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Plant Operator Problems with CEM's - A Common Evaluation

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ABSTRACT

In situations where continuous monitoring systems (CEM's) are available which have been 'proven' by regular use, the Regulator will normally require their use for the monitoring of airborne pollutants emitted by large plant. Disputes which arise between operators who purchase CEM systems and the system suppliers over the level of performance achieved are often difficult to resolve. Since the payment or non-payment of a significant amount of money is integral to these disputes a third party such as AEA Technology Environment is often brought in to give an expert opinion.

The range of CEM's problems and the types of plant on which such disputes can occur are illustrated by four case studies. In each case study the independent assessment of performance which was subsequently performed selected appropriate performance criteria to evaluate the installed system from a small set of performance standards with national or international recognition.

A different result emerged from each of the four case studies illustrating the complexity of the reasons for poor CEM's performance.

In all cases the causes for inadequate or poor performance were identified. The success of such assessments relies critically on selecting the right approach, on the relevance and quality of the reference measurements performed and on the quality of staff, equipment and procedures.

1. INTRODUCTION

The process of minimising emissions to the atmosphere of gaseous or particulate pollutants is not a cost benefit to operators of production plants, but the failure to do so could result in severe cost penalties. Since the range of instrumentation available on the market to monitor airborne pollutants is very wide with prices ranging from a few hundred pounds to tens of thousands of pounds the operator is faced with a difficult choice. On the one hand he could purchase an inexpensive system with little support and risk breakdown or he can purchase an expensive well supported system with good guarantees and expect to have a trouble free performance. In some parts of the world eg Germany, USA the operator's choice of system is constrained, by regulations, to systems which have proved that they can achieve a well specified level of performance on that type of application. In the UK there is no such constraint and operators are quite frequently disappointed by the performance of a CEM system purchased and installed as part of the requirement of the Authorisation to operate the plant issued by the Environment Agency.

When disputes arise between plant operators, instrument manufacturers the Regulator or interest groups a clear specification of what performance should be expected from the installed CEM system is required. Unfortunately this is usually not available. A CEM system may perform faultlessly in the laboratory, but the matrix of conditions on a plant can be very severe with high moisture, high acidity, complicated flow patterns and concentration levels of pollutants which can suddenly increase to many times the typical values.

This paper discusses four case studies in which AEA Technology has been asked to assess the performance of an installed CEM system. Sometimes the design and construction of the CEM system makes it unsuitable for the application and this showed up in one of these case studies. At other times the installation and maintenance procedures were inadequate and did not allow the system to reach the level of performance of which it was capable. In another example the ancillary equipment on the plant, which was connected to the CEM system installed, namely the data logging arrangement, was the feature which caused the apparent poor performance of the CEM system.

When carrying out assessments of CEM systems the procedures and standards employed as the basis of the assessment were selected from a small range of criteria such that the testing programme proposed was applicable to the installation in question. This approach helped to minimise cost and to quickly identify the cause of the concern over the quality of the data. All of the criteria employed are available in published form, but to ensure an accurate assessment of the CEM system the testing organisation should itself have third party verification of the quality of its staff and procedures. Such verifications of test organisations by for example UKAS, STA are becoming more common and prospective litigants in dispute procedures can now be confident that an assessment carried out by a verified test organisation will produce robust data and conclusions which will stand up to scrutiny.

2. CASE STUDIES

2.1 Chemical Waste Incinerator

AEA Technology Environment were contracted to assess the suitability of a continuous emission monitoring system supplied by a CEM manufacturer to monitor the emission from a low technology chemical waste incinerator which previously had operated with no abatement equipment, but recently had been uprated with a replacement unit. This unit was designed to dispose of the same solvent based feed stock as the previous unit. The plants new abatement equipment consisted of heat recovery filters to remove particulate material and alkali injection for acid gas control. As part of the application of the 1990 Environmental Protection Act (Integrated Pollution Control) and the Hazardous Waste Directive there was a requirement placed on the operator to install a continuous emission monitoring (CEM) system to monitor the emissions from the process and enable these figures to be reported to the regulatory body, the Environment Agency.

To fulfil this requirement a manufacturer was contracted to provide a CEM system, but the CEM system was connected to the plants logging/reporting system by a different company.

The required assessment by AEA Technology was an investigation on the ‘fitness for purpose’ nature of the CEM system resulting from a dispute between the operator who claimed that the system did not work properly and the system manufacturer. To this end a number of criteria were employed. These were: confidence limits given in the European Union Directive, availability requirements under the plant’s Authorisation and availability when compared to other systems used to monitor process emissions. In addition, assessment was made against criteria specified in the UK MCERTS scheme and in conjunction with recognised international standards for the measurement of emissions from processes. The standards which applied were:

> ISO 7935 Stationary source emissions - Determination of the mass concentration of sulfur dioxide - Performance characteristics of automated measuring methods
>
> ISO 10396 Stationary source emissions - Sampling for the automated determination of gas concentrations
>
> ISO 10849 Stationary source emissions - Determination of the mass concentration of nitrogen oxides - Performance of characteristics of automated measuring systems
>
> ISO WD12039.2 Stationary source emissions - Determination of the volumetric concentration of CO, CO_2 and oxygen - Performance characteristics and calibration of an automated measuring system.

The main standard referred to in the assessment was ISO 10396 Stationary source emissions - "Sampling for the automated determination of gas concentrations".

The system supplied was configured to operate at levels around the emission limits. During the initial start-up phase of the modified plant, the plant operated at higher than expected levels of acid gases which may have damaged the CEM system since the system was sampling gases that contained higher levels of corrosive gases than anticipated. There appears to have been no information requested and no provision made regarding the extremes in process emissions and the environment that the system would experience in the event of a failure of any component of the abatement equipment. The system installed was a generic system which had been designed to be used at processes emitting certain levels of pollutants which covered a wide variety of processes. There appears to have been no attempt to optimise the system to the conditions expected on the plant other than the emission limit values. The lack of information requested ie only the emission limits, would not have enabled this optimisation to have been undertaken. In addition, process information including likely interference species were not anticipated. Within an emission limit which is the same for different processes there can be a wide range of parameters that are present which will effect the results. For example, some waste incinerators having a limit of 10 mg m^{-3} for hydrogen chloride, can have moisture contents from 15-40% dependant on the abatement equipment employed. It is essential that the process parameters are allowed for in the configuration of the CEM system. This information was not requested by the manufacturer and the lack of emission stream information would have made the specification of a reliable CEM system very difficult. In addition, it appears that the characteristics of the sample point had not been investigated. An investigation should have taken the form of a grid measurements in the sample plane measuring; flow, temperature, oxygen and ideally each pollutant. This is a fundamental requirement under any recognised standard for continuous emission monitoring to establish that the sample taken, especially when sampling from a single point, is representative of the process emission.

The poor performance of the CEM system appeared to stem from the inability of the system to cope with higher levels of pollutants than specified by the emission limits and the non representative nature of the sampling point selected.

Data obtained by the installed CEM system was assessed by AEA Technology using the test of integral performance as outlined in International Standards Organisation Standards relating to the use of continuous automated measurement methods. This involved the comparison of data from the CEM system with data from a standard reference method using different detection principles. Integral performance is a measure of the working accuracy of the analyser system, but in this case there was only a limited amount of coincidental data. The source of standard reference method data was the routine monitoring work that had to be undertaken as part of the site's Authorisation. Only a limited number of data points were available, ideally there should have been 30. The data used was also based on data taken from two different sample positions so that the sampling was not in direct accordance with the procedures outlined in the standards. However, this means of assessment gave an indication of the working accuracy of the analyser system. In addition to the integral performance test, a significant error test was applied and evaluated against the ISO specification for each determinand. The data was also assessed against guidelines given in the Hazardous Waste EU Council Directive 94/67/EC.

The results are displayed in Table 1.

TABLE 1 Assessment of the Working Accuracy CEM System against Standard Reference Measurements of each Determinand.

Parameter	VOC	NO	SO_2	CO	HCl	Particulate
Integral Performance (S_A) as % of Authorised limit	58	8	31	51	20	45
EU Limits	Outside	Within	Outside	Outside	Outside	Outside
Systematic Error	No	Yes	Yes	No	Yes	No
ISO Specification	Outside	Within	Outside	Outside	Within	Outside

Based on the limited amount of previous data available the working accuracy of the CEM system appeared to fall short of that specified in Directive 94/67/EC except for the pollutant NO.

A specific source of dispute between the CEM manufacturer and plant operator was whether the availability of the system was that to be expected or worse than expected for this type of monitor.

The availability of a CEM system is defined as the proportion of the time for which the plant was operating that the system provided usable data for assessing the emissions from the plant. The criteria for acceptable performance of the availability of a CEM under the German TUV suitability tests is at least 90% but the system should be capable of achieving 95%. The UK MCERTS scheme has a requirement of >95% availability.

The Chemical industry as a whole, reports an instrument availability of CEM system greater than 90%.

CEM systems installed on other types of incineration process show similar values for ‘availability’.

In practice CEM systems applied to the chemical waste industry within the UK have experienced instrument availability’s of more than 95% for most pollutants. However, the availability has been lower for the more problematical species such as HCl, depending on the method of analysis. It has been reported that older CEM systems that have been in operation for periods of longer than five years can achieve availability of >95%. When compared with these values the availability of the installed CEM system of ~40% was clearly unacceptable.

The overall conclusions arrived at in this investigation were:

- The basic measurement principles employed in the CEM system are proven measurement techniques and are acceptable under internationally recognised standards.

- The information available suggests that the installation of the system had not followed recognised guidelines, with the result that the sample taken from the single point was not representative of the process emission.

- Reference methods to determine the performance characteristics of the system on the process were not undertaken on installation. Consequently the performance of the CEM system relative to the process was not assured after installation. This should have been part of the contract for supply as this would have verified the data produced by the system.

- The CEM system was designed to measure the concentrations of pollutants up to the emission limit value quoted. It had not been configured by the supplier to deal with the physical characteristics of the process on which it had been installed. An example of this was that the primary filtration on the system did not deal with the size fraction of particulate present in the gas stream after the abatement equipment.

- A large number of component failures occurred which shut down the system. This would suggest that the conditioning system, materials of construction and quality of components used in the supplied system were unable to deal with the process stream.

- Table 1 shows that on a limited amount of data available the system performance was poor when compared with the criteria specified by ISO standards and by the EU Directive on Hazardous Waste. The system installed was not capable of meeting expected criteria as provided in relevant standards primarily due to incorrect equipment specification resulting from a lack of process stream knowledge.

The system installed had not demonstrated that is was capable of achieving a level of availability which would be judged acceptable against the criteria specified by the German TUV scheme, the UK provisional MCERTS scheme or the level normally achieved in the incineration industry.

2.2 Coal Fired Power Station

Occasionally an installed CEM does not achieve the acceptance criteria set by the plant operator, but falls short by only a modest amount or in a small number of areas. In this situation the dispute between manufacturer and operator can be resolved without resorting to a full analysis of the CEM's performance but by recourse to independent testing using standard reference methods. This was the case when a coal fired power station installed a CEM system to measure NO, NO_2, SO_2, CO, O_2 and H_2O. The CEM system performed well in comparison with reference measurements on some determinands, but not on others. There was also some doubt about whether on some channels the CEM was at fault or the station's data logging system was to blame.

The approach taken by AEA Technology to resolve the disagreements was to make independent measurements with standard reference methods whilst also logging the outputs of the CEM.

A figure of merit called approximate pecentage comparison (Section 2.3) was defined as the absolute difference between AEAT and the CEM's data expressed as a percentage of the AEAT data. A comparison of the Standard Reference and the CEM measurements expressed in terms of approximate percentage comparison showed that:

- the NO readings ranged from 2 to 25%

- the SO_2 readings ranged form 6.6 to 10%

- the CO readings generally had an approximate percentage comparison of more than 80%

During the test measurements it became clear that the high error for CO was due to a malfunction in the data transfer link to the logging system and not the fault of the CEM. Discrepancies between variation in approximate percentage comparison for NO on different channels were also significant

2.3 Municipal Waste Incinerator

If a CEM system installed on a plant consistently produces results which are surprising when compared with expected emissions and independent testing the Regulator may ask for an assessment of the system's performance. Independent measurements similar to those carried out during compliance testing programmes can give a spot test result, but this may not be enough to identify areas of uncertainty which are causing concern.

A continuously monitoring CEM combined system installed on a municipal waste incinerator was assessed by AEA Technology for the Regulator. The continuously monitoring combined system consisted of (i) a cross stack monitor measuring NO, SO_2, and HCl (ii) an infra red cross stack instrument measuring CO and located upstream and (iii) a zirconium probe measuring O_2 again located upstream from the cross stack monitor and the standard reference measurements.

Carbon monoxide (CO), nitric oxide (NO), sulphur dioxide (SO_2) and oxygen (O_2) were measured by mobile field analysers provided by AEA Technology. These provided SRM measurements for comparison with the data produced by the CEM combined system. The CO mobile field analyser employed an infra red monitor using the non dispersive infra red (NDIR) method. The extracted sample was dried by a chiller followed by chemical drying with calcium chloride before being presented to the analyser. The NO mobile field analyser employed a chemiluminescence monitor. The extracted sample was dried using a permeation tube dryer prior to analysis. Sulphur dioxide was measured by a monitor using the NDIR method. The extracted sample was dried using a permeation tube dryer. Oxygen was determined by a paramagnetic analyser with the extracted sample dried by chilling followed by chemical drying before analysis.

The averaging time used to analyse the SRM data and the data from the CEM combined system was set at 5 minutes to correspond with the CEM integration time. Each measurement point consisted of a 30 minute average of the 5 minute values as required by the ISO standards for continuous measuring instruments. For HCl the CEM data was averaged to typically 1 hour per point or to the actual time over which the manual sample was collected.

All sample preparation systems were provided with a sample of the gas stream through a heated probe and filter followed by a heated line and a heated pump.

Each of the mobile field analysers was calibrated against standard gases using the ISO procedures which specify the requirements to which CEM systems should comply. The ISO standards employed were Oxygen - ISO CD 12309, Carbon Monoxide - ISO CD 12309, Sulphur Dioxide - -ISO 7935 and Oxides of Nitrogen ISO/DIS/10849.2. USEPA Method 26 and the CEN PrEN Draft Standard 1995 were used to obtain SRM data for HCl.

All of the determinands monitored in this study were covered by (i) ISO standards for CEM systems with the exception of HCl, (ii) the Plant Authorisation based originally on Process Guidance Note PGN IPR 5/3 and (iii) a future requirement based on the draft EU Council Directive on the incineration of non dangerous waste. These three requirements namely, ISO standards, IPR Guidance Notes and the draft EU Council Directive have been used to evaluate the CEM combined system installed.

ISO standard requirements outlined in ISO 7935 describe the integral performance S_A and the $|Z|$ test for a significant systematic error which were used to characterise the performance of the CEM combined system for each determinand.

The Process Guidance Note IPR 5/3 gives no guidance on assessing the performance of installed continuous monitors. The monitor must be able to measure hourly, 24 hour and in some cases 10 minute averages in order to indicate that the plant was operating within the limit values specified. The performance of the CEM combined system was assessed against the plant Authorisation based on the IPR note requirements by comparing the half hour averages with the hourly average limits specified.

The draft EU Council Directive requires that the emissions are measured to a stated uncertainty. The difficulty is that the 95% confidence intervals quoted are at the emission limit. The MSW incinerator operates below the emission limits for many of the determinands. Nevertheless the 95% confidence interval expressed as mg m^{-3} and measured at the operating level was used as a measure of the performance of the CEM combined system.

All of the SRM measurements employed extractive systems which passed the gases through drying systems before measurement. The CEM system on the other hand was a cross stack system which measured wet gases. A correction for moisture was applied to the CEM data which allowed raw data from the SRM measurements to be compared directly with moisture corrected CEM data. This data was compared and evaluated using the ISO procedures referred to above and represents the most reliable comparison of CEM data with SRM quoted data. In order to compare the data with IPR Guidance Note limits and the requirements of the draft EU Directive the data was corrected to standard conditions and in particular to 11% oxygen.

A comparison of corrected data was a less rigorous comparison of the CEM instrument with SRM's since the oxygen reading on the CEM may have been incorrect or not at an identical location to the SRM and may bias the readings of all the other determinands.

A comparison of CEM and SRM data corrected to 11% oxygen was carried out in addition to a comparison of data corrected for moisture but not for oxygen.

An assessment of a CEM system using the three sets of criteria outlined requires a reporting format which clearly identifies the strengths and weaknesses of the instrument's performance. A typical reporting sequence used in these assessments was as outlined below.

Spreadsheets were presented which list the data obtained from the CEM combined system and each SRM batch runs were corrected firstly to dry conditions only and then corrected both to dry conditions and to 11% oxygen. Performance criteria based on the ISO integral performance S_A and $|Z|$ test, the PGN IPR 5/3 limits and the draft EU Directive were applied and the results described. The report included data from the SRM method deployed, the uncertainty of the SRM method, the Process Guidance Note limits, the half hour limits set in the draft EU Directive and the 95% confidence interval specified in the draft EU Directive. The range of analyser used in the CEM combined system was given together with the percentage requirement of the range which the S_A value should achieve in order to comply with the ISO standard.

The comparison of the CEM combined system with the SRM methods was summarised for each of the determinands. The summaries also include an approximate percentage comparison figure (ACF) for ease of reference, derived as follows:

$$\mathrm{ACF} = \frac{\text{Average of differences between CEM and SRM}}{\text{Average SRM value}} \times 100$$

A + ve ACF results if the CEM reads high with respect to the SRM results.

Data produced by the CEM combined system was compared with SRM data for each of the determinands and the analysed results reported using a common format for ease of comparison. Typical results for NO and CO were presented as follows:

Nitric Oxide

Run 1 results corrected to dry conditions:

- meet the ISO specification for S_A
- fail the $|Z|$ test for systematic error
- record an ACF of -19% for the 10 measurements

Run 2 results corrected to dry conditions:

- meet the ISO specification for S_A
- fail the |Z| test for systematic error
- record an ACF of -10% for the 30 measurements

Run 1 results corrected to dry 11% oxygen conditions:

- comply with the draft EU Directive
- are within the PGN limits
- meet the ISO specification for S_A
- fail the |Z| test for systematic error
- record an ACF of -35% for the 10 measurements

Run 2 results corrected to dry 11% oxygen conditions:

- comply with the draft EU Directive
- are within the PGN limits
- meet the ISO specification for S_A
- fail the |Z| test for systematic error
- record an ACF of -30% for the 30 measurements

The CEM combined system reads low with an ACF of -35% in Run 1 and -30% in Run 2 at levels of NO concentration which as measured by the SRM are 116%, 97% of the PGN limits.

Carbon Monoxide

Run 1 results corrected to dry conditions:

- meet the ISO specification for S_A
- fail the |Z| test for systematic error
- record an ACF of +50% for the 12 measurements

Run 2 results corrected to dry conditions:

- meet the ISO specification for S_A
- fail the |Z| test for systematic error
- record an ACF of +77% for the 30 measurements

Run 1 results corrected to dry 11% oxygen conditions:

- comply with the draft EU Directive
- are within the PGN limits
- meet the ISO specification for S_A
- fail the |Z| test for systematic error
- record an ACF of +27% for the 12 measurements

Run 2 results corrected to dry 11% oxygen conditions:

- comply with the draft EU Directive
- are within the PGN limits
- meet the ISO specification for S_A
- fail the |Z| test for systematic error
- record an ACF of -38% for the 30 measurements

The CEM combined system reads high with ACF's of 27%, 38% for Runs 1, 2 but at levels of CO as measured with the SRM which are 12%, 20% of the PGN limit.

During the measurement periods the data from the CEM combined system demonstrated that:

- the requirement of the draft EU Directive on 95% confidence limits was satisfied
- the requirement to be able to generate data which can be compared with the PGN limit was satisfied
- the ISO specification for S_A was met
- all the determinands measured failed the ISO test for systematic error with the exception of Run 2 HCl, Run 1 O_2 and Run 1 SO_2.

The CEM data was lower than that of the SRM for NO, higher for CO, lower (Run 1) and higher (Run 2) for SO_2 and higher for HCl. Possible reasons for the differences were:

- the oxygen correction generally increases the difference between the CEM and SRM data. The difference of (1-2%) between the oxygen value measured by the on-plant system and the AEA Technology oxygen monitors was significant. AEA Technology used three different oxygen analysers (paramagnetic, zirconium, electrochemical) which agreed to better than 0.5%, but disagreed with the on-plant oxygen monitor by up to 2% oxygen
- the CEM system was not spanned or zeroed and could have drifted since the last calibration
- the flow profiles at the SRM sampling positions were measured and shown to be even, but this may not be the case across the optical path traversed by the CEM system.

A systematic error was detected for at least one calibration run in all determinands when compared with SRF measurements which cannot be explained by a difference in oxygen readings. The CO and NO_x monitors showed a systematic error on both calibrations. For some of the determinands the concentrations were less than the PGN limits and a positive systematic error did not take the readings over the limits, but the systematic error could be important nearer the limit. This was the case with NO where the emissions were at the limit and the CEM system read low by approximately 35% and 30%.

The presence of systematic error in all the determinands together with the fact that the CEM combined system was not normally zero and span checked since the last calibration pointed towards system drift as the cause of the concern in the CEM's performance. Alternatively the location of the cross stack CEM system may also be a reason for systematic errors to occur.

2.4 Clinical Waste Incinerator

When a new type of continuous monitor appears on the market there is often reluctance to deploy the monitor in preference to instruments which have traditionally been used and their performance proven by experience. As part of their Authorisation the operators of a clinical waste incinerator were required to install a continuous hydrogen chloride monitor providing that it could be shown that the measurement could be carried out reliably. AEA Technology were contracted to assess the continuous hydrogen chloride monitor.

The aim of the project was to assess the performance of the CEMs HCl analyser to ascertain the accuracy and reliability of measurement. Thus enabling a judgement to be made on its suitability for continuous measurement of the incinerators HCl emissions.

To provide this information the following tasks were undertaken:

i) Carbon dioxide profile to establish if there were any air ingress's that would affect the measurements of both the instrument and the standard reference method.

ii) Temperature flow profile to assure the suitability of the sample plane.

iii) Flow profile to show areas of non-uniform flow ie possible dead areas where reactions may continue and produce a result not representative of the process emission. Also to make sure that the standard reference method or instrument would not measure within such an area.

iv) Measurement of the analyser output and data logged output against a standard extractive reference method to determine the suitability of the analyser performance.

Samples were taken from a plane positioned before the ID fan prior to the duct leading to the stack. The CEM system was installed in a straight vertical piece of ductwork prior to the ID fan. For the purposes of this assessment three additional ports were positioned up-stream and a single port down-stream. These were to enable the duct profile to be characterised and the standard reference methods to measure along a similar axis as the instrument.

A profile of the carbon dioxide concentration was carried out using three non-dispersive infra red analysers simultaneously at ten points across the width of the duct. Each analyser system comprised of: a stainless steel probe, gas drying assembly, pump and analyser. The analysers were calibrated using the same calibration and zero gases prior to measurement. The systems were all configured to sample at the same rate. Each point on an axis was sampled for five minutes before readings were noted from all three analysers.

A temperature profile was carried out at ten individual points across the duct. Each measurement was taken simultaneously on three axis. Measurements were made by using a chromel/alumel thermocouple and electronic reader.

The flow profile of the duct was measured using three s-type pitots simultaneously at one of ten points across the duct on three separate sample lines respectively. The pressure measured at each point was then measured using an inclined gauge. These measurements were made in accordance with the guidelines in ISO 10780:1994 Stationary Source Emissions - measurement of velocity and volume flow rate of gas streams in ducts.

The standard reference method used for HCLwas based on the USEPA method 26, for the determination of Hydrogen Chloride emissions from stationary sources. A measured sample of stack gas was drawn through an absorbing train. This was made up of a series of five 125 ml gas washing bottles, the first of which was a dropout bottle, the next two contained 0.1N sulphuric acid and the last two contained 0.1N sodium hydroxide. Modifications to the standard method involved the use of an in-stack sample filter and the use of 100 l of absorbing solution in stack and PTFE transport lines to the absorbing train. The resulting solutions were analysed for chloride, calcium and sodium ions.

The analyser outputs were recorded in several ways; manually at the instrument (once every 2 mins), logged by the data logger installed by the manufacturer (averaged over 5 mins for every point) and logged by the operator every minute.

The ISO standards referred to in the UK Emission Monitor Certificate Scheme determines the integral of performance to measure the working accuracy of the instrument. This parameter is calculated from the difference in the pairs of measured results obtained by the instrument and the standard reference method. For this investigation nine half hour tests were undertaken. The average output of the analyser for the half hour period corresponding to the relevant SRM test was used. The value of S_A was calculated using the following equation:

$$S_A = \sqrt{\left(S_D^2 - S_C^2\right)}$$

$$S_D = \sqrt{\frac{1}{n-1}\left[\sum_{i=1}^{n} Z_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} Z_i\right)^2\right]}$$

Where:

S_A is the integral of performance in milligrams per cubic metre

S_C is the standard deviation of the standard reference method in milligrams per cubic metre

S_D is the standard deviation of the differences in the pairs of measured values ie between the SRM and the instrument

Z_i x_i-y_i is the difference in the paired test values in milligrams per cubic metre

x_i is the mass concentration of the HCl measured by the SRM in milligrams per cubic metre

y_i is the mean recorded concentration for the corresponding time period in milligrams per cubic metre

n is the number of paired measurements.

The ISO standards relating to the determination of performance characteristics of continuous emission monitors quote values of ±5.0% of full scale deflection as an acceptable value of S_A. However, there is currently no standard specific to HCl so a value of 5.0% was assumed. The drawback with this approach is that the range of the instrument is often much larger than the limit value set by the Authorisation.

As a second indicator of performance a test for significant error was applied using the following equations:

$$Z = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - y_i\right)$$

For a systematic error to be acceptable

$$|Z| \le 2\frac{S_D}{\sqrt{n}}$$

must be satisfied.

A relative error or ACF was also calculated, defined as the difference between the measured values divided by the standard reference method.

The third criteria employed for the evaluation of the CEM system was the EU Directive on the incineration of Hazardous Waste 94/67/EC. Annex III of the Directive gives values which the 95% confidence limits of the measurements should achieve relative to the emission values namely 40% of the emission limit when measured at the limit. This was adopted as a performance criteria which should be easily achieved by the new instrument.

The results of the test showed that there was a range of 6.0-7.1% relatively uniformly distributed over the duct cross sectional area which incicated that the sampling plane was acceptable under the criteria as described in BS 6069. A low temperature measured at a point in the far left corner of the sample plane gave a variation of 2.4% which is less than the < 5% variation required.

The results of the test showed that the flow profile across the duct was within accepted guidelines given ISO 9096 Stationary Source Emissions - determination of concentration and mass flowrate of particulate matter in gas carrying duct. Manual gravimetric method. The acceptance criteria in the standard is a ratio of highest to lowest velocities of less than 3:1 and the observed value was 1.5:1.

The data from the evaluation is summarised in Table 2 where values are given as percentage of the Authorisation limit.

TABLE 2 Comparison between Analyser and Standard Reference Method

Species	**S_A**	**Z**	**|Z|**	**Significant Error**	**ISO Specification**
HCl as % of Authorisation limit	6.11	0.4	4.71	Yes	Yes

Comparison between Logger Data and Standard Reference Method

Species	**S_A**	**Z**	**|Z|**	**Significant Error**	**ISO Specification**
HCl as % of Authorisation limit	8.87	5.78	7.44	Yes	Yes

The Z test showed the presence of a systematic error, but the size of the error was small and within acceptable guidelines. A more serious observation was that the data logged by the installed system when compared with the Standard Reference Method data differed significantly from the data taken directly from the analyser. This highlighted the need to optimise the averaging procedure used by the logger to the process variability.

The instrument showed a performance over the range of tests employed which complied with the EU Directive on the Incineration of Hazardous Waste; was acceptable according to the ISO criteria employed; showed an absolute error of measurement which was low throughout the measurement range; was installed at a location which was acceptable by international standards but required the data logger to be optimised to the process variability.

3. SUMMARY

Disputes regarding the performance of CEM systems have arisen between plant operators, instrument manufacturers and regulators on applications which include not only the clinical, municipal, hazardous waste incinerators and coal fired power stations described in Section 2, but in AEA Technology's experience, also at printing plants, sewage sludge incinerators, oil fired power stations and foundries.

Evaluation of CEM system performance carried out by AEA Technology were based on:

(i) ISO standards
(ii) MCERTS Performance Specifications
(iii) Process Guidance Note requirements
(iv) EU Directives
(v) Good Practice within the industry concerned.

The main symptoms of poor performance of the CEM systems described in Section 2 were:

- component failures leading to a reduced 'maintenance interval'
- absolute values which differ from SRM values , often due to a poor location
- data logging errors due to installation by an alternative supplier
- damage to components caused by lack of protection against process excursions

The reasons for concern regarding CEM system performance turned out to be different in all the Case Studies, but each was successfully identified by application of the criteria (i) to (v) outlined above. Frequently the poor performance of CEM systems arises not because of poor design or construction of the unit. Rather the faults are due to an inadequate installation and commissioning procedure which did not take into account the range of process conditions which could occur in adequate training of the plant maintenance personnel or to a location which was not stable or was not representative of the pollutants present in the off gases.

4. CONCLUSIONS

An increasing awareness by operators and regulators of the need for an installed CEM system to deliver a consistently good performance has led to a number of independent evaluations of CEM system performance. Anxieties regarding CEM systems have arisen from application to a range of processes. No one process appears to be much more difficult to achieve good CEM system performance at than any other although incinerators of waste materials do feature highly in the number of complaints received. A systematic process of performance evaluation of CEM systems has been developed at AEA Technology which includes current developments in UK regulatory requirements, EU Directives and existing Process Guidance together with the experience of what has been achieved at other installations in the UK and overseas.

In circumstances where potentially sound CEM systems are installed without sufficient optimisation to the range of conditions, both normal and abnormal, which can arise on a plant, the manufacture should expect a lower level of performance. This is also true if the installation location is less than ideal. Systematic errors can occur when compared with standard reference method measurements at a more representative location. Finally, the level of training given to plant operator maintenance staff and comprehensive QA procedures are crucial to the CEM system achieving a satisfactory performance.

REFERENCES

1. ISO 10849.2 - Stationary source emissions- Determination of mass concentration of nitrogen oxides- Performance characteristics of automated measuring systems.

2. ISO 12039 - Stationary source emissions - Determination of the volumetric concentration of CO, CO2 and oxygen - Performance characteristics and calibration of an automated measuring system .

3. ISO 7935 - Stationary source emissions - Determination of the mass concentration of sulfur dioxide - Performance characteristics of automated measuring methods.

4. ISO 10396 - Stationary source emissions - Sampling for the automated determination of gas concentrations.