The installation and operation of continuous particulate emission monitors in industrial processes has become well developed and common practice in industrial stacks and ducts over the past 30 years reflecting regulatory monitoring requirements. It supports requirements originating from LAPPC (Local Air Pollution Prevention and Control), IPPC (Integrated Pollution Prevention and Control), WID (Waste Incineration Directive) and LCPD (Large Combustion Plant Directive) legislation.

This guide provides an up to date overview of the issues effecting the quality and type of data which may be obtained in a specific industrial installation. Issues covered are:

- The type of monitoring provided by the instrument (e.g. QAL1 or filter leak monitoring) in response to different regulatory requirements
- The technology and Quality Assurance (QA features) of the instrument
- The installation considerations, instrument maintenance requirements and types of calibration/configuration procedures
Types of Continuous Monitoring of Particulate

Regulators in the UK tend to specify one of five types of continuous particulate monitoring depending on the purpose of the monitoring and the relevance of any EU directives. This has implications on the type of instrument that is selected and the type of calibration procedure that is applied to the instrument.

<table>
<thead>
<tr>
<th>Type of Continuous Monitoring</th>
<th>Type of Instrument required</th>
<th>Annual calibration procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg/m³ with uncertainties according to EN-14181</td>
<td>QAL 1 approved CEM (class 1 MCERTS)</td>
<td>QAL2 or AST including functionality test and multiple isokinetic samples</td>
</tr>
<tr>
<td>Quantitative monitoring in mg/m³</td>
<td>CEM capable of being calibrated e.g. (Class 1 or Class 2 MCERTS approved)</td>
<td>Functionality test and multiple isokinetic samples (see EA guidance RM QG-6)</td>
</tr>
<tr>
<td>Qualitative monitoring (approximate mg/m³)</td>
<td>CEM with output related to dust concentration (eg Class 2 MCERTS as a minimum)</td>
<td>Isokinetic samples plus instrument health check</td>
</tr>
<tr>
<td>Filter leak monitor</td>
<td>Filter leak monitor with trend output (eg Class 3 MCERTS) however Class 1 or Class 2 instrument can also be used</td>
<td>Configure outputs and Instrument health check</td>
</tr>
<tr>
<td>Gross filter failure detection</td>
<td>Instrument designed to detect large changes in emissions</td>
<td>Check alarm and Instrument health check</td>
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</table>

Processes regulated under LAPPC will also be familiar with the term ‘indicative’ monitoring which is usually interpreted as ‘filter leak’ monitoring, however in cases where the instrument is also approximately scaled by reference to an isokinetic test this should be considered as qualitative monitoring. Reflecting changes brought about in the recent review of Process Guidance Notes, Local Authorities are moving to specify ‘qualitative’ or ‘filter leak’ requirements more explicitly.

MCERTS is the Environment Agency’s monitoring scheme used to promote the adoption of appropriate quality self monitoring and there is a specific certification process which applies to Continuous Emission Monitors (CEMS). This has recently updated to version 3.1 and has 3 classes of particulate monitors (QAL1 CEMS, filter dust monitors and filter leak monitors). It should be noted that while plant operators are not required to use MCERTS approved instruments in the UK except in WID and LCPD plant (where QAL1 instruments must be used), it is common for plant operators (especially in processes regulated by the Environment Agency) to use MCERTS instruments for two reasons:

1) The OMA (Operator Monitoring Assessment) scheme, applied to processes regulated under WID, LCPD and IPPC, encourages the use of MCERTS certified CEMS with its assessment criteria
2) MCERTS certification provides plant operators confidence that they have adopted Best Available Technique (BAT) and that the CEM is likely to be fit for purpose (provided used in the correct application)

Types of Particulate Instrument

There are therefore four types of particulate instrument used to satisfy regulatory requirements.

1) QAL 1 approved CEM

A Continuous Emission Monitor (CEM) which has been independently certified to meet the European Standard EN-15267-3 (which is adopted in the MCERTS class 1 performance standard) may carry the certificate as QAL1 approved. This instrument may be used to continuously measure mg/m³ according to the uncertainties expressed in the WID and LCPD directive as well as used in other applications as specified by regulators on a case by case basis.
2) Quantitative monitor
A particulate CEM which may be used to monitor mg/m$^3$ continuously is referred to as a quantitative monitor. In the UK it is common that this instrument is also certified. The specific approval relevant to this type of instrument is MCERTS class 2 which allow slightly higher uncertainty compared to a class 1 instrument and less sophisticated on going Quality Assurance (QA) features built into the instrument. A class 1 instrument may also be used to satisfy these requirements.

Note: both QAL 1 approved CEMS and Quantitative monitors may be used in Qualitative mode when a limited number of Isokinetic samples are performed or there is reason to believe there is increased uncertainty in the results of the isokinetic sample (e.g. at dust levels below 1 mg/m$^3$ where isokinetic sampling provides confidence that dust levels are low but with less certainty)

3) Filter leak monitor
A filter leakage monitor monitors for changes in the operation of the dust arrestment plant (typically bagfilter). The plant operator is warned when there is any leakage and can fix the leak and hence bring the process in control. The trend of emissions and arrestment plant condition are obtained from an associated report. Importantly, there is confidence in data because there are self-checks on the instrument.
4) **Gross Filter failure detector**
A simple instrument provides an alarm when there is a very significant change in emissions associated with filter rupture. These instruments tend to be used only on smaller filters since they provide no information to improve the plant performance and have no trend output or Quality Assurance (QA) features to provide confidence they are working correctly.

**Technology and Design of Instruments**

Particulate CEMS measure a parameter (eg scattered light) which can be correlated to dust concentration by comparison to a gravimetric sample taken under iso-kinetic conditions (eg EN-13284-1) rather than the mass concentration directly. The performance and suitability of any particulate monitor is therefore application dependent. A number of techniques are used in practice which between them provides a practical and robust solution for most industrial applications. The core techniques used for continuous for monitoring particulate are

- **Light attenuation** (Transmisiometry): In which the amount of light absorbed by particles crossing a light beam is measured and correlated to dust concentration. In Opacity/Extinction instruments the amount of light reduction in measured directly whereas in Ratiometric Opacity the ratio of the amount of light variation (flicker) to the transmitted light is measured.

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

- **Probe Electrification**: in which the electrical current produced by particles interacting with a grounded rod protruding across the stack/duct is measured and correlated to dust concentration. Charge induction (AC Tribolectric and ElectroDynamic™) and dc Triboelectric instruments are types of probe electrification devices in which different signal and current analysis are performed.

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

1) has a stable, reliable response which can be directly correlated to dust concentration with limited cross interference from likely changes in process or flue gas conditions. MCERTS certificates for certified products provide guidance on the application suitability of different instruments. Manufacturers should be contacted for more detailed guidance on the application suitability of a specific type of instrument.

2) can operate long term in the application without the need for maintenance or cleaning. The Maintenance Interval as stated in the MCERTS certificate can provide guidance on servicing issues and longer duration tests and experience with an instrument also are very relevant.

3) sufficient resolution for the intended application. MCERTS certificates state the certification range in mg/m³ for the instrument which is the lowest dust range at which the instrument will still meet the MCERTS performance standards. The Environment Agency provides guidance on the factor allowed between the instrument certification range and Emission Limit Value (2.5 or 1.5 for low dust applications). The minimum detection level of the instrument should also be considered in relation to the normal operating condition of the plant to ensure a meaningful stable response from the instrument at normal plant conditions which can then be calibrated.
The table below shows the core application areas of the different technologies.

**Guide to Application Suitability for Particulate Monitoring Technologies**

<table>
<thead>
<tr>
<th>Measurement Technology</th>
<th>Stack Diameter (m)</th>
<th>Concentration (mg/m³) Min</th>
<th>Max</th>
<th>Filter Type</th>
<th>Certification</th>
<th>Dry</th>
<th>Humid</th>
<th>Wet</th>
<th>Hazardous Zone Gas</th>
<th>Dust</th>
<th>Velocity Dependence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge Induction (AC)</td>
<td>0.2 - 4</td>
<td>0.1 - 4</td>
<td>1000</td>
<td>Bag, Cyclone, Dry, Scrubber (1)</td>
<td>QAL3 (2)</td>
<td>TUV</td>
<td>MCERTS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Combination AC &amp; DC</td>
<td>0.2-2</td>
<td>1</td>
<td>1000</td>
<td>Bag, Cyclone</td>
<td>TUV</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Transmissometry</td>
<td>1 - 15</td>
<td>10 (3)</td>
<td>1000</td>
<td>Bag, Cyclone, EP, None</td>
<td>TUV, MCERTS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Opacity</td>
<td>2 - 10 (1)</td>
<td>30 (10)</td>
<td>1000</td>
<td>EP, None</td>
<td>TUV, MCERTS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Scattered Light (Forward)</td>
<td>1 - 4 (2)</td>
<td>&lt;0.1</td>
<td>1000</td>
<td>Bag, Cyclone, EP</td>
<td>QAL3, TUV, MCERTS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Scattered Light (Back/Side)</td>
<td>1 - 4 (2)</td>
<td>10</td>
<td>500 (10)</td>
<td>Bag, Cyclone, EP</td>
<td>QAL3, TUV, MCERTS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Concentration dependent
2. Repeatable flow dependent
3. Application specific
4. Stack diameter dependent
5. No water droplets
6. Using Wet Stack monitor
7. Model specific
8. Velocity range 0-20m/sec
9. Stack diameter dependent
10. Must have constant clean air purge supply 24/7

Since instruments are typically used in aggressive stack environments which provide a challenge to an instrument's operation and performance, regulators are becoming increasingly focused on ensuring that Quality Assurance (QA) checks are periodically done on instruments to ensure they are indeed operating correctly. For particulate monitors, it is becoming increasingly common for instruments to have built-in mechanisms for self-checking so that these checks can be done automatically without the need for direct operator involvement. These Quality Assurance (QA) checks are typically for:

- contamination and/ or signal drift at a level equivalent to an elevated dust level (span)
- instrument zero stability.

For instruments that are approved under MCERTS these checks must meet the Quality Assurance requirements of the performance standards (e.g. QAL3 for class 1 CEMS, internal reference checks for class 2 and 3 dust and filter leak monitors). These checks not only increase the confidence in emission results from instruments for regulator and plant operator alike but also provide the plant operator confidence that emission levels and incidents are being monitored by a working instrument which is likely to reduce false alarms or incorrect analysis.

**Instrument Installation**

Particulate monitors should always be installed in a location where the measurement volume of the instrument is located in a position which is representative of the particulate in the stack. Since instruments which report in mg/m³ are calibrated by reference to an isokinetic test and filter leak monitors must just respond to changes in dust, this location does not necessarily exclude locations where the dust concentration is non-homogenous across the stack, provided that when the dust concentration levels change in the duct the instrument’s measurement volume is exposed to a proportionate increase in dust.

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**Positions to be considered for installation of Particulate Monitors**
Both the instrument location and its measurement volume (length and position) should be considered together in a common sense way to ensure representative measurement. Any flue gas homogeneity results from EN-15859 (if performed on the stack) should be considered in relation to the specific needs of the particulate monitor (which are different to gas analysers due to different calibration approaches). Important is to consider if any particle stratification is likely to occur (especially under arrestment plant failure conditions) and ensure that multiple instruments or instruments with longer measurement volumes are used in these cases. In practice the best location for the instrument’s measurement volume of the instrument include:

- After the final ID fan where the particles are better mixed in the flue gas
- In areas of straights (4 diameters after bend or disruption and 2 diameters before bend or disruption)
- On the outside of bends (and not in the inside of bends) if plant geometry does not allow for alternative locations
- In the case of Intrusive instruments, not at the same location as the Isokinetic sampling location so as to avoid interference between the sample probes and instruments and visa versa
- In the cases where there is a small measurement volume (e.g. most light scatter instruments and extractive analysers) in a location of fully developed flow
- In the cases where there are multiple feeds to a stack in a position where the instrument will monitor the dust from all sources (i.e. where the flue gas is fully mixed or if this is not possible with a sufficiently large instrument measurement volume, using multiple instruments if necessary)

**Instrument Calibration/Configuration**

Ahead of any calibration or instrument configuration it is fundamental measurement practice and increasingly a regulatory requirement that checks are done to ensure the instrument is operating correctly. This ensures the cost of the calibration is not wasted and the resulting results are valid. The tests performed to ensure an instrument is prepared for correlation testing against isokinetic sampling or configuration is referred to as

- A functionality test for QAL1 and quantitative CEMs
- An instrument health check for filter leak monitors and Gross Filter failure detectors

These checks form the fundamental first part of any calibration or configuration procedure

The calibration procedure applied to the particulate monitor depends on the type of monitoring to be performed by the instrument.

1) If the instrument is to be used for EN-14181 reporting (e.g. WID or LCPD plant), quantitative (e.g. Part A or Part B processes) or qualitative monitoring (e.g. Part B processes) then the instrument response must be correlated to the results of multiple isokinetic gravimetric samples according to the standard reference method (SRM) which is typically EN-13284-1.

- The number of samples taken and the quality of the results defines the type of calibration that is applied to the instrument.
- Typically 5 or 3 SRM samples are taken since dust levels from many plant using bagfilters are relatively constant and the SRM results form a calibration cluster
- In instances where dust levels are highly variable, up to 15 calibration points are taken.
• Guidance to the number of samples to be taken for different conditions is given in the Environment Agency's guidance document RM-QG6.
• Even when instruments are to be set up in indicative mode (i.e. to report mg/m³ as an approximate level) it is good practice to take 3 samples so that any random errors in sampling are exposed as outliers.

2) If the instrument is to be used as a filter leak monitor then the instrument trend output range and alarm levels are configured once it has been established that the bagfilter is working according to specification. This is typically done by
a. an engineering inspection of the bagfilter to confirm that the bagfilter is operating correctly
b. by checking the output from the leak instrument to ensure there are no dust peaks on bag cleaning which are out of the ordinary (i.e. different than those associated with other bag rows being cleaned).

This enables the base level of the instrument to be set correctly.

Guidance on the calibration procedures for different types of continuous monitoring is provided in the following table:

Bagfilter after which Filter Leak Monitor is installed

in both cases the zero of the instrument should be checked since the calibration line or filter leak response curve often uses the zero condition as a calibration point. Since it is often difficult to create zero dust conditions at the time of calibration this is often done by reviewing historical data when the plant is known to be off (nights or weekends) and/or creating a zero condition with a simulated reference material.
### Options for Continuous Monitoring of Particulate for Part A and B processes

<table>
<thead>
<tr>
<th>Type of monitoring</th>
<th>Capability of instrument</th>
<th>Tests required on initial setup of instrument</th>
<th>Annual tests required</th>
<th>2 yearly tests required</th>
<th>What can be recorded from instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring to satisfy EN-14181</td>
<td>QAL 1 certified instrument e.g. Class 1 or 2 MCERTS</td>
<td>Instrument functionality test 5/5 point calibration (see RM-QG-6)</td>
<td>Instrument functionality test 5/5 point calibration(AST) (see RM-QG-6)</td>
<td>Instrument functionality test 5/5 point calibration (AST) (see RM-QG-6)</td>
<td>mg/m³ over time</td>
</tr>
<tr>
<td>Qualitative measurement</td>
<td>Instrument capable of being calibrated for a specific application e.g. Class 1 or 2 MCERTS</td>
<td>Instrument functionality test 5/5 point calibration (see RM-QG-6)</td>
<td>Instrument functionality test 5/5 point calibration (see RM-QG-6)</td>
<td>Instrument functionality test 5/5 point calibration (see RM-QG-6)</td>
<td>mg/m³ over time</td>
</tr>
<tr>
<td>Qualitative measurement</td>
<td>Instrument capable of being calibrated for a specific application e.g. Class 1 or 2 MCERTS</td>
<td>Instrument functionality test 5/5 point calibration (see RM-QG-6)</td>
<td>Instrument functionality test 5/5 point calibration (see RM-QG-6)</td>
<td>Instrument functionality test 5/5 point calibration (see RM-QG-6)</td>
<td>mg/m³ over time</td>
</tr>
<tr>
<td>Filter leak monitoring</td>
<td>Filter leak monitor with trend output e.g. Class 3 MCERTS</td>
<td>Set up and set reference</td>
<td>Instrument health check</td>
<td>Instrument health check</td>
<td>mg/m³ (approx) over time</td>
</tr>
<tr>
<td>Gas leak monitoring</td>
<td>The method which has a credible relationship between what is being monitored and a failure condition. See Note</td>
<td>Set up and set reference</td>
<td>Instrument health check</td>
<td>Instrument health check</td>
<td>Trend of plant operation over time</td>
</tr>
<tr>
<td>Gross filter failure detection</td>
<td>Instrument designed to detect large increases in emissions</td>
<td>Set up and set alarm</td>
<td>Instrument health check</td>
<td>Set up and set alarm</td>
<td>Incidence of Gross failure</td>
</tr>
</tbody>
</table>

**Note:** eg. Water level in wet scrubber or pH in wet scrubber but NOT differential pressure (dp) across a bag filter (dp measures filter blocking but does not drain).

### Instrument Maintenance

Particulate instruments are no different than any other type of electro-mechanical/optical equipment in that they require routine service, especially as they are exposed to the aggressive and dust contaminating conditions of flue gas. It is standard practice (through regulatory requirements and manufacturers’ guidance) for an annual inspection of the instrument to be conducted and this may be more frequent depending on the complexity and operating principles of the instrument. Manufacturers of instruments are best consulted for guidance on preventative maintenance requirements to ensure reliable operation from an instrument in a specific application.

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