Particulate Emission Monitoring Network suitable for CAM, MACT and PM-CEM Requirements

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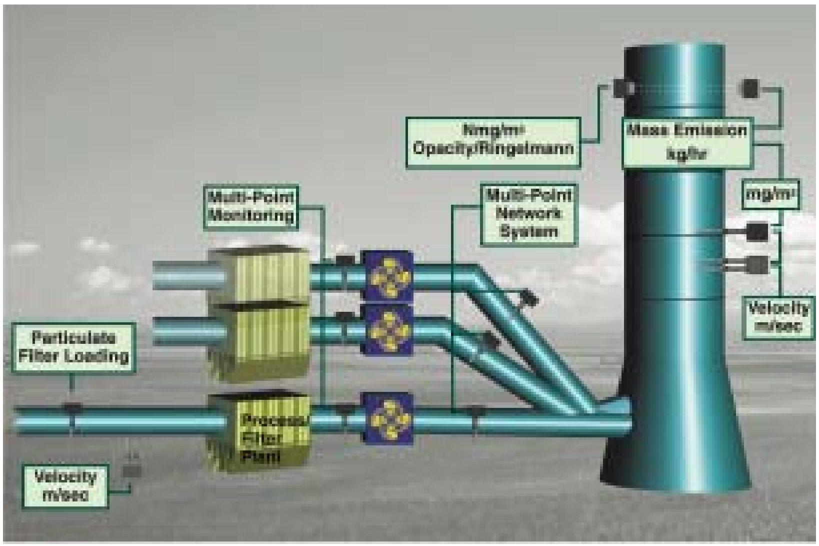
1.0 Summary

Plant operators faced with the issue of satisfying the monitoring requirements of EPA's new draft PM-CEM (Particulate Matter Continuous Emission Monitor) proposal, or new CAM (Compliance Assurance Monitoring) and MACT (Maximum Achievable Control Technique) rules, are naturally searching for effective and efficient solutions. For large sites where there are a number of emission sources and different types of dust arrestment plant, a networked monitoring system provides an efficient means of connecting a large number of different sensors to a central location and then collating data for easy interpretation and reporting. In addition it provides a means to monitor a number of useful emission indicators for each arrestment plant in a cost effective manner (including for example, baghouse filter condition, fan amps, arrestment plant pressure drop and/or particulate emission factor), enabling the implementation of a practical and robust solution for CAM or MACT monitoring.

This paper describes a flexible, industrially hardened monitoring network which connects not only to external transmitters measuring parameters such as fan amps, but most importantly to different types of particulate emission sensors. Since no one particulate measurement technology can be applied universally across all types of arrestment plant, it is advantageous and cost effective that the system can be designed with the appropriate sensing technology for each and every application point and with a choice of sensor features suitable for the application. Particulate emission technologies supported by the network include Electrodynamic (suitable for monitoring baghouses with varying velocity), TriboACE and Dynamic Opacity (Scintillation) (suitable for Electrostatic precipitators). Sensor types also include PM-CEMs, particulate indicative instruments and broken bag monitors. The paper overviews each of these monitoring technologies, discusses their suitability to different applications and describes how they can be connected in a network to provide an efficient CAM or MACT solution. The paper also provides an overview of how Electrodynamic and Dynamic Opacity (Scintillation) technologies are currently used in PM-CEM instruments in different parts of the world.

2.0 The need for a Network Solution

Networked systems in which multiple industrial sensors are connected to a central control and data management system provide a cost effective and convenient method for measuring plant wide processes. Historically the demand for a networked system for particulate emission monitoring has been limited due to the relatively small number of measurement points compared to the high one-off-cost of purchasing a central control station. However, as a result of technical developments which permit a Personal Computer to act as a cost effective central control station and changes in US regulation which require multiple emission points and emission parameters to be simultaneously monitored, a networked particulate monitor has increasing relevance.



Multiple emission points to be monitored across an industrial site

3.0 Regulatory Changes

3.1 MACT/CAM/PM-CEM

The specific regulatory changes which are likely to increase demand for particulate monitoring instruments and plant wide environmental monitoring networks derive from the Clean Air Act 1990 amendments. Of most important is the new Compliance Assurance Monitoring (CAM) rule, but also relevant are MACT and draft Particulate Matter Continuous Emission Monitors (PM-CEM) requirements. Certain of the MACT (Maximum Achievable Control Technique) rules, written for processes with hazardous pollutants, require broken bag monitoring on baghouses throughout the plant. The draft PM-CEM proposal suggests a new requirement for particulate emission monitoring on Cement Kilns and Incinerators instead of the traditional surrogate Opacity.

3.2 Compliance Assurance Monitoring (CAM)

Title V plants (the major metals, chemical, mineral and combustion processes) are required under the new CAM (Compliance Assurance Monitoring) regulations to develop a plan to ensure that the condition of significant arrestment plant is monitored to ensure correct operation. A CAM plan is required for Baghouses, Electrostatic Precipitators and Scrubbers fitted to processes in which the pre-abated emissions are above defined thresholds. The plant operator must select and monitor process indicators which provide a reliable indication of a change in arrestment efficiency.

It is likely that many plants will choose to monitor a number of process indicators across the plant and that a central control and reporting system will be specified to help plant personnel to monitor arrestment plant condition in an efficient cost-effective manor; hence the interest in a monitoring network.

Process indicators which may well be chosen for measurement include those from the following list.

These may be used on their own or in combination with other indicators depending on the actual operating characteristics and failure mode of specific arrestment plant:

For Bagfilters:

- Qualitative particulate emission trends
- Large changes in particulate levels (broken bag detection)
- Pressure drop across filter (determining bag blinding)
- Fan Amps (as measure of air flow)

For Electrostatic Precipitators:

- Actual particulate levels
- Particulate emission trends
- Plate voltages
- Hopper levels

For wet scrubbers:

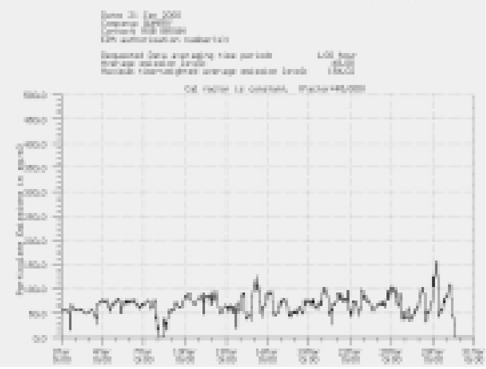
- Water levels
- Ph of discharge water
- Concentration of emission gas

4.0 Requirements for Network

The following specifications for a particulate monitoring network derive from an analysis of the reporting requirements of the CAM and MACT rules, an assessment of the typical arrestment plant on site and consideration of the parameters to be monitored (listed above). It also reflects a flexible approach in which the network is also suitable for more general CAM monitoring.

4.1 Supports different types of Monitoring

The network should be able to support different types of particulate monitoring in which different types of information are provided. At one level there is simple broken bag detection with alarm monitoring. However, larger plants usually benefit by using more appropriate trend monitoring, since arrestment plant problems can be anticipated before they become significant and the instruments assist maintenance personnel locate problem areas in the arrestment plant. Some plants may even consider continuous particle emission monitoring (PM CEMS) in which the output of an instrument is calibrated in mg/m^3 and therefore provides ultimate proof that emissions are below prescribed limits.



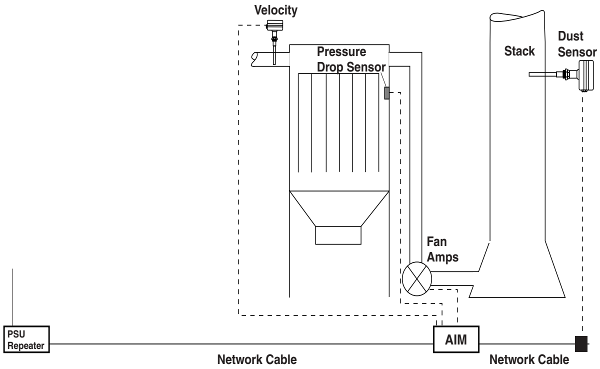
Typical Report from a PM-CEM

4.2 Uses appropriate Particulate Monitoring Technologies

The network should support a range of particulate monitoring technologies (for example Opacity, Scintillation, Electrodynamic or Light Scatter) since no one type of particulate sensor is universally applicable. This therefore permits particulate sensors suitable for Electrostatic Precipitators to be located on the same network as particulate sensors for Bagfilters and therefore the plant to use a single CAM network. This is relevant for large industrial processes such as Steel Mills, Cement plant and Foundries where often a combination of arrestment plant is used in different processes.

4.3 Compatibility with Auxiliary Inputs

The outputs from other process sensors (eg: level monitors) can be integrated onto the same network. Again this means that a single network can be used throughout the plant to monitor all CAM data.



Schematic showing monitoring performance measures for a baghouse as a CAM solution

4.4 Flexible Data Reporting

The reporting and data analysis software package must be site configurable to permit operators to tailor their own CAM reports depending on what they decide to monitor and report. This issue has special significance with the advent of credible evidence in which plant may wish to monitor certain parameters, but only record a limited number of these along with alarm events.

5.0 Description of Candidate Network

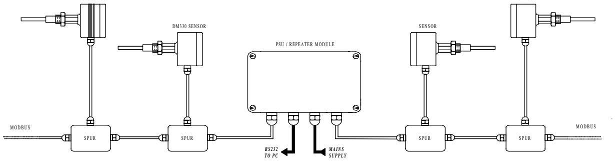
PCME has developed a particulate monitoring network which is a candidate solution for plants satisfying CAM, MACT, PM-CEM or process particulate monitoring requirements. A description follows for the network referred to as DustMaster which may comprise up to 255 particulate sensors or auxiliary inputs.

5.1 Architecture

The sensors are connected by a single four conductor cable which both delivers power to the sensors and provides a communication link between the sensors and a central Personal Computer or DCS (Digital Control System).

Specifically:

- The network supports MODBUS/RS-485 communication hence permitting reliable communication to an industry standard. Sensors connected to the network are programmed with a specific identifier (address) from 1 to 255.
- 24V DC power is supplied to the network via a power supply unit or control unit. Power can be boosted to the network to permit network cable lengths of up to 10,000m.
- The network cable can be simply linked directly between the sensors or alternatively branched by a spur unit. This second approach permits the sensors to be conveniently disconnected without disturbing the network.
- The network is controlled by the central PC or DCS or in cases where a PC is not always available by a central control unit which acts as the Modbus controller.



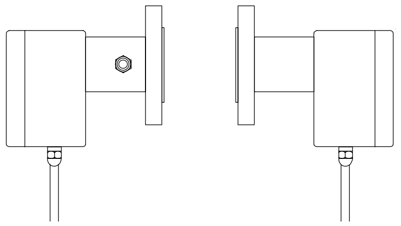
Architecture of DustMaster network

5.2 Sensors supported by the Network

The network can be connected to a variety of sensor types and instruments as follows:

SC-600 Sensor

This optical scintillation instrument, comprising transmitter and receiver mounted either side of the stack, is suitable for PM-CEM monitoring in Electrostatic Precipitator, Combustion and large Bagfilter applications. This instrument has approvals which satisfy ISO-10155 the international standard for continuous particulate monitors (similar to the PS-11 US draft standard) and has automatic zero and span checks providing high quality control.



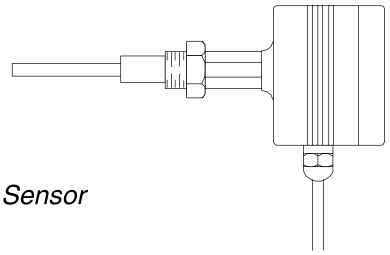
Transmitter and Receiver

DV-400 Sensor

This instrument while similar to the SC-600, provides particulate trend monitoring capability for applications where measurement capability is not required. This instrument is suitable for monitoring changes in Electrostatic Precipitator performance making it relevant to CAM.

DM-990 Sensor

An Electrodynamic type sensor provides particulate concentration measurement in baghouses and is capable of measuring in applications with varying velocities, high humidities (non-condensing) and high temperatures (up to 600°C). The sensor has automatic zero and span checks and automatic contamination failure detection.



DM990 Sensor

DM-330 Sensor

A TriboACE type sensor suitable for particulate trend monitoring in baghouses with fixed velocities. Provides a signal proportional to dust levels.

DM-220 Sensor

A TriboACE sensor suitable for broken bag detection in baghouses. The sensor supports two adjustable alarm levels permitting early warning of the onset of problems, as well as gross failure detection.

Auxiliary Input Module

An interface module which permits four non-dust sensors (ie measuring other arrestment plant conditions) to be connected to the network via 4-20mA or contact closure interface. The module also used to connect to SC-600 and DV-400 instrument and multiple modules can be used on the network.

Broken Bag Locator Interface

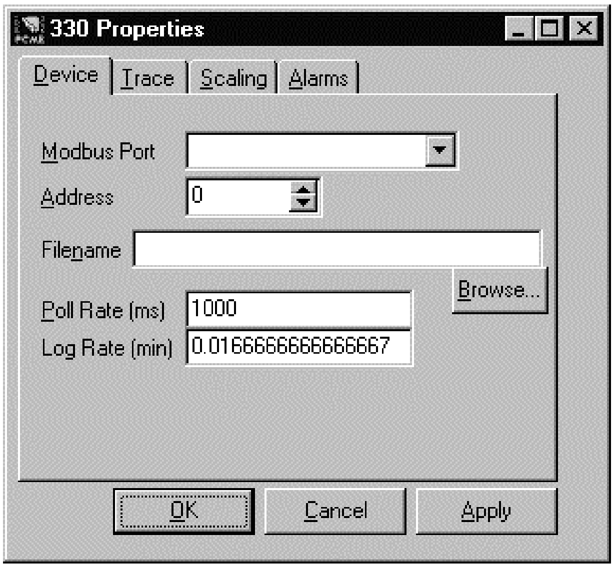
A module to be connected to the baghouse cleaning controller to permit software to automatically identify location of breaking or failed bag rows.

5.3 System and Sensor Configuration

The system is set up centrally from the PC or control unit. Parameters which are set as part of the initial configuration of a system are:

- Numbers and types of sensors
- Averaging periods for data analysis
- Alarm and action levels
- Data logging periods and data storage
- External alarms and 4-20mA outputs
- Sensor calibrations

The screen for setting up and configuring the DM-330 sensor is shown to the right.



330 Properties

Device | Trace | Scaling | Alarms

Modbus Port:

Address: 0

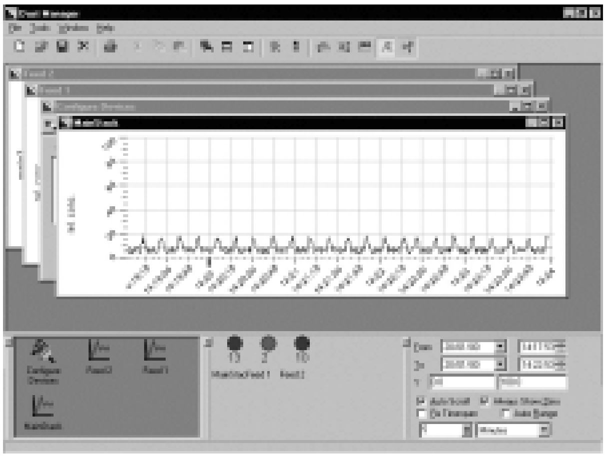
Filename:

Poll Rate (ms): 1000

Log Rate (min): 0.0166666666666667

5.4 Realtime Display and Data Reporting

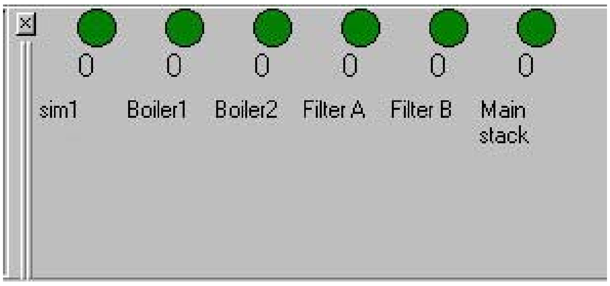
The value of each process or emissions parameter may be viewed individually or concurrently on line along with the status of each sensor. Reports can be produced directly from displayed data or from historically stored data.



5.5 Alarm Notification

The status panel at the bottom of the display page shows the alarm status for each sensor on the network. Alarm conditions can also be programmed to trigger external devices such as visual or audible alarm. An electronic alarm log can be maintained if required as can a log of actions taken to resolve alarm incidents

6.0 Technologies used for Particulate Monitoring



sim1	Boiler1	Boiler2	Filter A	Filter B	Main stack
0	0	0	0	0	0

The technologies used within the respective particulate sensors and instruments which make up the network include Scintillation, Electrodynamic and TriboACE. This portfolio of technologies permits sensors to be used in the majority of particulate emission applications including those with baghouse and electrostatic precipitators. These technologies like all other in-situ techniques cannot be applied to wet emission applications without pre-conditioning of the fluegas. The characteristics of each technology is as follows:

6.1 Dynamic Opacity (Scintillation)

Like Opacity monitors, Dynamic Opacity (Scintillation) monitors measure the effects of particles on a light beam passing across the stack. However, the essential difference is that they measure not only the beam intensity as such, but the ratio of the temporal variation in intensity to the intensity. This intensity variation derives from the statistical variations in the distribution of particles in the air-stream. The higher the concentration of particles, the greater the range of variation. Empirical results confirm a simple linear relationship between scintillation and dust concentration and show that with zero dust there is no scintillation (ie the instrument has a true zero, unlike Opacity devices). The term Dynamic Opacity or Scintillation is related to the dust concentration as follows:

$$\text{Dynamic Opacity} = \frac{\text{Variation in intensity}}{\text{Intensity}} = \text{K x C}$$

Where C is the dust concentration and k is an empirical constant for the particle physical properties.

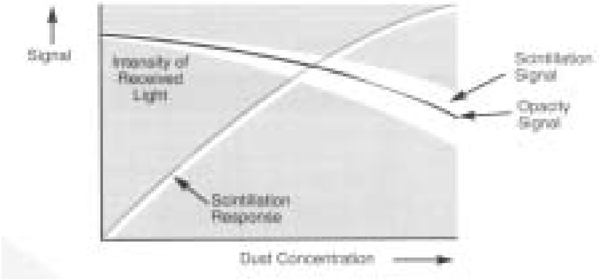


Diagram showing Dynamic Opacity vs concentration

Practical Considerations

1. One of the most important characteristics of the Dynamic Opacity (Scintillation) technique is its tolerance to instrument contamination. A Dynamic Opacity (Scintillation) monitor will continue to function without error even when its lenses are heavily coated with dust. As a result there is no need to fit large air purge blowers to the system. In high dust loading applications, the transmitter and receiver are connected to a supply of instrument air (using 1 CFM of air) to stop the light beam being completely obscured by catastrophic build up. Provided sufficient light is getting through for the instrument to make a measurement (at least 10% of clean instrument amount), its response is unaffected by any contamination since the numerator and denominator of the ratio are affected by the same amount.
2. The Dynamic Opacity (Scintillation) instrument is not significantly affected by the absolute alignment between the transmitter and receiver, since like contamination this affects the numerator and denominator of the ratio by the same amount. As a result the adjustable mounting alignment of the instrument can be set by eye sight on first setting up the instrument.
3. The instruments are generally single pass since there is no need to increase the path length due to concerns on detection level. Unlike the Opacity technique the instrument measures no signal when there is no dust and therefore it is possible to increase the signal to noise ratio. In practice this means the instrument can detect low dust concentrations as low as 2.5mg/m^3/m (at least 10 x better than an Opacity device).
4. Relevant light and electronic automatic zero and span checks can be built into the instrument to check for instrument integrity. As with all types of in-situ devices, these do not check for changes in particulate calibration.
5. There are also certain applications in which measurements must be made in terms of opacity and Ringelmann (colour) characteristics as well as mg/m^3. To allow for such applications, Dynamic Opacity (Scintillation) monitors can be switched into Opacity measurement mode.

Their limitations are as follows:

- The calibration of a Dynamic Opacity (Scintillation) instrument will shift if there are changes in parameters affecting the attenuation of light by a particle. These include particle size, shape and particle material.
- The calibration is also effected by changes in process conditions effecting the statistical distribution of the particles. In practice this means that the start-up and shut down of

certain processes may not be accurately monitored by Dynamic Opacity (Scintillation).

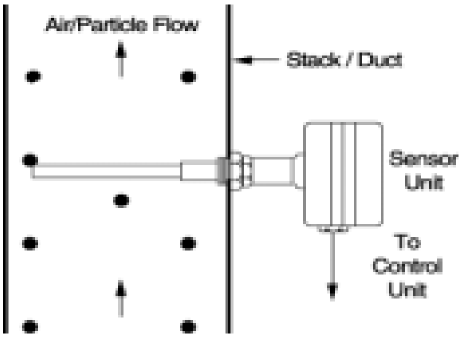
- Like Opacity, the Scintillation response is affected by water vapour and refraction due to thermal gradients. This can result in an offset which increases the minimum detection level to be above 2.5mg/m^3.

In practice Dynamic Opacity (Scintillation) instruments can be a more reliable alternative to Opacity instruments where regulations require particulate measurement as opposed to Opacity. They are often used in combustion applications and other industrial processes with large stack discharges from an Electrostatic Precipitator or Bagfilter.

6.2 Electrodynamic

In an Electrodynamic system a grounded sensing probe is installed across part of the stack and the resulting current from charged particles passing the sensor analysed and measured. The dc current produced by particle collisions on the rod is eliminated by ac filtering techniques. The instrument conditions the remaining alternating signal produced by charged particles inducing charge flow in the sensor rod as they pass it and analyses and measures the frequency component thereof. Since the signal is not dependent on particle collisions, the related problems of rod contamination and velocity dependence by which Triboelectric are limited, are minimised.

In applications where the particle charge, particle size and particle distribution remain constant the resulting alternating current is proportional to dust concentration. These instruments can be calibrated in mg/m^3 by comparison to the results of an isokinetic test.

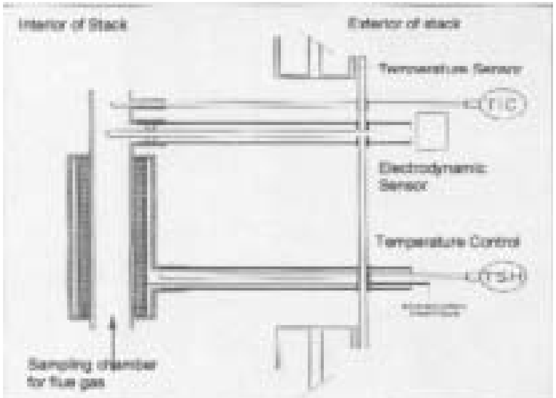


Schematic of interaction between particle and Electrodynamic sensor

Practical Considerations:

- The sensor rod can be completely insulated to extend operation into humid (drier) applications.
- The sensor rod can tolerate contamination without reduction in performance since the measurement signal derives from induction rather than collision.
- The sensor can be incorporated in an in-situ heating chamber assembly to permit measurement in wet stacks. This is providing a pragmatic alternative to Beta systems.

Technical limitations are as follows:



Schematic of heated chamber and electrodynamic sensor for wet applications

1. The use of Electrodynamic technology for particulate measurement requires applications with predictable particle type and pre-charge, non-condensing conditions and a minimum velocity of 5m/s. There are only minor effects of changing velocity if the velocity is greater than 8m/s
2. The standard instrument cannot be used for measurement with the presence of water droplets, however, is often used in non-condensing humid applications (after driers), since it can discriminate between solid particles and water vapour.
3. The technology is only suitable for indicative monitoring in applications in which the pre-charge on the particle is likely to change. In practice this covers Electrostatic Precipitator (EP) and combustion applications where charge on the particle may be changed by EP

condition and flame ionisation effects respectively.

Electrodynamic instruments are suitable for qualitative monitoring and continuous measurement requirements on Bagfilters in the metals, mineral and chemical industries. Instruments using this technology are approved for both measurement and qualitative monitoring in the UK and Germany.

6.3 TriboACE

These instruments while similar to Electrodynamic simply measure the magnitude of the AC current resulting from charged particles passing a grounded rod. The technique has the inherent characteristic of not being affected by contamination on the sensor rod due to an induction measurement principal. The essential difference with electrodynamic instruments is that frequency analysis is not occurring, so response is still effected by changes in particle velocity. This means that like Triboelectric instruments they are restricted in use to qualitative monitoring and applications with constant velocity as found in many smaller baghouses.

7.0 Satisfying PM- CEM requirements

The Dynamic Opacity (Scintillation) and Electrodynamic techniques discussed above provide a solution to the challenging issue of particulate emission measurement. These technologies may offer regulators and end users in the US with a pragmatic and cost effective solution to requirements for continuous particulate emission monitoring which is now on the horizon from a regulatory perspective. While particulate emission monitoring has become quite common in other parts of the world, it is relatively new in the US due to a historic reliance on Opacity or color limits. US EPA is seriously considering requiring **Continuous Particulate Measurement or PM CEMS** (Particulate Matter Continuous Emission Monitors) in a number of industrial processes including Incinerator and Cement Kiln applications.

7.1 What is a PM-CEM?

A PM-CEM provides an output calibrated to show particulate levels in mg/m^3 on a continuous basis. This output is generally recorded for reporting and analysis purposes. It is worth emphasising that none of the technologies used for particulate emission monitoring (with the exception of the oscillating tapered element approach) actually measure mass concentration; all work by inferring mass concentration from measurement of a different property of the particulate (ie attenuation of a light beam by the particles) and are calibrated by comparison to a reference isokinetic sampling method. And here lies the important challenge of particulate monitoring: to measure a property that is only effected by mass and not other particle or process conditions which change in that particular stack. This explains why there are a number of different measurement techniques (each with their own cross-sensitivities) suitable for different types of application. The eight techniques commonly used for some type of particulate monitoring are:

1. Opacity
2. Dynamic Opacity (Scintillation)
3. Back/Side Scatter
4. Forward Scatter
5. Oscillating Filter (Vibrating tapered element)
6. Beta Attenuation
7. Triboelectric
8. Electrodynamic

The important issue that defines which techniques are suitable for the higher accuracy requirements of PM-CEM monitoring (as opposed to simpler qualitative monitoring) is whether a technique can be harnessed in an instrument to provide an output which repeatably relates to the dust concentration determined by isokinetic sampling over a range of dust concentrations and importantly over time. Of course this is application specific. Reflecting that there are systematic errors in isokinetic sampling (typically 10%), the correlation between instrument output and isokinetic result is assessed in terms of a statistical analysis. For example ISO-10155 (the international performance standard for particulate monitors) defines a minimum correlation coefficient of 0.95 and limits on other statistical limits such as confidence and tolerance interval. The performance curve as defined by ISO-10155 is shown over.

EPA is currently developing a standard similar to ISO-10155, PS-11 which defines the performance of particulate monitors in terms of a statistical correlation with isokinetic tests to EPA method 5.

Concentration monitors are typically calibrated at least once a year by reference to an isokinetic test, since this is the only way of checking the calibration in mg/m^3. More frequent quality control checks are performed to satisfy more advanced regulatory requirements to ensure the instrument is working properly. These are typically implemented as automatic zero or span checks which simulate to the instrument the parameter being measured (eg A reference object which scatters light is inserted in measurement volume of light scattering instrument).

7.2 Use of Dynamic Opacity (Scintillation) and Electrodynamic Technology in Particulate Monitors

Dynamic Opacity (Scintillation) and Electrodynamic sensors are already used for continuous particulate emission measurement in many parts of the industrial world including Germany, UK, Japan and Australia. Of relevance to the evolving US situation is the accreditation of these techniques by regulators in the UK and Germany under the MCERTS and TUV approval schemes respectively. Both these countries operate type approval schemes in which an instrument is subjected to a performance test based on actual performance in a field application over a three-month period. While being different to the proposed PS-11 standard in that instruments are not assessed each and every time they are installed, these approval schemes do show what performance an instrument is capable of in a typical application.

Scintillation Approvals

The SC-600 product meets the field trial standards of the UK Environment Agency's MCERTS Approval Scheme. The instrument meets the standard over a particulate range of 0 to 150mg/m^3 and has been tested in a 600MW coal fired power station following an electrostatic precipitator. This product is now gaining acceptance in the Power, Steel and Cement industries as a reliable alternative to Opacity when regulations move to particulates.

Electrodynamic Approvals

Electrodynamic instruments similar to the DM-990 have been approved for measurement of particulate over the ranges of 0-15mg/m^3 and 0-30mg/m^3 in Germany and UK respectively. The UK MCERTS Class 4 approval and German BImScHv 17 approval are for bagfilter applications and are relevant to applications found in the US where particulate monitoring may be required:

1. Newer incinerator plant where baghouses are fitted to the final emission stack and used to collect particulate from the limestone dry scrubbing process
2. Emissions from non-ferrous baghouse plant where particulate is toxic and of more significant environmental concern.

It is likely that Electrodynamic and Dynamic Opacity (Scintillation) techniques which are being used to satisfy PM-CEM requirements in the UK and Germany will satisfy requirements for pragmatic solutions as the issue of PM-CEM evolves in the US.