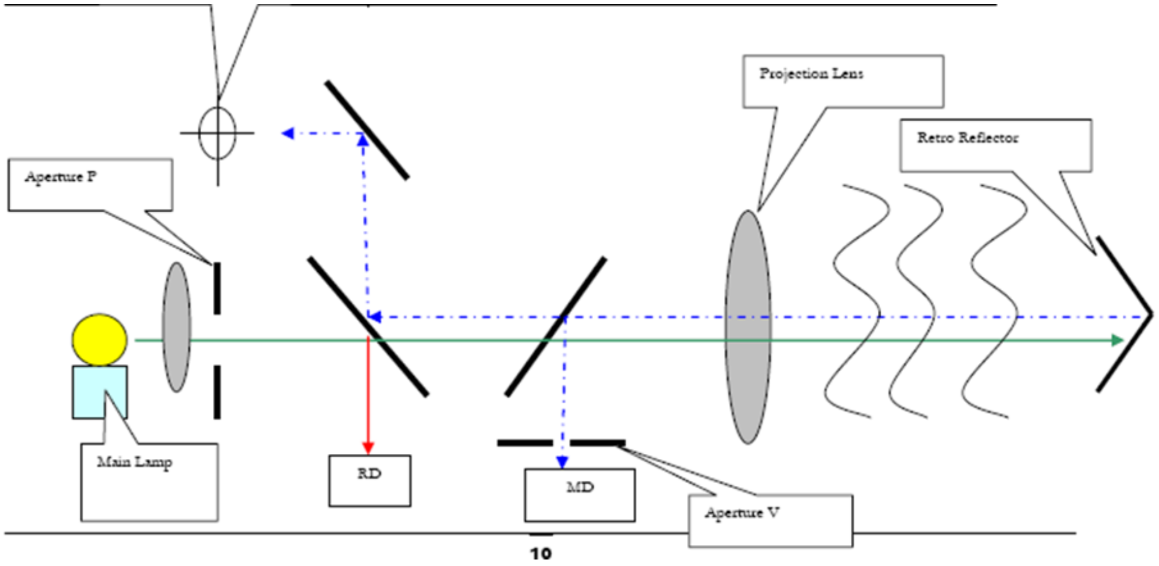


Figure 15 Shows the typical arrangement of a transmissometer with the left side showing the components internal to the instrument, and the right showing the retroreflector positioned on the opposite side of the duct.

A.2.1.3 Transmissometer – Use and limitations

The most common configuration of a transmissometer is to measure opacity, which is a direct correlation to Ringlemann and dark smoke measurement. However, European regulation requires the measurement of mass concentration. When used to achieve this measurement, there are a number of factors that should be considered:

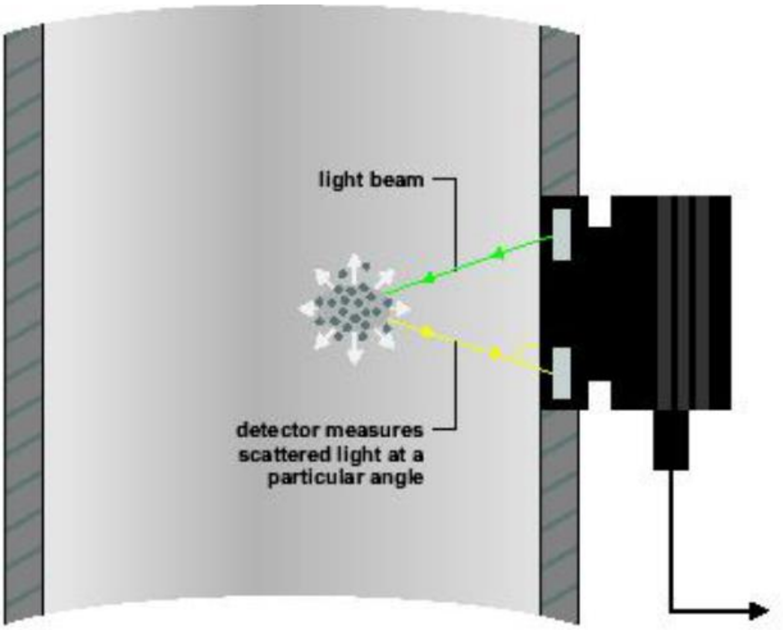
- Below dust concentrations of 10 mg m^{-3} per metre of path length, these systems generally cannot detect dust, as the response caused by the particles is typical of the zero-drift observed. The sensitivity can be increased by increasing the path length, i.e., measuring in large duct diameters;
- Dual pass units which use retro- reflectors suffer less from alignment issues between the source and detector than single pass units;
- The attenuation of light is influence by contamination of the lens, which appears as a higher concentration. Consequently, units are available
    - that provide a stream of air to keep the lenses clean;
    - that account for lens contamination when determining the concentration.

A.2.1.4 Light Scattering

When a particle moves across a beam of light some of the light is deflected and some is reflected. The amount of scattered light found is dependent on the number of particles present, and hence the concentration. Forward and back scattering systems are available, and the units are typically configured:

- Back scatter – source and detector are on the same side of the duct. (Figure 16) and typically at 45° to the light beam;
- Forward scatter - the source and detector are opposite to one another, but the detector is off-set by approximately 15° from the light beam.

Figure 16 - Typical arrangement of a back-scatter PM CEMS



As with any light-based system both forward and back scatter devices must be calibrated on the process, as they are dependent on the physical properties of the PM present.

Forward scatter devices are typically configured into a probe, and therefore can be mounted from a single side.

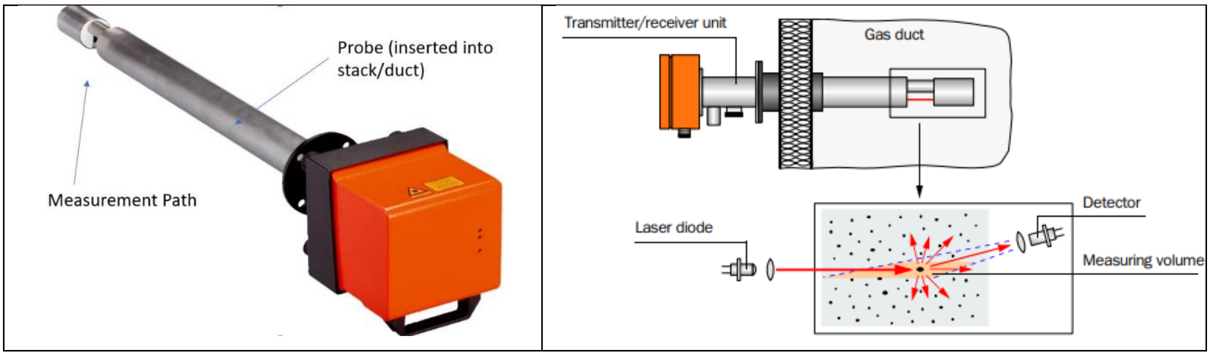
A.2.1.5 Forward scatter devices - Use and limitations

The intensity of the light is dependent on the angle that the observation, is made and other factors, such as the refractive index and the parameters mentioned in section 6.1. Both in-situ and extractive configurations are available. The in-situ systems can be configured:

- to use the duct as the measurement cell requires mounting and therefore access to both sides of the duct;
- as a probe assembly, and hence requires installation from one side of the duct. However, these units only measure a small proportion of the duct, typically 30 cm between the source and the detector;
- Air purges are required to ensure that the optical surfaces are kept clean. This is also critical if there are corrosive gases present that may etch the optics;
- It is important that the detector is shielded from the source light, and other sources of the light. Generally, this is considered with the unit design, but corrosion, and holes in the duct can lead to stray light interfering with the measurement.

These devices tend to have better sensitivity than back scatter, using LEDs and lasers, as the source of light.

Figure 17 - Example of forward scatter probe[24]



A.2.1.6 Back Scatter devices – Use and Limitations

These units are particularly sensitive to changes in particle characteristics, such as size. Often light sink is required to ensure that there are no internal duct light reflections that interfere with the measurement. In this respect, regular checking of the duct work is essential to ensure that there are no light sources other than the CEMS.

As with other systems, scintillation is affected by the presence of droplets, as they result in a flicker, as they pass through the light beam.

A.2.2 Extractive Light scatter devices

These devices enable PM measurements to be made in ducts that are below dew point (dew point is the temperature which the gas stream starts to condense)– they extract a sample of the flue gas, which is passed to a heated measurement chamber to avoid condensation of material. This is achieved by isokinetically sampling a portion of the gas stream from the duct, through a heated system that raises the sample gas stream above the dew point, so that droplets are no-longer present. The determination of PM is undertaken typically using a light-based scattering device.

Extractive light devices are typically more expensive to install, as they require additional duct work to extract a sample, and return the sample to the duct. They also require additional power supplies for heating. As with scatter devices, they are affected by particle size, shape, and density. These systems are designed to enable PM measurements to be made in wet gases, i.e., in the presence of droplets, which are not differentiated from PM, as they attenuate the light between the source and detector, consequently, will be seen as PM. Figure 18 **Error! Reference source not found.Error! Reference source not found.**shows the typical arrangement of an extractive PM sampling CEMS. This isokinetically extracts a portion of the gas stream from the duct, via heated lines, and heated sample cell, which ensures that there are no droplets present. This situation can be found after wet scrubbers, or on processes that involve high moisture contents. Heating the gas stream to above the dew point prevents droplets in the measurement section. The PM concentration is then measured using a light-based system, e.g. forward scattering. After passing through the measurement cell, the sample gas stream is ducted back into the stack.

Figure 18 - Example of an Extractive PM Sampler[25]

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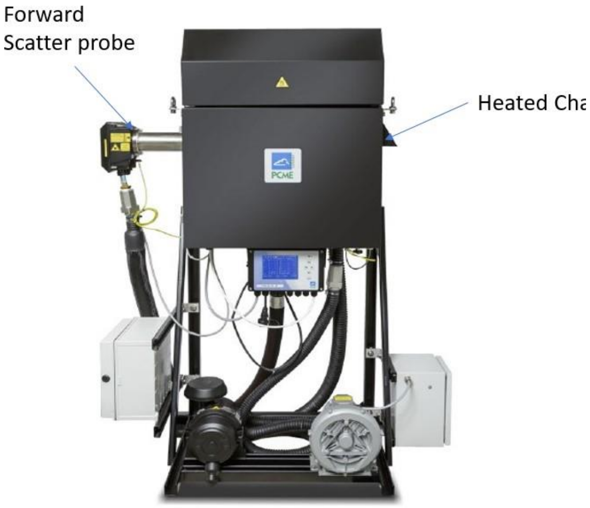
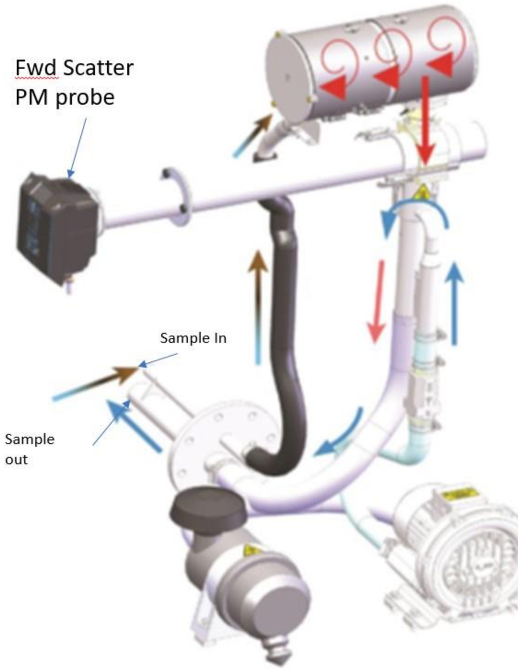
[24] Courtesy of SICK UK

[25] Courtesy of Envea





These systems are relatively inexpensive to install and operate but are capitally expensive to purchase.

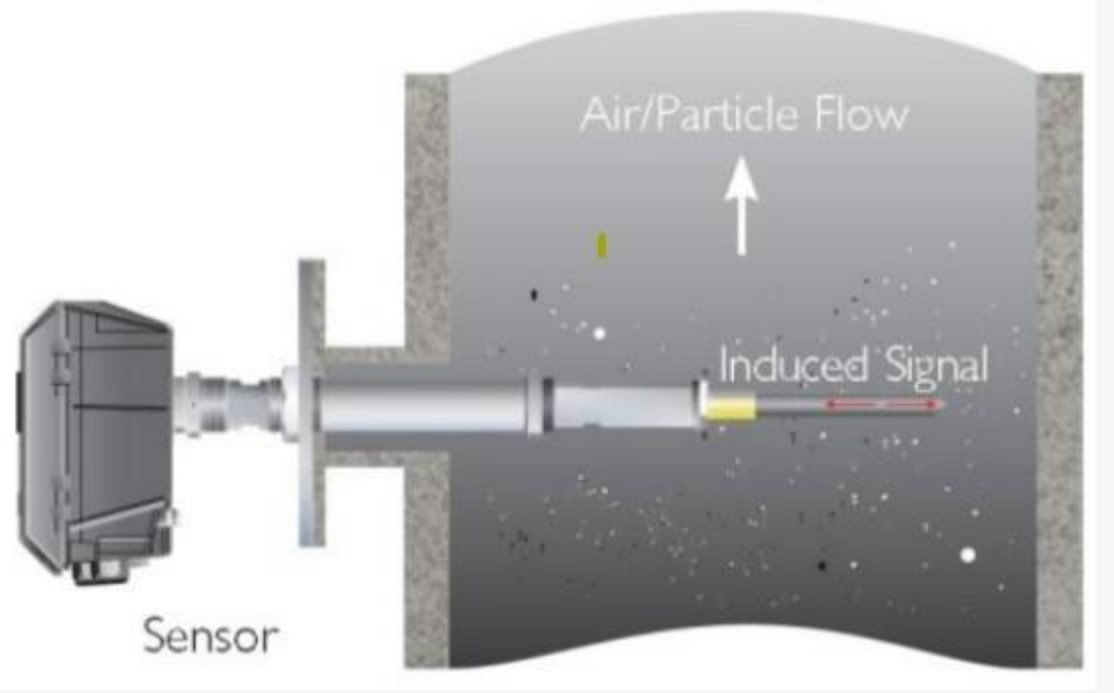
A.2.3 Optical Scintillation Light ‘Flicker’

This type of measurement has been developed from transmissometers, but rather than measuring the attenuation of the light beam, these utilise the flicker resulting from the passage of a particle through the light beam. They are arranged so that a transmitter and receiver are arranged on either side of a duct, and connected to the same processor. The particles passing through the beam result in a modulating signal being received at the detector. The ratio of the fluctuations in the light (scintillations) to the average light intensity at the detector is proportional to the particle concentration. Using this approach has the benefit of cancelling out the impact of degradation of the lamp, drift, and optical fouling. These units are affected by the presence of droplets and perform better in dry ducts.

A.2.4 Probe Electrification – Charge transfer-based systems

The probe is inserted into the stack (Figure 19), and responds to charge transfer and generation resulting from the impact and proximity of moving particles to the probe.

Figure 19 - Typical charge-sensing probe



This type of monitor detects three different effects, which are a consequence of PM moving in the duct past the probe:

- Charge transfer by direct impact;
- Frictional charge resulting from impact;
- Induced charge resulting from the PM moving past the probe.

There are some factors that limit the use of these systems, such it is recommended that they are not used after electrostatic precipitators. These systems are dependent on measuring a current, consequently care is needed to ensure that the probes are isolated from any metal, e.g., duct work. In some cases, the build-up of material on the probe can result in “bridging” between the probe and the duct. This impacts on the measurement, as the charge hence current leaks away, so reducing the measured current, therefore results will be lower than actual concentration. This affect can also be seen in high moisture content ducts, where moisture condenses on the surface of the duct and probe.

Figure 20 shows the components typical of a tribo- based PM monitor:

- a probe that is positioned in the stack following location requirements;
- A control module;
- Data logging system and interface;

These systems can collect data from a number of sensors into one data logging system.

Figure 20 - Example of Tribo electric probe CEMS

A.2.4.1 Tribo-electric systems

These are the simplest version of this technology measuring the DC charge that is developed when particles directly collide with the probe. These can be affected by:

- Contamination – build-up of material on the probe;
- Shorting of the probe, and therefore loss of charge. This effect can be reduced by an insulator between the probe, and the mounting to the stack or an air purge. However, this needs regular cleaning, to ensure that this is not bridged, due to high PM concentrations and/or moisture condensing;
- Velocity and changes in velocity. A minimum velocity of 5 ms^{-1} is required to develop enough charge to enable measurement.

These systems are widely used as bag filter monitoring devices checking for bag failure, to ensure optimum efficiency of the filtration device.

When used to measure concentration, these devices need to be calibrated against a reference method (Appendix 2).

A.2.4.2 AC or Electrodynamic CEMS

These units monitor the AC current developed by particles moving past the probe, and not the DC generated from impaction. This results in the impact of probe contamination being significantly reduced. Also, monitoring a narrow range of current reduces the impact of gas velocity on the measurement. An insulator is required to ensure quality of measurement. This must be kept clean, to ensure accuracy/quality of measurement. It is recommended that:

- They should not be used after ESP's;
- If the stack diameter is greater than 3m, multiple probes should be used;
- Velocity should be between 8-20 ms^{-1};
- Measurement of concentration < 50 mg m^{-3};
- Not to be used in the presence of droplets.

A.2.5 Beta Ray Attenuation

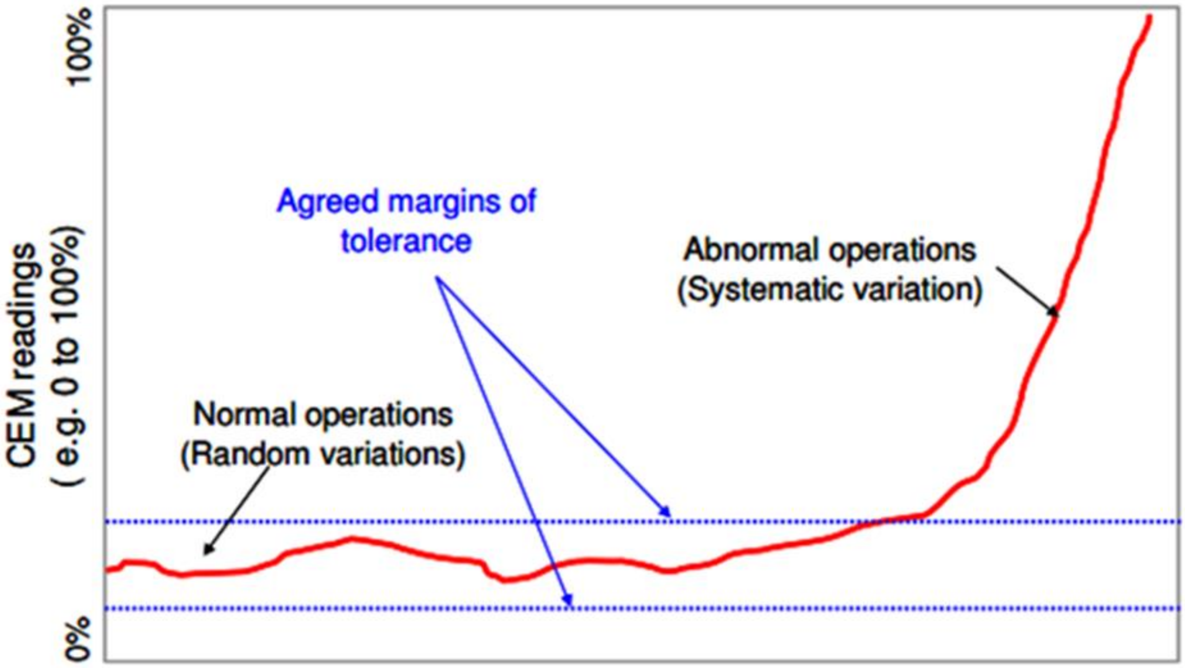
A β-ray absorption CEMS extracts a sample isokinetically (i.e.at the same velocity as found in the duct at the point), from the gas stream, through a filter tape where the PM is deposited. The thickness of the PM material on the tape is determined by measuring the reduction in β-radiation passing through the filter. The systems are designed to account for reduction in radiation levels of the sources used. Measurements of the radiation are made prior to and after the deposition of PM onto the tape, and the difference is used to determine the amount of PM present. Consequently, measurements are not continuous in nature.

A.2.6 Indicative PM CEMS

The above techniques under certain conditions may provide concentration information that can be classed as indicative information. An example of a typical output from a PM CEMS operating as an indicative devise is shown in Figure 21. This approach is used for both compliance and abatement monitoring, and usually involves:

- Displaying emission data in real time, to provide a visualisation of the data. This can be done utilising a data acquisition and handling system (DAHS);
- Agree warning and action limits with the EPA. This acts as an alarm level at which action to maintain the performance of the abatement system, and hence ensure emission are maintained at acceptable levels;
- On an alarm (when output rises above tolerance levels) the operator takes action to investigate cause, and take appropriate action to return to compliance.

Figure 21 - Typical output from an Indicative PM CEMS



A.2.7 Selection of PM CEMS

Technologies used to monitor PM are influenced by different factors, so CEMS selection requires an understanding of the process to be monitored, and the measurement technology, to achieve acceptable quality of measurement and the long-term operating capability of the unit. Table 10 shows the requirements and capabilities of PM Monitoring technologies.

Measurement Technology		Stack Diameter (m)	Concentration mg m^{-3}		Filter type	Dry	Humid	Wet	Velocity Dependant
			Min	Max					
Probe Electrification	Charge Induction (AC)	0.2-4	0.1	1000	Bag, Cyclone, none	Y	Y	Y	No (8-20 msec $^{-1}$)
	Combination AC & DC	0.2 – 2	1.0	1000	Bag, Cyclone	Y	Y	Y	Y
Transmissometry	Opacity	2-10	30	1000	EP	Y	Y	Y	N
Scattered Light	Forward		<0.1	300	Bag cyclone EP	Y	Y	Y	N
	Back		10	500	Bag cyclone EP	Y	Y	Y	N
Extractive	Light Scatter				Wet Scrubber			Y	

Table 10 - Characteristics of PM CEMS

A.2.8 Calibrating PM CEMS

Calibration of a PM CEMS usually takes place once or twice a year, depending on the model, and the manufacturers requirements. As a consequence of not measuring PM concentration directly, the monitor has to be recalibrated every time there is significant change that results in a change in the physical characteristics of the PM being measured, e.g., change of fuel, or a change of abatement.

The differences between measurement techniques, the PM concentration, and the influence of particle size, shape, and colour means that a CEMS must be calibrated on the process being measured. This requires the use of reference standards. However, there are situations such as highly efficient abatement when the measured values fall significantly below the ELV, and below the verified performance of the SRM. In this case the unit becomes an indicative device.

On processes that are not required to meet the requirements of EN 14181, but are still required to calibrate PM monitors, an alternative standard methodology is provided in ISO 10155[26]. The procedure involves comparing the averages of the SRM and the CEMS output to generate a calibration factor.

An alternative to monitoring PM emissions is to use dust monitors to ensure the performance of abatement systems and ensure environmental protection. The standard EN 17389 can be used[27] to undertake this verification.

A.2.8.1 Performance checking of PM monitors

This is generally achieved by using surrogate materials that influence the means of detection by a known quantity. As an example, diffraction gratings are used to attenuate the light when undertaking linearity or function checks on a light-based system.

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[26] ISO 10155 Stationary source emissions -- Automated monitoring of mass concentrations of particles -- Performance characteristics, test methods and specifications

[27] EN 17389 Stationary source emissions – quality assurance and quality control procedures for automated dust arrestment plant monitors

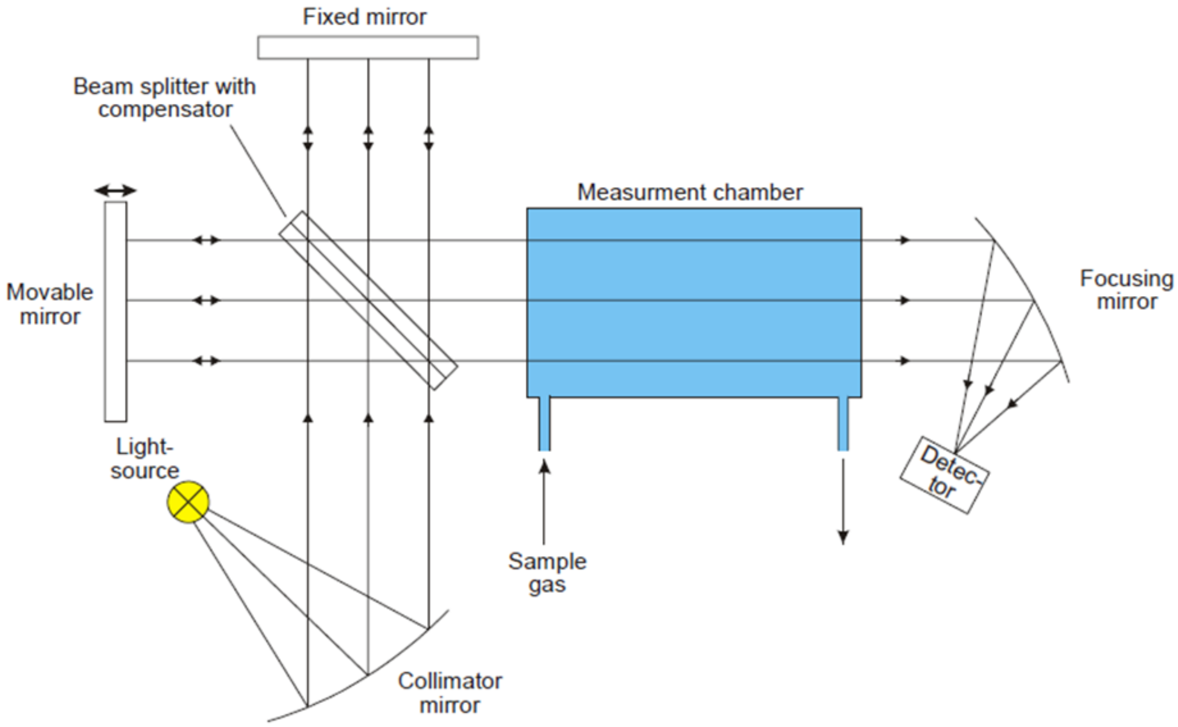
Appendix 3 – Detection Principles Gases

A.3 Gaseous Species

A.3.1 Fourier Transform Infra-Red detection

Fourier Transform Infra-Red (FTIR) gas analysers (Figure 22) identify and measure gaseous compounds by their absorbance of infrared radiation. This is possible because every molecular structure has a unique combination of atoms, and therefore produces a unique spectrum when exposed to infrared light. Instrumental analysis of the spectrum (2 to 12 micrometre wavelength) enables the qualitative identification and quantitative analysis of the gaseous compounds in the sample gas. Importantly, FTIR analysers are able to simultaneously measure CO_2, CO, SO_2, NO, NO_2, HCl, H_2O, and other analytes in complex gas matrices, detecting virtually all gas-phase species (both organic and inorganic), except diatomic elements such as N_2, O_2, and noble gases, such as Helium and Neon.

Figure 22 - Schematic of an FTIR CEMS



A FTIR gas analyser collects a complete infrared spectrum (a measurement of the infrared light absorbed by molecules inside the sample gas cell) ten times per second. The actual concentrations of gases are calculated from the resulting sample spectrum using a patented analysis algorithm.

The CEMS has the capability to measure additional components by developing process -specific applications comprising infrared spectra in a library, which can be used to identify and quantify components in a sample. CEMS using FTIR that have been certified have a defined application containing the components required to be monitored. These systems are usually configured as hot wet, as it is capable of measuring water.

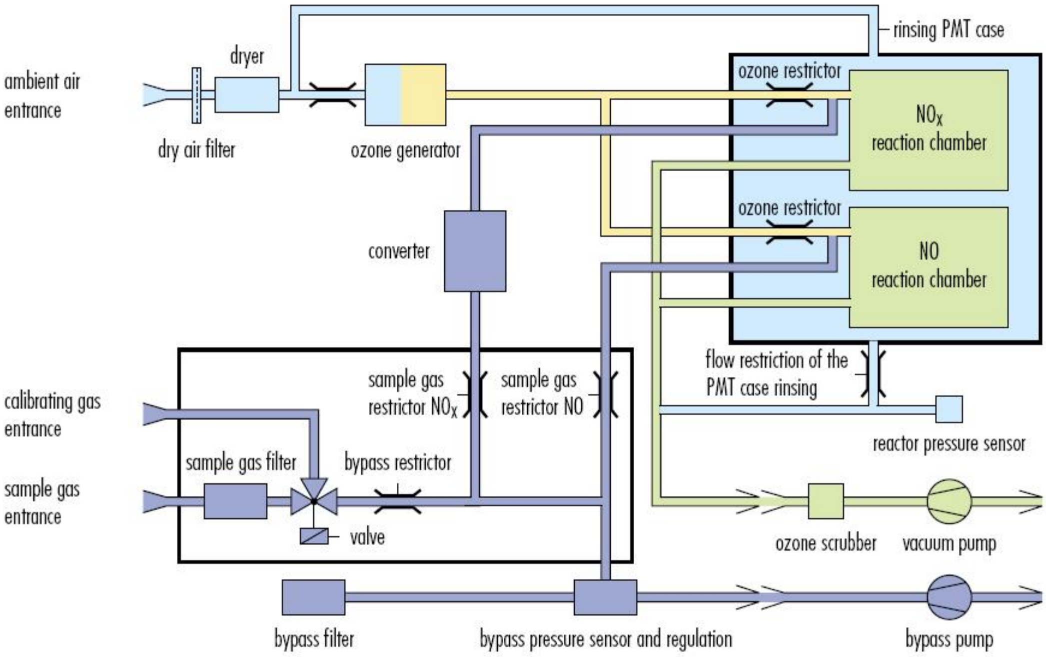
A.3.2 Chemiluminescence

This analyser utilises the reaction between nitric oxide (NO) and ozone (O_3), which results in the emission of light. This light is proportional to the concentration of NO present. The reaction is

$$NO + O_3 \rightarrow NO_2 + O_2 + h_v$$

Hence the method only measures NO, and any NO_2 present needs to be converted to NO, before analysis, to provide a total oxides of nitrogen measurement. This methodology forms the principle of detection behind the CEN reference method for the measurement of oxides of nitrogen (NOx). Figure 23 shows a schematic of an analyser

Figure 23 - Typical Chemiluminescence analyser

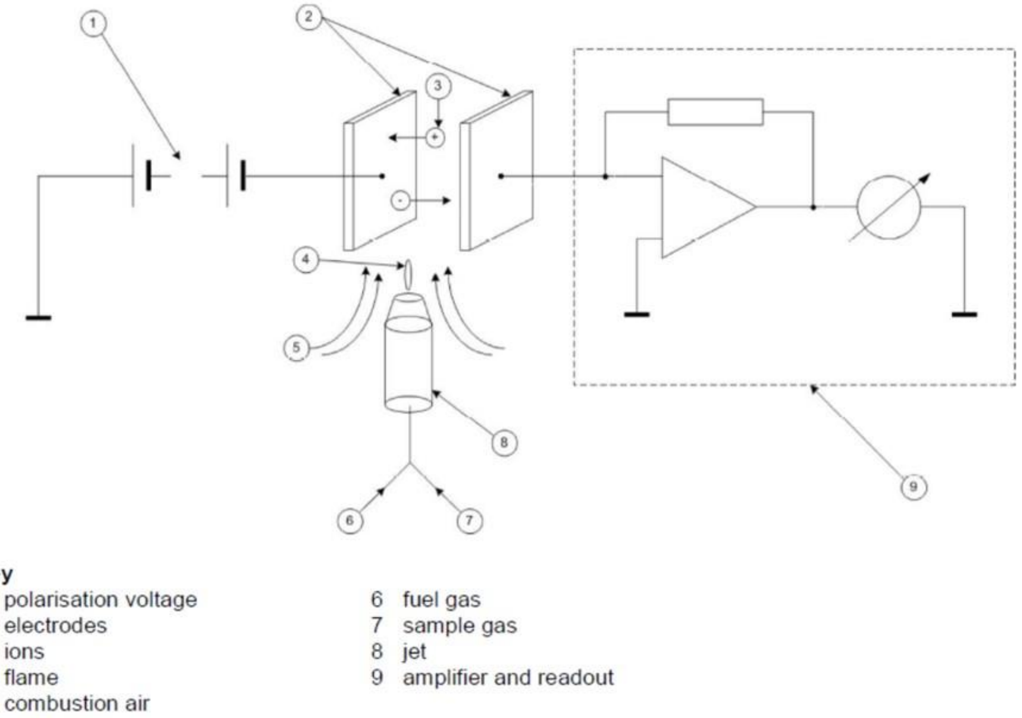


A.3.3 Flame Ionisation Detector

Organic carbon compounds are relatively easily ionisable using a flame ionisation detector (FID). A FID uses either a hydrogen or hydrogen/helium fuelled flame to ionise organic molecules. The resulting cloud of charged ions generate a current between charged electrodes by applying an electric field. This current is approximately proportional across several orders of magnitude to the mass flow rate of organic bound carbon atoms, and hence can be related to the number/concentration of organic molecules present.

However, not all bonds within the organic molecule ionise in the same way, this is dependent on the structural bond of the C atoms in a particular molecule. Consequently, this can produce different responses for different molecules (response factors). However, if the molecules present are known then it is possible to develop an overall response factor for a gas stream. A typical arrangement for an FID is shown in Figure 24

Figure 24 - Configuration of FID analyser



Key
1 polarisation voltage
2 electrodes
3 ions
4 flame
5 combustion air
6 fuel gas
7 sample gas
8 jet
9 amplifier and readout

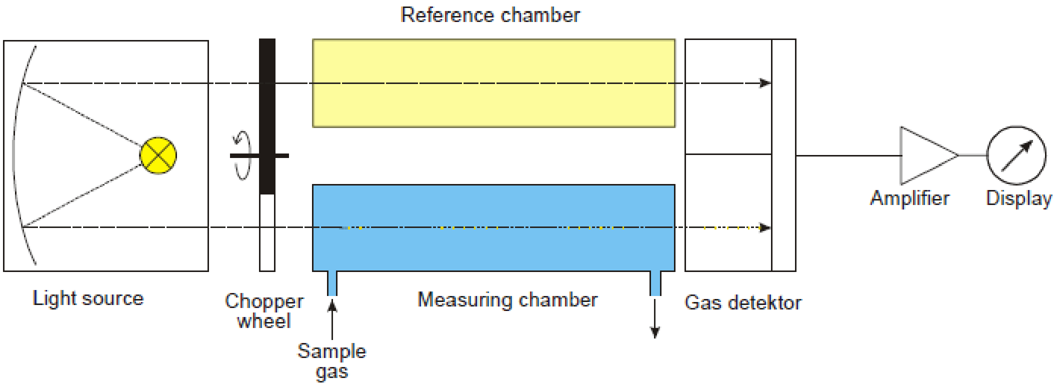
The measurement of TVOC are made wet, and the sampling train shall include:

- Heated particle filter;
- Heated transport lines - these maybe heated across a range of temperatures range from just in line with process emission temperatures to 180°C for a combustion process;
- The FID themselves are heated;
- Care should be taken with the exhausts from the FID, as this is a point where condensation is likely to take place. Under low temperature conditions, it is possible for ice to form, and cause an increase in pressure in the sample cell;
- Care should be taken as to the supply of combustion air. If this is plant air this should be carefully cleaned to be sure that it is VOC free, especially if the plant is using an oil-based compressor. Also, if the FID is drawing its combustion air from the local environment, this needs to be VOC free. The FID will respond to VOC's drawn into the measurement cell even if this is incorporated in the combustion air.
- The location of the unit must be considered carefully, especially if there are hazardous zones involved. This will also impact on the design of the CEMS.

A.3.4 Photoionization Detector (PID)

A photo ionisation detector Ultraviolet light is used to ionise organic moles, and then measures the current produced by the movement of the charged ions produced. These are non-selective, i.e., they will produce a response to a mixture of organic compounds in a similar way to an FID. Also like the FID, it is possible to develop a response factor, if the composition of the gas is known.

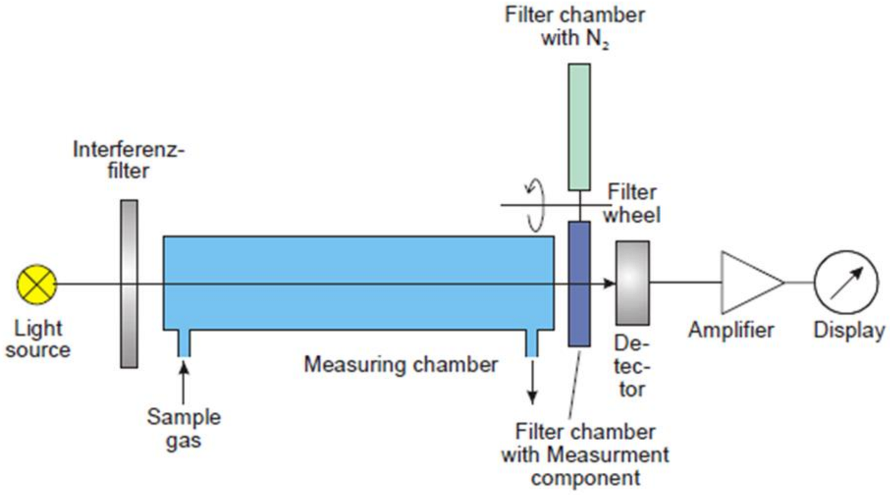
A.3.4.1 Non-dispersive infrared absorption



Non-dispersive infrared absorption (NDIR) is typically applied to measure pollutants, such a carbon monoxide (CO), sulphur dioxide (SO_2), and nitric oxide (NO), but can also be applied to hydrocarbon pollutants. This principle is a selective detector using absorption of light at specific energies to determine concentration according to the Beer Lambert law. The analyser assesses differences between the reference cell and the measuring cell, to determine the concentration of the measured component. As with all IR systems, water is a significant interference, so conditioning to remove moisture prior to the measurement is critical. The conditioning system has to be carefully designed, as this can have a negative impact on measurement quality.

To eliminate some of the interferences, the detector contains the component to be measured. Multiple components can be measured utilising a number of components contained in the system. Gas filter correlation (Figure 25) is a variation on this configuration and is aimed at reducing the potential for interferences from other absorbing components. This uses a combined filter wheel, rather than a second cell, and is used to measure IR absorbing components such as CO2, CO, SO_2, and NO, etc.

Figure 25 - Typical Gas filter Correlation device



A.3.5 Lower Explosive Limit instruments

This type of analyser is used to determine lower explosive limit (LEL) and utilise NDIR, thermal and electrochemical technology, and are capable of measuring % levels of VOC that relate to the explosive limit of a gas. They are not compound specific, and are generally calibrated to measure methane, but indicated as a percentage of the lower explosive limit (% LEL). The LEL for methane is 5%. These analysers have an effective measurement range of 0-100% LEL (0-5% if methane). These analysers can be intrinsically safe for use in high risk zones.

An LEL meter applied for personal or area safety is not intended to pin-point leaks, but to alert staff to potentially high levels of methane. However, similar technologies are also used by gas fitters and others to monitor for leaks in pipework.

Several techniques are applied but the main detection techniques and measurements for portable units are:

- catalytic combustion (pellistor) – flammable gas;
- infrared – hydrocarbons;
- thermal conductivity - flammable gas;
- semiconductor - flammable gas;
- flame ionisation detection - hydrocarbons.

There are international standards for the detection and measurement of combustible gases.

- EN 60079-29-1:2007 Explosive atmospheres. Gas detectors. Performance requirements of detectors for flammable gases
- EN 60079-29-2:2015 Explosive atmospheres. Gas detectors. Selection, installation, use and maintenance of detectors for flammable gases and oxygen

- EN 60079-29-4:2010 Explosive atmospheres. Gas detectors. Performance requirements of open path detectors for flammable gases
- EN 50270:2015 Electromagnetic compatibility. Electrical apparatus for the detection and measurement of combustible gases, toxic gases or oxygen

A.3.6 Techniques used for Peripheral measurements

Peripheral Measurements are required to enable measured concentrations to be corrected to a specified condition. The reporting conditions result in a change in the gas volume, in which the material is measured, and hence results in a change in concentration. These reference conditions are defined to enable a wide range of process operations in a sector to be operated, using the same ELVs.

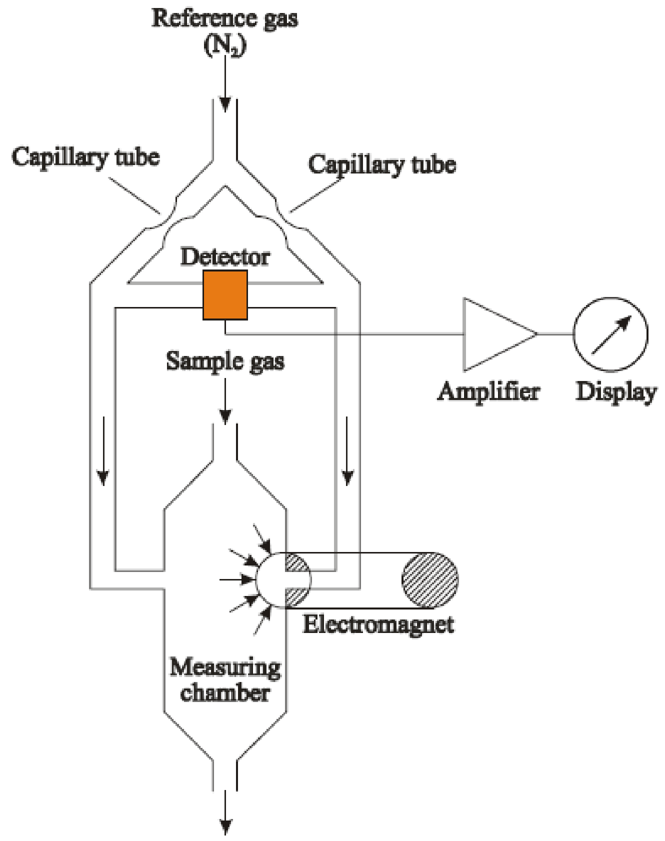
Some examples of the peripheral measures that required to enable reporting requirements are:

- Dust Concentration measured in stack with a reporting requirement of STP dry, would require the measurement of Temperature, Pressure and Moisture;
- Volume Flow rate measured in stack with a reporting requirement of STP dry, would require the measurement of Temperature, Pressure and Moisture;
- VOC Concentration measured using a FID hot wet system, with a reporting requirement to standardise conditions, e.g. STP dry 11 % O_2 would require the measurement of Moisture and Oxygen. Note that the concentration is measured in the FIDs cell which is calibrated to STP.

A.3.6.1 Oxygen - Paramagnetic

A paramagnetic oxygen analyser (Figure 26) utilises the influence of a magnetic field over an oxygen molecule, which is a consequence of the electron structure of the molecule. A typical unit consists of a nitrogen-filled glass dumb-bell suspended in a measuring chamber, so that it can rotate (deflect) from the resting position. This is partially within an uneven magnetic field. With oxygen present, the dumb-bell is deflected by the interaction of the oxygen molecules and the magnetic field. This deflection is compensated by a current flow through a coil on the dumb-bell until the dumb-bell reaches its zero position. The current required to return the dumb-bell to its zero position is proportional to the oxygen concentration.

Figure 26 - Schematic of a paramagnetic oxygen analyser



A.3.6.2 Oxygen – Zirconia

At a high temperature, zirconia becomes an electrical conductor enabling the flow of oxygen ions in its molecular lattice. A zirconia probe or cell is divided into two sections. If there are different oxygen concentration in each then a potential voltage is generated, which is proportional to the oxygen concentration.

Zirconium probes are mostly used for in situ measurements and for boiler oxygen measurements. However, there are systems that have adapted this technology to be fitted into an analyser. The capability to measure oxygen in a moist and dry gas streams enables it to be used to measure moisture content of a gas stream.

A.3.6.3 Oxygen – Electrochemical Cell

An electrochemical cell unit utilises a reaction between oxygen and an electrolyte. The electrolyte acts as an -ve electrode. The reaction produces a current between the -ve and +ve electrodes, which is proportional to the concentration of oxygen present.

These units have a limited lifetime due to the reaction depleting the electrolyte present.

A.3.6.4 Moisture

There are a number of ways of determining moisture, e.g. CEMS utilising FTIR measure moisture directly. Alternatively, there are analysers that make use of properties of both moisture and the capability of a measurement technique, such as zirconia.

A.3.6.5 Wet/Dry Oxygen measurement

The capability of zirconia to measure in both wet and dry gas streams, enables the moisture of a gas streams to be determined by measuring the difference between the two gas streams. This difference is proportional to the moisture concentration.

$$H_2O\ (\%) = 100 \times \left(\frac{O_{2\ Dry}(\%) - O_{2\ wet}(\%)}{O_{2Dry}(\%)} \right)$$

However, consideration should be taken before deciding on this approach, as at low oxygen levels (<6%), the formula does not hold, as small errors in either O_2 measurement can produce massive errors in H_2O.

A.3.6.6 IR

Moisture can be measured by IR, but presents a problem with calibration due to the lack of calibration gases. The calibration has to be undertaken using devices that generate water vapour from a known/measured quantity of water. This is usually best undertaken by the service engineer.

A.3.6.7 FTIR

FTIR has the capability to directly measure moisture. As a result of it utilising IR (moisture is a major interferent), and usually in a hot/wet configuration, it is an important part of its measurement to ensure accuracy of measurement for all of the components being measured.

Component	Configuration of CEMS		Detection principle	Characteristic	Example Process
Particulate Material	Extractive		Beta Ray Attenuation	Is independent of particle physical characteristics	
Particulate Material	Extractive	Hot/Wet	Light scattering	Suitable for use measuring ducts below dew point. e.g. after a wet scrubber	Chemical process
Particulate Material	In-situ		Light Scattering forward and back	LOD down to 1mg m^{-3}	Incineration.
Particulate Material	In situ		Transmissometer/Opacity	Must be calibrated on process as the response is dependent on particle size, composition, shape, colour and refractive index; the typical range is 10 to 2,000 mg/m^3; These are not suitable for low concentration emissions	Casting Pharmaceutical
Ammonia (NH_3)	Extractive	Hot/Wet	FTIR NDIR TDLS		
Ammonia (NH_3)	In-situ		TDLS		
Carbon Dioxide (CO_2)	Extractive	Hot			
Carbon Dioxide (CO_2)	In-situ		DOAS		
Carbon monoxide (CO)	Extractive		FTIR NDIR		

Component	Configuration of CEMS		Detection principle	Characteristic	Example Process
Hydrogen Chloride	Extractive		FTIR NDIR		
	In-situ		TDLS		
Hydrogen Fluoride	Extractive		FTIR		
Methane	Extractive		FTIR NDIR FID		
Mercury	In-situ		DOAS		
Oxides of Nitrogen	Extractive		FTIR NDIR Chemiluminescence		
Sulphur Dioxide (SO_2)	Extractive		FTIR NDIR		
Speciated VOC	Extractive		Gas Chromatography (GC)	This can be cycled continuously but does not strictly provide a continuous measurement as there is a period of analysis required (30mins)	Pharmaceutical
Speciated VOC	Extractive		FTIR	Applications can be developed to determine the concentrations of components emitted LOD ppb	Pharmaceutical

Component	Configuration of CEMS		Detection principle	Characteristic	Example Process
Speciated VOC	Extractive		NDIR	Usually measures only one compound at a time. Other compounds that have the same absorption typical water which is a major interference	Pharmaceutical
Speciated VOC	In-situ		DOAS	Typically used to measure specific VOC's e.g. Benzene	Pharmaceutical
Total VOC	Extractive		FID	A carbon counter Oxygen is an interferent. It is possible to develop a response factor that increases the accuracy of measurement when the composition of the gas stream is known.	Pharmaceutical
High level VOC	In-situ		DOAS	Used to measure specific compounds	Pharmaceutical
	Extractive		FTIR	Can measure individual compounds present (ppb)	Pharmaceutical
	Extractive		NDIR	Use to measure individual compounds (ppm)	Pharmaceutical
	Extractive		Continuously cycling Gas Chromatography	Not truly continuous typically 30 cycle time	Pharmaceutical
LEL	Extractive		catalytic combustion (pellistor) – flammable gas, infrared - hydrocarbons	Measured quantity - %LEL or flammable gas concentration Continuous or integrated	Petrol Storage

Component	Configuration of CEMS		Detection principle	Characteristic	Example Process
			thermal conductivity - flammable gas semiconductor - flammable gas flame ionisation detection - hydrocarbons.	measurement - continuous Complexity – simple Deployment period – short or long term Measure in the range 1–10,000 ppm (but limit of detection and higher range boundary depends on detection technique and application). catalytic technique is sensitive to low oxygen atmospheres or very high methane (greater than 12%). Catalytic, conductivity and semiconductor systems can become ‘poisoned’ or consumed with use. Certified units are suitable for use in flammable atmosphere (intrinsically safe), rugged and portable.	
TDLS	In-situ				

Table 11 - Appropriate technologies for specific pollutants

A.3.7 Measurement of Ammonia (NH_3)

Ammonia can be emitted directly from a process, or as a product of a control system, such as NO_X control. The measurement of ammonia is undertake using a number of the detection principles listed in Appendix 2 (TDL, IR, FTIR and Chemiluminescence). As a consequence of the nature and chemical characteristics, a critical component of any CEMS measuring Ammonia is the system design. This can result in the sample being lost in the transport lines, so care needs to be taken when designing and operating the system.

A.3.8 Measurement of Carbon Monoxide (CO)

Carbon monoxide (CO) can be measured utilising;

- IR;
- NDIR;
- FTIR;
- Electrochemical.

A.3.9 Measurement of Hydrogen Chloride (HCl)

Hydrogen Chloride (HCl) can be measured using both in-situ and extractive CEMS systems utilising

- IR;
- FTIR;
- Tuneable diode laser.

The materials and construction of any gas conditioning system are critical to avoid cold spots, where condensation could occur. HCl is soluble and very reactive, so any moisture that forms within can result in the loss of sample, possibly internal corrosion, and reaction with other components present in the gas stream.

Care should be taken when utilising calibration HCl gases, due to the reactivity of the gas. It is suggested that:

- the lines between calibration gas bottle and analyser should be kept as short as possible;
- the lines should also be kept dry;
- Gases should be passed through the lines until a stable reading is achieved. This may result in the use of large quantities of gases.

A.3.10 Measurement of Oxides of Nitrogen (NO_X)

Oxides of Nitrogen are defined as Nitric Oxide (NO) and Nitrogen Dioxide (NO_2), and are reported as NO_2. However, there are a number of ways to measure the NO_X:

- Measurement of NO with a NO_X converter. The converts any NO_2 present to NO. The total NO present is then measured. The converters are required to have an efficiency greater than 95%, and requires regular checks ensure that this level of performance is maintained;
- Measurement of NO and NO_2, this can be done using FTIR, and some Chemiluminescence analysers, which have inbuilt converters;
- Measurement of NO only and the addition of a percentage to account for the NO_2. This is used when the proportion of NO_2 present is usually less than 5% of the total NO_x present.

There are some processes such as gas turbines, nitric acid and fertiliser plants where the ratio of NO to NO_2 varies, and consequently only the first and second approaches can be used.

A.3.11 Measurement of Mercury

Measurement of mercury can be undertaken by both extractive and in-situ systems, and utilise different detection principles.

- Extractive systems employ CVASS with a gold trap, Zeeman AAS;
- In-situ systems employ DOAS.

A.3.11.1 Zeeman atomic absorption spectroscopy (Zeeman AAS):

CEMS have been developed to continuously measure mercury (Hg) concentration in flue gas photometrically by means of Zeeman atomic absorption spectroscopy (Zeeman AAS). An Hg discharge lamp emits light in the element-specific wavelength. In the presence of a strong magnetic field generated around the lamp, this light is divided into several components, which form the measuring and reference wavelengths simultaneously (Zeeman effect). The advantage here is that there are no moving parts and that cross sensitivities, lamp deterioration, and contamination are compensated for directly.

Total Hg can be measured by utilising a heated system that volatises any Hg associated with particulate present so that all Hg present is in the form of vapour.

A.3.11.2 Cold Vapor Atom Absorption Spectrometry (CVAAS) with gold trap

This method follows the sample principles as other forms of absorption spectroscopy. However, a UV lamp is used and a specific wavelength of 253.7nm is measured. The reduction in this wavelength is proportional to the concentration of mercury present in fused silica optical cell. AAS, because it is specific to particular atoms, is not susceptible to interferences that are present in reactions such as fluorescence. Combining this with a UV lam producing a narrow band of wavelengths, so interferences are further reduced.

The presence of a gold trap results in enhancement of the sensitivity where mercury present is absorbed and concentrated onto the surface of the gold. This is then subsequently released.

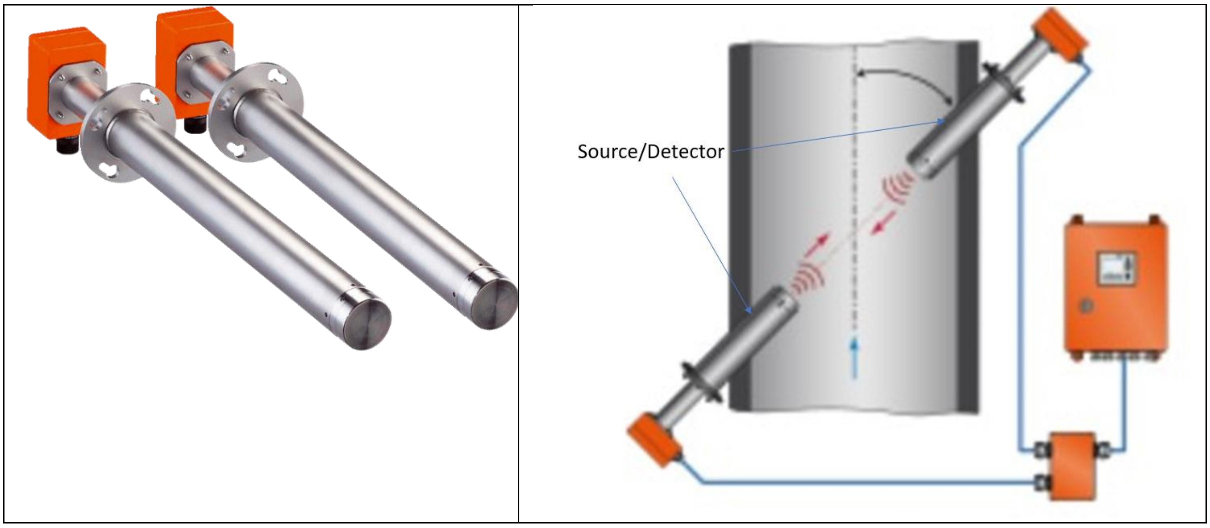
A.3.11.3 Calibration of Mercury CEMS

Mercury CEMS are calibrated using a calibration gas generator that provides known concentrations of mercury vapour from elemental mercury. Some units can provide concentrations of mercury chloride. These systems control pressure and temperature to ensure that required concentrations of mercury are produced.

A.3.12 Ultrasonic flow measurement

Figure 27 shows a typical ultrasonic flow measurement CEMS, and the orientation when installed into a stack or duct.

Figure 27 - Typical Ultrasonic Flow measurement[28]



Ultrasonic flow monitors use pulses of sound in the ultrasonic range, up and downstream of the flow as shown in Figure 27, i.e., with and against the flow. Measurement of the time taken for the two pulses to travel between units enables the vertical component, i.e., the stack velocity to be determined. The units are typically arranged at 45° to the duct. This arrangement requires units to be installed on either side of the duct. Where there are access issues, there are systems available utilising ultrasonic flow measurement that are arranged in probe system. Consequently, these can be installed from one side of the duct.

A.3.13 Pitot tubes and differential pressure measurement

Pitot tubes form the basis of the reference method for flow measurement, and for measurements where flow is critical, such as for PM. There are a variety of configurations, but all basically comprise of two inlets or tubes. One of which is directed into the flow (Total), and the other directly out of the flow (Static pressure within the duct). The difference between these two measurements is directly

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[28] Courtesy of SICK UK

related to the velocity at the point of measurement. The fact that the pitot can only measure at one point increases the uncertainty, when used for continuous flow measurement across a large duct.

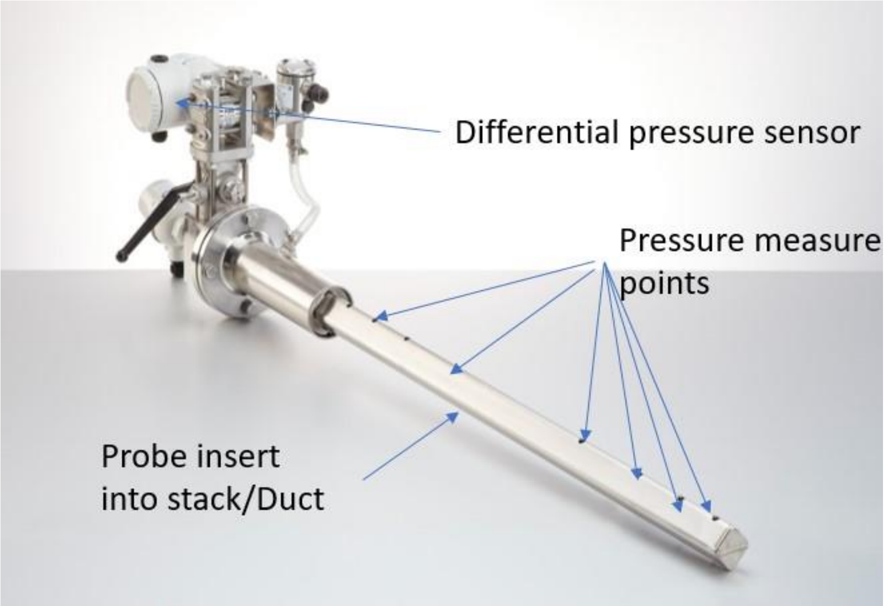
To measure the differential pressure between the total and static lines, a differential pressure cell or manometer is used. These probes can be fixed units measuring at one point in the duct. The selection of the point is important, and should be representative of the average flow rate.

To calculate the velocity and volumetric flowrate the molecular weight of stack gases must be measured.

A.3.13.1 Averaging differential pressure probes

These are modified forms, as pitot comprising a probe that is inserted into the stack either fully, or halfway across the diameter. The probe has a series of holes strategically positioned to enable the average total measurement, and average static measurement to be made, hence providing differential pressure that is related to the total flow in the duct

Figure 28 - Averaging differential pressure pitot[29]



This type of pitot can be arranged across two perpendicular diameters improving the overall accuracy of the flow measurement. All forms of pitot’s are susceptible to blockage by particles and droplets. The impact of which can be reduced by the installation of a back-purge system.

A.3.13.2 Thermal flow meters

These units utilise the cooling effect of the gas stream passing the sensor, i.e., heat is removed from the sensor by the gas stream. The cooing of the sensor is off-set by increasing the heating of the sensor to maintain its temperature (20-40°C above stack). The power required to provide this heating is proportional to mass flow in the duct.

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[29] Courtesy of Durag

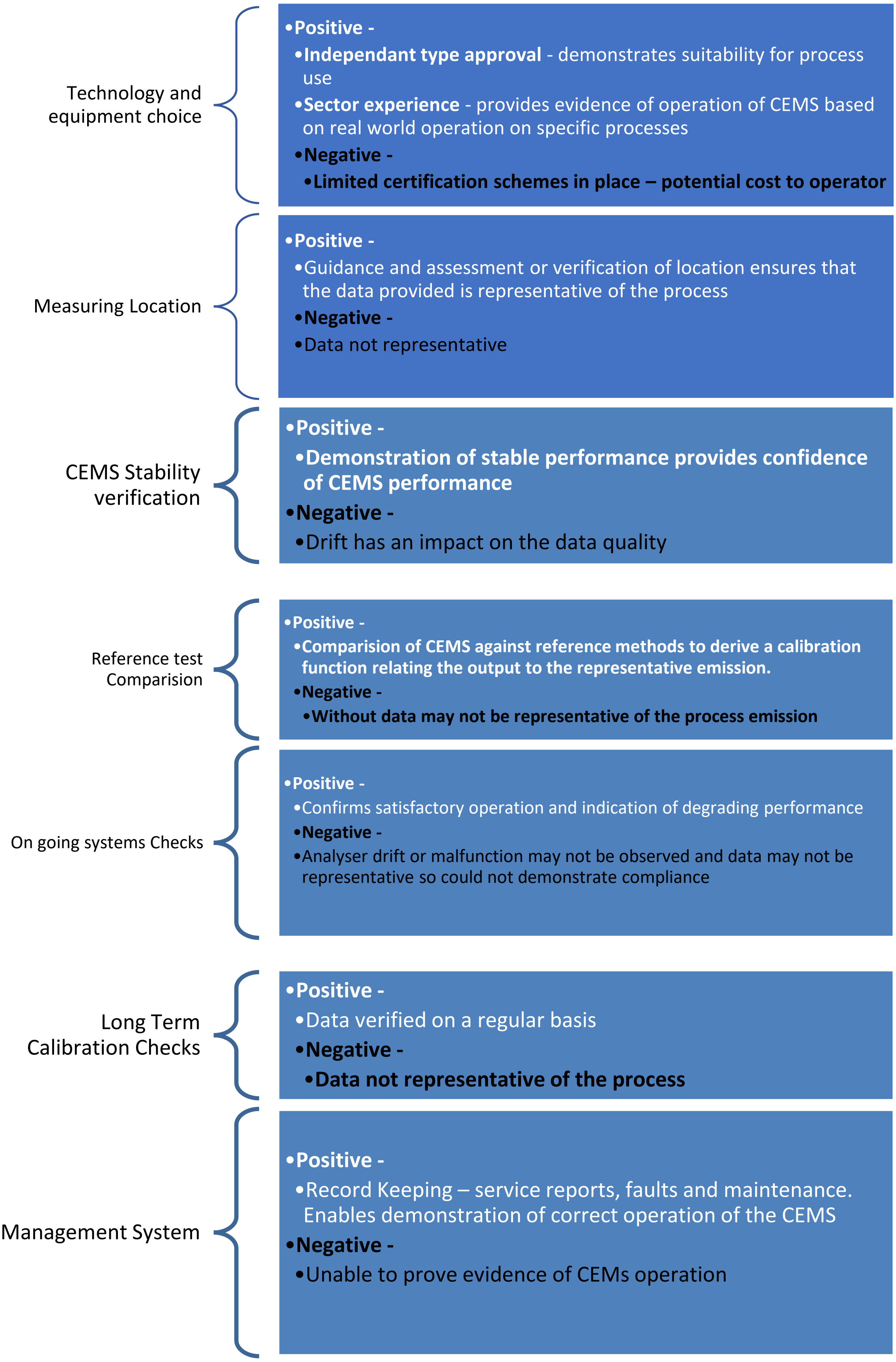
Figure 29 - Thermal flow meter

A.3.13.3 Vortex Flow meters

A strut across the measurement area is used to create turbulence. The number of vortices produced is proportional to the gas flow and can be measured using an ultrasonic sensor.

Appendix 4 – CEMS Best practice

Figure 30 - CEMS Best Practice



Technology and equipment choice

- **Positive -**
  - **Independant type approval** - demonstrates suitability for process use
  - **Sector experience** - provides evidence of operation of CEMS based on real world operation on specific processes
  - **Negative -**
    - **Limited certification schemes in place – potential cost to operator**

Measuring Location

- **Positive -**
  - Guidance and assessment or verification of location ensures that the data provided is representative of the process
  - **Negative -**
  - Data not representative

CEMS Stability verification

- **Positive -**
  - **Demonstration of stable performance provides confidence of CEMS performance**
- **Negative -**
  - Drift has an impact on the data quality

Reference test Comparision

- **Positive -**
  - **Comparision of CEMS against reference methods to derive a calibration function relating the output to the representative emission.**
  - **Negative -**
    - **Without data may not be representative of the process emission**

On going systems Checks

- **Positive -**
  - Confirms satisfactory operation and indication of degrading performance
  - **Negative -**
  - Analyser drift or malfunction may not be observed and data may not be representative so could not demonstrate compliance

Long Term Calibration Checks

- **Positive -**
  - Data verified on a regular basis
  - **Negative -**
    - **Data not representative of the process**

Management System

- **Positive -**
  - Record Keeping – service reports, faults and maintenance. Enables demonstration of correct operation of the CEMS
- **Negative -**
  - Unable to prove evidence of CEMs operation

Data Validity

- **Positive -**
  - Demonstration of compliance
  - **Negative -**
    - **Data not representative of the process**

Supplier Support

- **Positive -**
  - Maintence contracts - limit the amount of time continuous emission data is unavailable
- **Negative -**
  - Unable to demonstrate compliance

Quality of calibration gases and reference materials

- **Positive -**
  - Ensures traceability of data produced
  - **Negative -**
    - **Unreliable data**

Redundacy

- **Positive -**
  - Installation of a second system reduces the loss of data (or plant operation) due to CEMS failure
- **Negative -**
  - Additional Costs