1. Introduction

The use of CEM systems, from their historical conception as instruments to monitor flue gases for control of industrial combustion, has expanded over the last decade to cover environmental emissions from many different types of industrial processes. As technology has advanced, improved flue gas treatment systems have reduced the levels of pollutants to be monitored and driven by new regulations and improved knowledge of the consequences of environmental pollution, Environmental Agencies worldwide have required that smaller processes be monitored. New technologies have led to new and improved CEMs systems with Environmental Agencies insisting that continuous emission monitors meet more stringent specifications, including repeatability and the capability to be fully challenged to demonstrate compliance. In addition, reporting regimes necessitate maximum availability. Pressure from the market place also requires the modern CEM system to have a low cost of ownership, which, in effect means that high reliability must be a design criteria.

2. Typical Specification

There are many applications for continuous emission monitors, covering a plethora of industries. The specification of the CEM system will depend on, not only the type of process, but also the pollutant gases that are required to be measured.

2.1 Typical CEM System

Pollutants to be monitored with typical ranges

Range 1	0-200ppm CO	0-250 mg/m^3 CO
Range 2	0-200ppm NO	0-270 mg/m^3 NO
Range 3	0-250ppm NO2	0-500 mg/m^3 NO2
Range 4	0-300ppm SO2	0-850 mg/m^3 SO2

Other gases to be monitored
Range 1 0-20% CO_2
Range 2 0-20% H_2O

Stack Temperature   150-250°C
Stack Diameter   1-5m
Performance Required: Accuracy<±2% FSD
                           Repeatability<±2% FSD
                           Linearity<±2% FSD
                           Zero drift per 24 hours <0.5% FSD non-cumulative
                           Operational test period greater than 2200 hours
                           (hours without maintenance)
Reporting   Display concentrations of all Requirements:
                           Measurements gases to be displayed in ppm,
                           mg/m^3 or %

Output   Concentration to be transmitted as 4-20mA signal, in addition to this a serial digital link should be available to connect the CEM system to a supervisory computer.

*FSD is the full scale deflection

2.2 Regulatory Authorities

The choice of CEM system will depend on many factors, including the monitoring and reporting requirements of the local Environmental Authority.

3. Continuous Emission Monitoring: A brief outline of the different CEM systems

3.1 Extractive

Until recently the extractive CEM system was dominant in most applications. The majority of these systems fit into the following three main categories.

3.1.1. Cold Extractive

In this type of system, a sample is continuously drawn from the stack through a sample probe and transported via a heated line to the system housing, which in addition to the analyser(s), contains all the necessary sample preparation components. Sample preparation involves removing the water vapour from the sample by rapid chilling prior to analysis.

In extractive CEM systems the sample probe incorporates an external and or an internal filter to prevent particulate matter entering the sample line. Build-up of particulate matter on the filter can be prevented by the addition of a "blowback" cleaning system where high pressure air is periodically blown back through the filter to remove the particulate matter. However, the "blowback" system can be ineffective, depending on the nature of the particulate matter, and sampling problems can occur. A plugged probe can prevent sample gas from being correctly measured and lead to the recording of reduced emission levels. Plugging can also place strain on the systems fittings, sample line and valves and potentially lead to leaks that may go undetected once the plugging is cleared. If a leak arises sample gas dilution can occur resulting in lower gas concentrations compared to actual concentrations. Such a system therefore requires a significant amount of maintenance to ensure that filters are free of particulate matter and all the sample preparation components are operating correctly. The selection of filter porosity is also very important as too great a porosity can result in fine particles entering the sampling line which can then scrub gases by reactive or adsorptive processes. Another major drawback with this system is that a significant percentage of any soluble gas, such as NO_2, SO_2 and to a lesser extent NO is removed along with the water vapour.

3.1.2. Hot Extractive

Again, a sample is continually removed from the stack and transported through a heated line to the system housing where the analysis of the stack gas at temperature is carried out. This is achieved by ensuring that all sample wetted parts are maintained well above the temperature at which condensation would occur. In many applications, this would be approximately 200°C, however, in several applications, for example the monitoring of ammonia, the temperature has to be maintained at approximately 325°C to ensure that ammonium chloride does not form. Obviously, all the components making contact with the sample have to be specified to operate at elevated temperature, including solenoid valves, filters, pump heads, and also the analyser sample cell.

3.1.3 Dilution System

To avoid the need to remove the water vapour and to ensure condensation does not occur in the sample line or analyser components, a technique of diluting the sample at the take-off was developed. Protection against condensation is achieved by diluting the sample to a level at which even the lowest ambient temperature would not cause any condensation to form. The sample is transported from the take-off point to the system housing, where additional sample preparation components and the analysers are mounted. The major drawback of this system is that, in addition to maintaining the dilution system, the analyser has to be significantly more sensitive to monitor the diluted gas.

3.2 Cross Duct and Reflective Cross Duct Analysers

This was a significant step forward in continuous emission monitors, negating the need for expensive, bulky, and high maintenance sample systems. However, the disadvantages soon became clear with the inability to directly zero and calibrate the instruments. There are also restrictions on the diameter of stacks which could be reliably monitored with this type of system (10m limit where NO is being measured). The cross stack and reflective cross stack rely on the stack as the sample cell, sending pulses of infrared or UV light through the stack to either a receiver or a reflector, which is then returned to the stack mounted transmitter/receiver unit. A benefit is that the analysed samples are true and unmodified with response times also being fast. Disadvantages include the need to install the receiver and emitter on opposite sides of the duct. The DOAS (Differential Optical Absorption Spectroscopy) technology is expensive when only one or two gases have to be measured. There is a tendency for components to suffer from heat and corrosion effects of the stack gases.

3.3 In-situ Open Path Analyser

In this configuration, the reflector is mounted on the probe, a slot in the probe allows the gas to pass between the in-stack window and the reflector. In an attempt to zero and calibrate the instrument, a second reflector is swung in front of the in-situ stack window and the system zeroed. In addition, test gas can be passed into the enclosed portion of the probe, enabling the instrument to verify calibration. The major problem with this configuration is that the full system is not challenged, i.e. a second reflector is used and effects on the first reflector are not taken into account.

3.4 Enveloped Folded Beam

In this configuration, the transmitter and receiver are mounted in one enclosure and the pulses of infrared or UV light passed out through a tube containing two lenses, one on the exit of the optical housing, the second, a process lens, mounted in the stack. The pulses of infrared/UV then pass through a second portion of the probe, which is fitted with sintered panels, allowing the flue gas freely to pass into the cell. The pulses of infrared/UV light strike a retro reflector and are returned through the same path to the transmitter receiver.

3.4.1 Auto Zero/Auto Cal

To comply with various Environmental Agency requirements, in particular, US EPA 40 CFR Part 60 & 75, the instrument has to be challenged on a daily basis. Clearly, extractive instruments can be challenged by diverting zero and the test gas into the sample cell, enabling the instrument to be recalibrated and any errors reported. This is also possible in the enveloped folded beam. Normally, the flue gas passes through the sintered panels, filling the in-situ gas cell, where the absorption of infra red or ultraviolet light takes place. Periodically, either automatically or on demand, a solenoid valve can be activated by allowing instrument air to be discharged into the in-situ cell, forcing out the flue gas, enabling the instrument to check zero and adjust if necessary. In the same way, certified test gas, traceable to a National Standard, can be introduced into the sample cell, enabling the instrument to check, and, if necessary, adjust calibration. It is recommended that the auto-zero is carried out on a daily basis, however, experience has shown that calibration verification need only be carried out every three months or so. Under US EPA 40 CFR Part 60 & 75, it is a requirement to carry out these checks on a daily basis. If the instrument is outside $\pm 2\frac{1}{2}$ % on either the zero or the span, the instrument is deemed to be out of calibration for that day.

4. Multi Component Analysis

Traditionally, analysers were designed to monitor a single gas species and if multiple gas analysis was required then a series of analysers were used. With the requirement to monitor and report several pollutant gas emissions the

modern CEM system is capable of simultaneously monitoring and displaying concentrations of five to six species.

5. Analyser Selection

The type of analyser selected will depend on the species and concentrations to be monitored.

	Photo-meter	Photo-meter	Spectro-photometer	Spectro-photometer	Chemilumi nescence
Species	IR	UV	IR	UV	
CO	x		x		
NO	x	x	x	X	x
SO2	x	x	x	X	
NO2	x	x	x	X	x
CO2	x		x		
H2O	x		x	X	

6. Cross Sensitivity

For many years, the only way of reliably monitoring several flue gas components, such as NO, NO2, SO2 and HCL was to remove the water vapour from the stack gas sample prior to carrying out the analysis. This was due to the cross sensitivity between water vapour and the components to be monitored, **as can be seen from the chart**, water vapour absorption occurs at the wavelengths the pollutant gases are measured. Two techniques have been applied to reduce cross sensitivity. By using gas filter correlation (GFC) the prime sensitivity is improved and cross sensitivity dramatically reduced. In addition, by monitoring water vapour and applying a cross sensitivity correction, the effect of water vapour can be virtually eliminated, ensuring that the accuracy of the instrument is within the 2% requirement. These techniques can be used to remove the cross sensitivity of other species.

7. Pressure and Temperature Compensation

To ensure that the instrument is within $\pm2\%$ accuracy, it is necessary to carry out automatic correction for changes in sample temperature and pressure. This is achieved by continually monitoring the temperature and pressure within the sample cell and compensating for any changes.

The pressure compensation deals with changes in barometric and flue gas pressure, in addition, if the certified test gas applied to the probe causes a pressure rise this too can be compensated for.

8. Typical Installation

The in-situ CEM system is flange mounted, with the in-situ sample cell protruding into the stack. The analyser is connected via a serial link to the analyser control unit, which displays, data logs and re-transmit's the concentrations of the monitored flue gas components. In addition, the auto zero / calibration unit, fitted with three solenoid valves. Controlled by the microprocessor in the analyser, allows the periodic zero and calibration to be carried out. Several analysers can be connected to a single Analyser Control Unit.

8.1 Analyser Control Unit (ACU)

This unit consists of a touch screen PC housed in an IPC rated enclosure. The PC displays live readings, logs data and re-transmits concentrations of monitored gas species.

8.2 Integrated Stack Monitoring System

It is often necessary to report the pollutant measurements normalised to a level of oxygen or carbon dioxide. This can be achieved by connecting an oxygen analyser directly into the stack mounted infrared / UV analyser. The data from the oxygen analyser is then transmitted to the analyser control unit, and used to calculate and display a normalised concentration of pollutant gas.

Similarly, a velocity device can be connected to the analyser, enabling the concentrations to be displayed in mass units. In many applications, it is also necessary to measure the opacity / dust. Again, an appropriate instrument can be connected to the P2000, and the concentrations of dust displayed on the analyser control unit.

9. Approvals

Several countries have developed Continuous Emission Monitoring Approval schemes. In Europe, seven existing directives related to industrial emissions including the Integrated Pollution Prevention and Control (IPPC) directive of 1996 have been brought together into a single clear and coherent legislative document **(Directive 2008/1/EC).** This sets out rules for permitting and controlling industrial installations with regards to pollutant emissions and is aimed at minimising pollution from various industrial sources within the EU. Plant operators are required to obtain an environmental permit from authorities in EU countries. The directive is based on several principles

A. An integrated approach
B. Best available techniques
C. Flexibility
D. Public participation.

The integrated approach means that the permit must take into account the whole environmental performance of the plant – e.g. emissions to the air, water and land, generation of waste, use of raw materials, energy efficiency, noise, prevention of accidents and restoration of the site once it has closed. The permit conditions including emission limit values (ELVs) must be based on Best Available Techniques (BAT) as defined in the IPPC directive. The directive contains elements of flexibility by allowing the licensing authorities, in determining permit conditions, to take into account: technical characteristics of the installation, geographical location and local environmental conditions. The directive ensures that the public have a right to participate in the decision making process and to be informed of its consequences. Permit applications, permits, results of monitoring and emission data reported by member states are all accessible by the public.

In the UK **BS EN 14181** covers stationary source emissions and quality assurance of automated measuring systems (AMS). This is a significant and demanding standard for sites operating under the Waste Incineration Directive (WID) and the Large Combustion Plant Directive (LCPD). The standard is divided into four main sections as follows

QAL1 - Desktop verification of suitability for any specific application.
QAL2 - In-depth commissioning and independent validation.
QAL3 – On-going quality assurance programme
AST - Annual Surveillance Test, an on-going re-validation programme.

In QAL1, the Continuous Emission Monitoring (CEM) / Automated Measurement System (AMS) must be proven to be suitable for the intended application prior to installation. MCERTS product certification at an appropriate range (1.5 or 2.5 times the daily average emission limit value, WID & LCPD respectively) is taken as evidence of compliance with the QAL1 requirements.

A QAL2 is the full scale validation of the AMS after installation has taken place. The validation requires a minimum of 15 valid parallel measurements to be made over at least 3 days with the monitoring being carried out evenly throughout the period for all the determinands that are continuously measured. This process requires close co-operation of the operator, the supplier of the AMS, test house and load environmental authority

The QAL3 phase governs the ongoing quality assurance of the AMS and the data it generates. This essentially requires a zero and a span to be carried out to ensure that the accuracy and the reliability of data is acceptable.

Annual Surveillance Test (AST)

An AST is used between QAL2 tests to demonstrate that the AMS functions correctly, its performance remains valid and that the calibration function and variability derived during the QAL2 remains as previously determined.

In the US, the Environmental Protection Agency (EPA) regulates emissions under the Code for Federal Regulations (CFR). This is divided into fifty volumes known as titles and title 40 of the CFR (40 CFR) lists all environmental regulations with Part 60 & 75 covering a wide variety of combustion sources from commercial, institutional, industrial and utility boilers through to incinerators, refineries and combustion turbines.

A tabulated summary of the schemes covering the US, UK and Europe is given below.

	US	UK &Europe	
Law	40 CFR Part 60 & 75, State Laws	European Directives	
Authority	EPA, State	Federal and State	Environmental Agency
Method	Compliance on Site	Type Approval	License to Operate Approval
Reference	EPA Spec.	Standard Reference Methods	
Test House (Analysers)	Operator Report to EPA	TUV Institutes	MCERTS
Technical Specifications	40 CFR Part 60 & 75 etc	European Directives	

9.1 The various monitoring schemes have their small differences, but typically, as in MCERTS, they cover the following.

- Linearity
- Cross Sensitivity
- Sample Pressure and Temperature
- Environmental Conditions
- Standard Reference Methods
- Availability
- Zero and Span Drifts

The European Monitoring Certification Schemes requires lab tests followed by field tests.

9.2 Monitoring Certification Scheme European Lab Performance Standard

	SO2	NOx	CO	CO2	HCl
Accuracy	±2%	±2%	±2%	±2%	±2%
Linearity	±2%	±2%	±2%	±2%	±2%
Cross Sensitivity	<4%	<4%	<4%	<4%	<4%
Response Time Max.	200 s	200 s	200 s	200 s	200 s
Repeatability	±2%	±2%	±2%	±2%	±2%

9.3 Monitoring Certification Scheme Field European Standard

	SO2	NO$_x$	CO	CO$_2$	HCl
Availability	≥95%	≥95%	≥95%	≥95%	≥95%
Min Maintenance Interval	8 days	8 days	8 days	8 days	8 days
Zero Drift	≤3%	≤3%	≤3%	≤3%	≤3%
Span Drift	≤3%	≤3%	≤3%	≤3%	≤3%
Determination Coefficient of Calibration Coefficient R^2	≥0.90%	≥0.90%	≥0.90%	≥0.90%	≥0.90%
Lack of Fit	≤2%	≤2%	≤2%	≤2%	≤2%
Reproducibility	≤3.3%	≤3.3%	≤3.3%	≤3.3%	≤3.3%

9.4 MCERTS Monitoring Scheme Standards Used

STANDARD USED	COMPONENT
EN 14791	SO2
EN 15058	CO
EN 14792	NO
EN 1911	HCl
EN 13284-1	Dust

10. Summary

CEM systems are inherently application dependent and it is the best system for the application that has to be determined. It has been demonstrated that the enveloped folded beam technique resolves many of the problems associated with extractive and cross stack systems. It can also be shown that it complies with the stringent requirements of Environmental Agencies and it should be seriously considered when selecting a continuous emission monitoring system.

References

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"Continuous Emission Monitoring – A technology for the 90s", Proceedings of an International Speciality Conference, Chicago, Illinois, November 1992.