



**A Review of the Industrial Uses  
of Continuous Monitoring Systems:  
Minerals Industry Processes**



# **A REVIEW OF THE INDUSTRIAL USES OF CONTINUOUS MONITORING SYSTEMS: MINERALS INDUSTRY PROCESSES**

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## 1. Introduction

This report provides a review of the application of continuous monitoring techniques available to the minerals industry. It is one of a series (Ref. 1.1, 1.2, 1.3, 1.4) covering the industrial process sectors regulated by the Environment Agency under Integrated Pollution Control (IPC). The review includes assessments of the suitability and availability of instruments, relevant research and development, details of manufacturers and their instruments, and information on the operational use of such instruments.

### 1.1 Background

One of the underlying principles of the system of Integrated Pollution Control (IPC), which was introduced through the Environmental Protection Act 1990, is the use of best available techniques (BAT) to prevent, minimise or render harmless releases to the environment. Accurate monitoring is essential for management to determine as true a picture as possible of concentrations and total mass of substances discharged to the environment. It is also an effective technique to control and minimise pollution at source. Continuous, on-line, real time methods are widely seen as the best monitoring techniques, where the technology is suitable and available, and the Agency encourages their use.

General guidance on monitoring techniques for minerals processes is provided through the IPC Guidance Note S2 Series (S2.3.01-04) (Ref. 1.5, 1.6, 1.7, 1.8). These specify that continuous sampling and monitoring instruments should be installed where appropriate. Advice on specific monitoring techniques is contained in the Technical Guidance Notes on Monitoring (*HMIP, Technical Guidance Notes, Monitoring, M1-M4*) (Ref. 1.9, 1.10, 1.11, 1.12).

The suitability of continuous monitoring techniques to specific processes, however, depends on the type of process, the conditions of the gas or effluent stream, and the substances to be measured. Minerals processes, in particular, have some unique and difficult-to-measure waste streams and process operations. The batch nature of frit processes, for example, and the particulate, fibrous and phenolic mixture in waste gases from mineral fibre plants create special challenges for continuous monitoring.

Continuous monitoring technology is constantly evolving with new products and techniques becoming available. Such technical and commercial developments will obviously affect the availability of specific continuous monitoring devices. Similarly, considerable developments in the general principles for continuous monitoring, calibration and verification techniques, emerging continuous monitoring technologies, environmental regulations and equipment standards, manufacturers details, and so on, can also be expected.

This review has therefore been world-wide in scope in order to ensure that current technical guidance on continuous monitoring is comprehensive and takes into account likely future changes in monitoring requirements, performance and cost. It has examined the use of continuous monitors in the minerals industry across a range of countries.

Previous reports (Ref. 1.1, 1.2, 1.3, 1.4) in this series detailed the general principles and pros and cons of the various sampling and analytical techniques. The fundamentals of these

techniques have changed little since these reports and most of the information is still relevant, and therefore is not duplicated in this report.

## 1.2 Project objectives and programme of work

The objectives of the project can be summarised as follows.

1. To review the application of continuous monitoring techniques, including all types of auxiliary instrumentation, to the minerals industry. This has included an assessment of their:
  - *suitability* in terms of, for example, the range of substances and process conditions encountered in the sector, as well as the limits of detection and release limits;
  - *availability* in terms of, for example, price, accessibility and range of techniques.
2. To collate the details of continuous monitoring equipment and auxiliary instrumentation, including costs, performance characteristics and reliability.
3. To assess the current applications of continuous monitoring techniques across the minerals industry, reviewing the number of instruments in operation in the UK and, where possible, in the other leading continuous monitoring countries.

To fulfil these objectives the seven tasks, summarised below, were undertaken:

### ***Task 1. Suitability***

Suitability was an important aspect of the study, involving a qualitative assessment of continuous monitors for process parameters, for example kiln temperature and O<sub>2</sub> concentrations, and for the principal released substances. This included assessing any effects of the various abatement systems used in the sector. The task also reviewed the impact of legislation on the type of monitoring equipment required for each type of process.

### ***Task 2 Review of availability***

"Availability" implies the device is proven to be effective and can be purchased from somewhere in the world. A continuous monitoring device may be "available" for minerals processes, even if it has not been directly used on specific processes, provided a reasonable degree of "read across" from other applications is possible. The issue of availability was examined separately for the techniques applicable to each sector.

### ***Task 3 Review of relevant R&D***

Techniques and instrumentation under development were reviewed, in conjunction with UK and overseas equipment suppliers, monitoring and instrumentation trade associations and research establishments, in order to predict future progress in continuous monitoring technology. Techniques being developed are presented on a sector-by-sector basis.



**Task 4 Review of the generic principles of relevant continuous monitoring technologies**

This task merely focused on referencing previous studies, where relevant, due to the limited developments in continuous monitoring technologies between this and previous reports. Details of the techniques are covered in specific sectors.

**Task 5 Review of calibration and verification procedures**

Correct calibration and verification of equipment is critical to its suitability for industrial processes. Similarly with Task 4, these issues are not specific to minerals processes and are adequately addressed in other recent reports, and therefore this subject has not been covered in depth. A parallel study for the Agency, undertaken as part of this work, provides an update of calibration and verification procedures for continuous monitors in large combustion plants.

**Task 6 Review of manufacturers and techniques/instrument summary details**

Specific details from manufacturers were collated:

- company commercial information, for example location, contact details, type of equipment, country, employees, turnover;
- continuous monitoring principles of measurement (categorised by company and substance measured);
- continuous monitoring application details (extent of reference plants, type of equipment, costs, operating ranges, approval testing).

The information was gathered primarily through telephone conversations with suppliers, using a pro-forma questionnaire to ensure that the information received was comprehensive and compatible. The detailed information is included in the appendices.

**Task 7 Review of operator experience**

This review represented the core of the project - to provide information on the ease with which continuous monitoring techniques can be used. The review examined issues such as operator experience, reliability of monitoring techniques employed/trained, maintenance requirements, and limitations and other known problems. Table 1.3a profiles the site visit programme undertaken.

**Table 1.3a visit programme (sites)**

Sector	UK	Europe	USA	TOTAL
<i>Cement /lime</i>	3	1	4	8
<i>Mineral fibres (1)</i>	3	3	3	9
<i>Frits</i>	2	1	1	4
<i>Asbestos processes</i>	2			2

Sector	UK	Europe	USA	TOTAL
<i>Ceramic processes</i>	1	1		2
<b>TOTAL</b>	11	6	8	25

Note 1)

Optical fibres excluded from site visit programme due to relative insignificance of releases and number of plants.

Information obtained from the site visits has been incorporated in the main report, as appropriate.

### 1.3 Information Sources

Information was collected from both equipment suppliers and users, as well as third parties, such as research organisations, trade associations and consultants. A list of continuous monitoring equipment suppliers contacted during the project is provided in Appendix A of this report. Trade Associations contacted include GAMBICA (instrumentation, control, and automation industry trade association), BCA (British Cement Association), BLA (British Lime Association), Eurosol (UK mineral fibre industry trade body), EURIMA (European mineral fibre industry trade body) and Portland Cement Association (PCA) (USA). Research organisations and consultants contacted include ESRC, CERAM Research and Gossman Consultancy (USA).

### 1.4 Acknowledgements

The information in the report is based on the large amount of useful and relevant information submitted by the instrument supply companies, discussion and correspondence with major UK, French, German and USA mineral companies, and the technical references which are listed.

The authors would like to thank all those who contributed and acknowledge that, the preparation of this report would not have been possible, without the high level of co-operation received.

### 1.5 Structure of the report

The remainder of this report is structured into three main parts. Sections 2 and 3 describe the general issues of affecting the use of continuous emissions monitors (CEMs) in the minerals industry covering legal and technical factors. Sections 4 to 8 contain the analysis of the application of CEMs in the five main sectors reviewed in this study. The findings from each of these section analyses are then brought together in the conclusions in Section 9.

## 2. Overview of mineral processes

The purpose of this section is to provide a background to the IPC-regulated minerals sector in the UK. It describes the structure of each sector together with the key features of the production processes and release characteristics.

### 2.1 Structure of the minerals sector

Minerals processes subject to regulation under IPC cover a variety of industry sectors and sub-sectors. These are shown in Table 2.1 together with the number of IPC-authorized processes.

**Table 2.1: Structure of IPC-regulated minerals processes**

Process	No. of IPC-regulated processes
Cement	23 <sup>(1)</sup>
Lime	37 <sup>(1)</sup>
Insulation fibre (glass + rock wool)	8 <sup>(2)</sup>
Continuous filament glass fibre	2 <sup>(2)</sup>
Ceramic fibre	2 <sup>(2)</sup>
Glass frit	3 <sup>(2)</sup>
Enamel frit	1 <sup>(2)</sup>
Ceramic processes (number of kilns)	16 <sup>(3)</sup>
Asbestos processes	14 <sup>(4)</sup>

**Notes:**

1. HMIP, 1996, BAT Technical and Economic Review of Cement and Lime Processes.
2. HMIP, 1996, Technical and Economic Review of Techniques to Control Releases from Non-Asbestos Mineral Fibres and Frit Manufacturing Processes.
3. HMIP, 1996, Technical and Economic Review of Ceramic Processes.
4. Environment Agency, 1997, Central Register.

### 2.2 Cement/lime processes

The cement and lime sector accounts for over half of the minerals processes regulated under IPC. Table 2.2a presents an approximate profile of these processes broken down by the process type.

**Table 2.2a Structure of the IPC-regulated cement and lime sector**

Process Type	Cement			Lime			
	Wet	Semi-wet/ semi-dry	Dry	Shaft kiln	Rotary kiln	Rotary hearth	Fluidised bed
Number in operation	11	7	5	18	8	8	3

Wet processes are still the most common in the cement sector, although these are gradually being replaced by more energy-efficient dry processes. Vertical shaft kilns predominate in the lime sector, largely due to their lower energy consumption compared to rotary kilns.

Cement and lime processes produce similar releases, the majority of which are to air in the form of PM, SO<sub>x</sub> and NO<sub>x</sub>. Table 2.2b summarises the key substances released from cement and lime processes.

**Table 2.2b Releases from cement and lime processes**

Process	Part of process	Medium	Key substances
Cement and lime	Quarrying	A	PM
	Raw material prep, handling, storage	A	PM
	Fuel prep, handling, storage	A	PM, VOCs
	Site drainage	W	SS, pH
	Kiln	A	PM, SO <sub>x</sub> , NO <sub>x</sub> , CO, VOCs, metals, halogenated compounds (e.g. HCl, metal halides), dioxins
	Clinker cooler (cement only)	A	PM
	Hydrator (lime only)	A	PM
	Cement milling	A	PM
	Product storage and handling	A	PM

The main releases from the production of cement occur from kiln exhaust gases, clinker cooler exhaust and cement mill exhaust.

The principal abatement system used in both cement and lime processes is the electrostatic precipitator (EP) to remove dust from kiln, cooler and mill exhausts. EPs can operate under conditions of high humidity and high temperature (up to 370°C), although bag filters are now being increasingly used to up grade existing ESPs, especially on the lower temperature gases from clinker coolers and milling operations. Wet scrubbing systems are hardly ever used on these processes.

### Characteristics of cement and lime process (post-abatement) releases

- Kiln exhaust gas                      Moist, hot gas stream, high CO<sub>2</sub> level, fine dust. Sulphur and halogen concentration dependent on the type of process (variation in adsorptive capacity of material within kiln processing system).
- Clinker cooler exhaust              Moist, warm gas, fine dust loading.
- Cement mill exhaust                Ambient temperature, fine dust.

### Influence of fuel type

A wide range of fuels are now being burned in cement (and some lime) kilns. The main fuels are coal and petroleum coke, as well as oil, LPG and gas in the lime industry. Other fuels include substitute liquid fuels (SLF) such as solvent waste residues, and substitute solid fuels such as waste tyres, either whole or chipped. The choice of fuel can influence emission characteristics and the need for CEM equipment, with those burning hazardous wastes requiring emissions monitoring in accordance with the legislation on hazardous waste incineration<sup>(Ref. 2.1)</sup>. Specifically, these fuels can alter emissions with consequential requirements for monitoring of different compounds, as shown in the following tables<sup>(Ref. 2.2)</sup>.

**Table 2.2c Continuous monitoring**

**Minimum criteria for operator monitoring at baseline conditions and maximum substitution rate - example for cement kilns**

Substance/ criteria to be measured	Testing required (indicated by asterisk) Kiln stack
Particulate	*
NO <sub>x</sub> (as NO <sub>2</sub> )	*
SO <sub>2</sub>	*
CO	*
HCl	* (1)
Oxygen, moisture and temperature	* (2)
HF	* (1)
VOCs (as TOC)	* (1)

Note 1) Continuous monitoring of these parameters may be difficult but systems are now available and continuous monitoring should be conducted where appropriate.

Note 2) To be measured whenever other measurements are made.

Specific additional determinants are required in relation to particular substitute fuel types as detailed below. In general this is because of the possible presence of particular substances in such fuel inputs, and the need to demonstrate their fate in the process.

**Table 2.2d Additional monitoring requirements specific to particular fuel types**

Substitute fuel	Additional monitoring
Substitute liquid fuel	Pentachlorophenol Hexachlorocyclohexane (all isomers) DDT (all isomers)
Tyres (whole or shredded) (or detailed specification)	Zinc Polynuclear Aromatic Hydrocarbons (as set out, calculated and expressed in the extant version of the Agency's <i>'Inventory of Sources and Releases - Guidance for Operators'</i> ) Benzene, butadiene, styrene, HBr and chloromethane (stack emissions only)
Refuse-derived fuel	Zinc
Wood chips and sawdust	Pentachlorophenol Hexachlorocyclohexane (all isomers) Tributyl tin compounds
Dried sewage sludge pellets	Zinc
Dried sewage sludge	Zinc
Waste photographic emulsions e.g. X-ray film	Silver
Commercial (paper, cardboard, rags etc)	Zinc
Any material containing organophosphates	Total phosphorous compounds

## 2.3

### Mineral fibre processes

The mineral fibre sector comprises several types of processes. Table 2.3a presents a profile of the number and types of the Agency IPC-regulated mineral fibre processes.

**Table 2.3a Structure of the IPC-regulated mineral fibre sector**

Process type	Continuous filament glass fibre	Ceramic fibre manufacture	Insulation fibre (glass + rock wool)	
	Gas fired furnace	Electric melting furnace	Gas fired furnace	Coke fired cupola
Number in operation	2	2	6	2

Due to the variety of mineral melting and downstream spinning and coating processes, this sector gives rise to a complex set of emissions, including PM, acid gases and a

range of VOCs. Table 2.3b provides the key substances released in the production of insulation fibre, ceramic fibre and continuous filament glass fibre.

**Table 2.3b: Releases from mineral fibre processes**

Part of process	Medium	Key substances
Raw material handling	A	PM, phenol, formaldehyde, ammonia, amines, VOCs, organic fume
Melting (cupola)	A	PM, SO <sub>x</sub> , NO <sub>x</sub> , H <sub>2</sub> S, CO, metals
Melting (gas fired)	A	PM, SO <sub>x</sub> , NO <sub>x</sub> , fluorides, chlorides, CO
Melting (electric)	A	PM, NO <sub>x</sub> , fluorides, chlorides
Fiberising (ceramic)	A	ceramic fibre, PM, VOCs
Fiberising (insulation)	A	PM, phenol, formaldehyde, ammonia, amines, VOCs, organic fume
Curing (drying oven)		PM, phenol, formaldehyde, ammonia, VOCs, organic fume, NO <sub>x</sub>
Burnout oven (ceramic)	A	ceramic fibre, PM, VOCs
Product cooling	A	ceramic fibre, PM, VOCs, organic fume
Trimming, packaging	A	ceramic fibre, PM
Pipe section production (insulation)	A	PM, phenol, formaldehyde, ammonia, amines, VOCs, organic fume
Tail gas incineration	A	VOCs, SO <sub>x</sub> , NO <sub>x</sub>
Wastewater	W	Ammonia, COD

### Characteristics of mineral fibre process releases

Process descriptions and associated releases are described in IPC Guidance Note S2 3.03 - Manufacture of Glass Fibres, Other Non-Asbestos Mineral Fibres, Glass Frit, Enamel Frit and Associated Processes. The Guidance Note also includes benchmark release levels for key substances to air and water.

Fibre processes can be summarised as having several common process stages:

**MELTING → FORMING → CURING → COOLING**

Continuous monitors are already used to control/monitor a number of process parameters, including temperature, and oxygen, carbon monoxide and particulate concentration. Emissions from the furnaces are typified by high-temperature "sticky" gases, and these can pose difficulties for some continuous monitoring techniques. The more difficult streams, though, are those from the forming/curing area. These gaseous streams are wet (containing water droplets), especially if passed through some form of wet scrubbing device, and contain particulate and fibrous material as well as ammonia, phenols, formaldehyde and other VOCs. The high moisture content poses severe interference problems for all continuous monitoring techniques, and the need to distinguish between fibrous and other particulate matter creates additional difficulties for continuous monitoring. Where curing oven exhausts are ducted separately from

forming areas, such as at the Rockwool plant in Wales, continuous monitoring techniques can be applied without too much difficulty, but often they are combined with forming area emissions and thus suffer the same difficulties as monitoring forming gases alone.

At present aqueous waste streams are only significant for continuous filament fibre and ceramic fibre processes. Glass wool and rock wool processes are designed to recirculate process waters. The introduction of staged scrubbing to remove ammonia gases is a future possibility which would, however, create an effluent stream. Effluents from continuous filament processes contain a mixture of dissolved and solid matter, with high BOD and COD loading.

## 2.4

### Frit Processes

There are currently only three glass frit processes and one enamel frit process in the UK. With the exception of one continuous lead bisilicate kiln, all other frit kilns are operated on a batch basis. Table 2.4a summarises the key releases and pollutants associated with glass and enamel frit processes.

**Table 2.4a Releases from frit processes**

Part of process	Medium	Key substances
Raw material handling	A	PM, Cd, Pb, other metals
Charging	A	PM, Cd, Pb, other metals
Melting	A	PM, NO <sub>x</sub> , Fluorides (enamel frit only), Cd, Pb, other metals
Quenching	W	Cd
Drying	A	PM, NO <sub>x</sub> , Cd, Pb, other metals
Bagging	A	PM
Milling	A	PM, lead, other metals
	W	Cd
Abatement plant	L	Solid waste
Waste water	W	Cd

### Characteristics of frit process releases

Frit processes and associated releases are described in IPC Guidance Note S2 3.03. The Guidance Note also includes benchmark release levels to air for key substances as well as benchmark release levels to water for key substances.

The principal emissions from frit kilns are to air, and in most cases are monitored for PM and NO<sub>x</sub>. HF is a product from enamel frit kilns and requires monitoring. Heavy metals such as cadmium and lead are present in low concentrations and currently require monitoring on a periodic basis.

## 2.5

### Asbestos processes

There are 14 IPC-authorised processes in the asbestos manufacturing sector. These comprise a mixture of processes manufacturing: asbestos cement products, friction products, textiles, reinforced plastics and seating materials.



The main releases from these processes tend to be VOCs and ammonia, with asbestos fibres already tightly controlled and regulated. Table 2.5a summarises the key releases and pollutants associated with asbestos processes.

**Table 2.5a Releases from asbestos processes**

Part of process	Medium	Key substances to be monitored
Raw material handling	A	Asbestos fibre, PM
Mixing	A	Asbestos fibre, PM, formaldehyde, phenol, ammonia, total amine, VOCs
Coating or impregnation	A	PM, formaldehyde, phenol, ammonia, total amine, VOCs
Drying/curing	A	PM, formaldehyde, phenol, ammonia, total amine, VOCs, NO <sub>x</sub> , HCl
Cutting	A	Asbestos fibre, PM
Machining	A	Asbestos fibre, PM
Waste gas treatment	A	PM, VOCs, NO <sub>x</sub>

#### Characteristics of asbestos process releases

Process descriptions and associated releases are described in IPC Guidance Note S2 3.02 - Asbestos Processes. The Guidance Note also includes benchmark release levels to air and water for key substances.

Asbestos processes generate releases of particulates, fibrous material, VOCs and ammonia. Continuous opacity monitors are already installed on most plants for particulates, and periodic VOC monitoring is becoming more widespread. No prescribed substances are released to water, although monitoring for suspended solids and pH may be required for pH adjustment, and effluent treatment needed for some processes<sup>(Ref. 1.6)</sup>.

## 2.6

### Ceramic processes

IPC-authorised ceramic processes comprise solely the manufacture of Fletton bricks. There are approximately 16 kilns producing these bricks across five sites. All kilns are of the "Hoffman" type which employ a reducing atmosphere during part of the firing cycle. This gives off a characteristic odour of organics with a high sulphur content.

Table 2.6b summarises the key releases and pollutants associated with Fletton brick manufacturing processes.

**Table 2.6b: Releases from ceramic processes**

Part of process	Medium	Key substances to be monitored
Firing	A	PM, SO <sub>x</sub> , NO <sub>x</sub> , oxides of carbon, VOCs, halogen compounds
Raw material storage	A	PM
Clay preparation	A	PM
Clay shaping	A	PM

**Characteristics of ceramic process releases**

Process descriptions and associated releases are described in IPC Guidance Note S2 3.04 - Ceramic Processes. The Guidance Note also includes benchmark release levels to air and water for key substances.

The Fletton brick process releases a mixture of odour, organic and inorganic compounds. Monitoring of odorous compounds such as mercaptans creates particular difficulties due to the very low detection levels required, and the variety of odorous species which can give rise to complaints. For continuous monitoring, the measurement of surrogate indicators such as H<sub>2</sub>S has been used successfully for other processes, such as sewage treatment facilities.

### **3. Continuous monitors - legal and technical framework**

#### **3.1 Introduction**

This section examines the development of laws, regulations and technical guidelines concerning the use of continuous monitors in the UK, Germany, the Netherlands, France, the USA and the EU and their relevance to the minerals sector. The legislation covering continuous monitors is examined, in particular the parameters that must be monitored continuously under the different legal systems. Some of the main aspects of the legal/technical frameworks in these countries have already been described in earlier studies <sup>(Ref. 1.1, 1.2)</sup>. In this report, comments are made where there are aspects of interest specific to the minerals sector or where there have been significant changes in recent years to the specific legislation or guidance covering the use of continuous monitoring technology. In most countries, though, there is little specific requirement for continuous monitoring in the minerals sector.

#### **3.2 The United Kingdom**

##### **3.2.1 Legislation**

The Environmental Protection Act 1990 introduced a system of Integrated Pollution Control (IPC) for the regulation of the most potentially polluting and/or technologically complex industrial processes (including minerals processes). The processes that are prescribed for IPC are defined in the Environment Protection (Prescribed Processes and Substances) Regulations 1991 and subsequent amendments. In England and Wales processes prescribed for IPC are regulated by the Environment Agency, the successor body to HM Inspectorate of Pollution (HMIP).

The former HMIP issued guidance in the form of process guidance notes (CIGNs) to assist HMIP inspectors in their assessment of an application for, or a variation of, an authorisation under the Act. The notes were also for use by applicants as guidance on the criteria against which inspectors judged applications. The CIGNs included advice on techniques for monitoring releases in connection with release limits for specified substances.

The minerals sector CIGNs have now been superseded by IPC Guidance Notes (S2 Series for minerals processes). The S2 Series Guidance Notes provide benchmark release levels for key substances, which are considered in relation to site-specific Best Available Technique Not Exceeding Excessive Costs and Best Practicable Environmental Option assessments when framing conditions in authorisations. The Notes, however, do not include advice on techniques for monitoring releases. They do, however, refer to the monitoring series of Technical Guidance Notes produced by HMIP between 1993 and 1995 (the M series M1, M2, M3, M4 <sup>(Ref. 1.9, 1.10, 1.11, 1.12)</sup>). As with the CIGNs, these TGNs are issued as guidance to inspectors, providing information on technical subjects of relevance to their regulatory functions. The Notes are also aimed at monitoring contractors, industry and any other interested parties as guidance on the technical information used by regulators when carrying out their duties. These Notes are currently being updated by the Agency for re-publishing in the year 2000.

### 3.2.2 Standard reference methods

TGN M2 and M4 describe available national and international standard methods for monitoring the types of pollutants to be found in flue gases, including those from minerals processes.

The standards described include:

- BS3405 <sup>(Ref. 3.1)</sup>, and BS6069: Section 4.3 (ISO9096) <sup>(Ref. 3.2)</sup>, and ISO/DP 10155.2 <sup>(Ref. 3.3)</sup> (for automatic methods); in addition to German (VDI), Italian (Unichem), French (AFNOR) and American (USEPA) methods for particulate matter.
- German, French, Italian and American methods for SO<sub>2</sub>, NO<sub>x</sub>, HCl, HF, metals and organics.
- BS1756 <sup>(Ref. 3.4)</sup> for both SO<sub>2</sub> and NO<sub>x</sub> in flue gas; and BS 6069: Sections 4.1 (ISO7934: 1989) <sup>(Ref. 3.5)</sup> and 4.4 (ISO7935:1992) <sup>(Ref. 3.6)</sup>. Manual and continuous measurement of SO<sub>2</sub> respectively.
- ISO/CD 11564 <sup>(Ref. 3.7)</sup> and ISO/CD 10849.2 <sup>(Ref. 3.8)</sup>. Manual and automatic methods of measurement of NO<sub>x</sub> respectively. These documents are not publicly available, however, as they are still only in draft form.
- BS6069 (Ref. 3.9) pt. 4.2. Stack method for asbestos by fibre control measurement.
- BS:ISO 10155 (Ref. 3.10). Automated monitoring methods for particulates.
- BS:ISO 11564 (Ref. 3.11). Stack methods for determination of NO<sub>x</sub>.
- ISO 10849 (Ref. 3.12). Performance characteristics of automated NO<sub>x</sub> measuring systems.
- ISO 10780 (Ref. 3.13). Stack method for measurement of flow rate in gas stream ducts.
- BS:EN 1948 (Ref. 3.14). Stack methods for the determination of PCDDs and PCDFs (dioxins).
- BS:EN 1911 (Ref. 3.15). Stack method for manual measurement of HCl.

### 3.2.3 Performance criteria and QA/QC procedures for continuous monitors

The Agency has established its monitoring certification scheme: MCERTS, to promote quality monitoring data based on international standards. MCERTS initially focuses on the product certification of continuous emissions monitoring systems (CEMs) for the continuous monitoring of chimney stack emissions from industrial processes. MCERTS performance standards based on ISO and CEN standards have been published by the Agency. Assessment of conformance is by means of a combination of laboratory and field tests.

The initiative leading to the establishment of MCERTS arose from a need identified by the Agency for a scheme in the UK to assist industry in choosing monitoring systems, including CEMs, which are fit for the purpose and promote public confidence in self-monitoring regulatory regimes. The initiative attracted support from the UK instrument manufacturer's trade association, GAMBICA, which recognised the world-wide benefits for its members of an accessible, rigorous, well-founded and independently accredited monitoring scheme.

Outline proposals <sup>(Ref. 3.16)</sup> for the establishment of a UK-based internationally acceptable certification scheme, to be known as MCERTS, were produced by the National Physical Laboratory (NPL) and AEA Technology's National Environmental Technology Centre (NETCEN), under the guidance of a steering committee representing the Agency, GAMBICA and other interested parties. The proposals included the establishment of a certification service complying with the EN45000 series of European Standards, draft MCERTS performance standards for instrumentation based on ISO and CEN standards and requirements for conformance assessment by means of laboratory and field testing. The Agency consulted industry, trade associations etc on the proposals in 1996 and received responses overwhelmingly in support of establishing a scheme.

The Agency appointed Sira Certification Services (SCS) to operate MCERTS on its behalf. SCS provides the formal MCERTS Certification Body accredited by the UK Accreditation Service (UKAS) as complying with European Standard EN45011. SCS is independent of all interested groups including those seeking certification for their products and/or services and end-users.

The scheme is being expanded progressively to cover other instruments for monitoring ambient air quality, waste water discharges, receiving water quality and discontinuous monitoring systems. The Agency has also published proposals for the inclusion of manual stack emissions monitoring within MCERTS <sup>(Ref. 3.16)</sup>.

### ***Performance standards***

MCERTS performance standards <sup>(Ref. 3.17)</sup> based on relevant sections of international ISO or CEN standards have been published by the Agency covering instruments in the following categories:

- extractive stack emission monitoring instruments, where a sample of the stack gas is drawn from the stack into the measuring cell;
- cross-stack or in-situ emission monitoring instruments, where the measurement of the targets species is made within the gaseous atmosphere of the stack.

And for use in measuring a range of atmospheric pollutants emitted by:

- large combustion plant;
- incineration of municipal and hazardous waste;
- solvent-using processes.

The atmospheric pollutants which are covered by the scheme have been selected so that there is maximum overlap with, and benefits to, industrial processes other than those listed above. The species considered to be of most importance are sulphur dioxide (SO<sub>2</sub>), the oxides of nitrogen (NO and/or NO<sub>2</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), hydrogen chloride (HCl), volatile organic compounds (expressed as total

organic compounds (TOC), oxygen ( $O_2$ ), water vapour ( $H_2O$ ) and particulate material. Other instruments which monitor the temperature, pressure and mass flow of the stack gas are also included. The measurement ranges covered for each of the species depends upon the specific industrial process for which the CEM is to be used, and is agreed at the time of applying for certification.

The Agency will periodically review the MCERTS performance standards to keep them up to date with advances in the technical design of CEMs and with CEN work on performance criteria and performance testing for continuous monitors - see Section 3.7.

#### **Conformance assessment**

Assessment of a CEMs conformance with the relevant MCERTS performance standard is by means of laboratory and field testing. All testing has to be carried out in accordance with procedures accredited by UKAS as complying with European Standard EN45001: General criteria for the operation of testing laboratories. Currently, laboratory and field testing of CEMs is available from the National Physical Laboratory and AEA Technology. Test house performance standards will be published by the Agency to allow other organisations to offer testing services to MCERTS requirements.

The laboratory tests cover the intrinsic performance of the equipment, including:

- linearity;
- cross-sensitivity;
- sample pressure and temperature;
- delay time, response time;
- lower detection limit;
- repeatability;
- environmental conditions;
- physical disturbance.

The field tests are a key element of the overall assessment of instrument performance. A three-month field trial is required to establish:

- operational characteristics;
- influence of physical and chemical environment;
- evaluation of the accuracy with a Standard Reference Method;
- reproducibility;
- availability and maintenance interval;

- zero and span drifts.

### ***Certification procedure***

The instrument certification procedure consists of the following stages:

- *Initial application:* The instrument manufacturer submits an application to the MCERTS Certification Body together with unambiguous identification of the instrument, two sets of drawings, control copy of any software and evidence of quality control procedures for example ISO 9002, ISO 9001.
- *Selection of the certification committee:* The Certification Body appoints a certification committee (normally three people) who have knowledge and experience of the instrumentation.
- *Review of application:* The certification committee reviews the application and agrees the relevant performance standards and appropriate laboratory and field tests for the instrument's intended applications.
- *Quotation for testing:* The Certification Body, in conjunction with the applicant, will ask qualified test laboratories (initially NPL and AEI Technology) to quote. The client confirms the test programme, test schedule and quotation, usually in a preliminary meeting with the Certification Body and the test laboratories. The client places a contract with the Certification Body to cover all testing and certification. The Certification Body places a contract with the chosen laboratories.
- *Laboratory and field tests:* The manufacturer sends the instrument(s) directly to the test laboratory. At the conclusion of testing the reports are sent to the Certification Body and the manufacturer. The testing laboratory immediately informs the Certification Body of any failures during testing to allow the applicant to take corrective action.
- *Review of test results:* The certification committee reviews all test results and decides to issue or refuse a certificate. The reasons for refusal will be reported, as will any special conditions applying to the certificate. The certificate and accompanying schedule will list the valid range of applications and processes. A complaints and appeals procedure exists, which may be involved in the event of any disagreement.

### **3.2.4 Data-logging and processing**

Data-logging and processing are also covered in HMIP Technical Guidance Note M2. In Germany there exists a well-defined administrative structure for reporting. At present this form of documentation/administration has not been formulated in the UK. It is predicted that the reporting system to be adopted by the UK will require sophisticated data handling.

The National Compliance Assessment Service of the Environment Agency is currently working on standard reporting forms, and extension of the MCERTS system is to include data acquisition.

### 3.2.5 Performance criteria for controlled process measurements

UK legislation contains no specific guidance on process measurements for the minerals sector, except where specified in process-specific authorisations. There are no general "binding" rules, unlike systems elsewhere in Europe.

## 3.3 Germany

### 3.3.1 Legislation

All facilities in Germany, which would be included within the UK minerals process sector, including cement, lime, glass & mineral fibre, glass & enamel frit and asbestos processes, require a licence to operate under the Bundesemissionschutzgesetz (BImSchG) or Federal Air Quality Law from 1984 (amended 1990). The fourth regulation of the law - 4BImSchV<sup>(Ref. 3.18)</sup> - from 1985 defines the categories of industrial plants which require a licence for emissions to air. The licensing authority is the State Environment Office in the Regierungsbezirk (administrative region) within which the plant or facility is sited.

In preparing or revising a licence, the licensing authority will make use of the emission conditions and the monitoring requirements described in Technische Anleitung zur Reinhaltung der Luft (TALuft)<sup>(Ref. 3.19)</sup> - Technical Guidance on Air Quality Control<sup>3</sup> - issued in February 1986. The licensing authority must also consider any technical developments in the particular industrial sector since 1986, in particular with regard to emission reduction technology when issuing a new, or revising an existing, licence. Where local circumstances dictate, or where emission reduction technology has been improved, the licensing authority is free to specify lower emission limits or more extensive monitoring requirements than are given in TALuft. For example, emission limits for NO<sub>x</sub> from the cement industry have recently been lowered to 500 mg/Nm<sup>3</sup> for new plants and 800 mg/Nm<sup>3</sup> for old plants (previously 1,300 mg/Nm<sup>3</sup> to 1,800 mg/Nm<sup>3</sup> respectively).

The monitoring requirements for emissions to air will be specified in the individual licence issued for the specific plant concerned. However, Section 3.2 of TALuft - *Measurement and Monitoring of Emissions* - provides guidance on monitoring covering all the relevant sectors. The issues covered include:

- specification for measurement position;
- initial and repeat measurements;
- measurement planning;
- selection of measurement procedure;
- continuous measurements.

Some of the requirements contained in TALuft have been superseded by subsequent guidance notes issued by the Federal Ministry of the Environment, for example, on the evaluation of emission data and calibration of continuous monitors. However the



essential elements of the monitoring requirements under TALuft remain unchanged, that is:

- discontinuous measurement of controlled parameters to be carried out on commissioning (or following a significant process change) and every three years thereafter;
- the measurement methods used should be those described in the relevant VDI Guidelines,<sup>(Ref. 3.20)</sup>
- a decision on the use of continuous monitors should, in general, be based on the expected mass flow of pollutant in kg/hr.

Continuous monitoring of emitted pollutants is to be specified in the licence if the mass flow of pollutants exceeds the following thresholds:

Dust:	5 kg/hr
SO <sub>2</sub> :	50 kg/hr
NO <sub>x</sub> (NO + NO <sub>2</sub> )*:	30 kg/hr
CO: efficiency	5 kg/hr (when monitoring combustion 100 kg/hr (in all other cases)
HF (inorganic fluorine compounds):	0.5kg/hr
HCl (inorganic chlorine compounds):	3 kg/hr
Chlorine:	1 kg/hr
H <sub>2</sub> S:	1 kg/hr
Class I Organic Compounds:	1 kg/hr
Sum Class I-III Organic Compounds:	10 kg/hr

\* Note: If NO<sub>2</sub> emissions can be demonstrated to be less than 10 per cent of the total NO<sub>x</sub> emitted, then continuous measurement of NO plus calculation of NO<sub>2</sub> will be permitted.

Some of the facilities within the minerals sector will generate mass flows in excess of those listed above and hence will have a requirement written into the licence to install continuous emission monitors. Licence conditions are site-specific. However, the following parameters are likely to be subjected to a continuous monitoring requirement, depending on the size of the facility:

Cement and lime works:	particulate, SO <sub>2</sub> , NO <sub>x</sub>
Mineral fibre:	particulate, phenol, formaldehyde, VOCs

Enamel frit: particulate, HF, NO<sub>x</sub>

### 3.3.2 Standard reference methods

For the parameters likely to be monitored in the sector, there is a full set of VDI standard measurement methods. For example:

Dust:	VDI 2066 Parts 1–7, which describe various arrangements for isokinetic sampling and analysis.
SO <sub>2</sub> :	VDI 2462 Part 8 H <sub>2</sub> O <sub>2</sub> Thorin Method, which is similar to ISO 7934.
NO <sub>x</sub> :	VDI 2456 Part 10 Dimethylphenol Method.
HF:	VDI 2470 Part 1 Absorption Method.
Phenol:	VDI 3485, B11 - Messen von Phenolen; p-Nitrolanilin – Verfahren.
Formaldehyde:	VDI 3862 B11 - Messung aliphatischer Aldehyde C1 bis C3 nach dem MBTH Verfahren.
VOC:	VDI 3481 Part 1 FID Method.

The methods specified for dust, SO<sub>2</sub> and NO<sub>x</sub> are well developed and documented for the level of emissions expected from sources in the minerals sector. For example, the relative standard deviation for VDI 2456 for NO<sub>x</sub> is between 2.4 and 2.7 per cent for NO concentrations in the range 500 - 1500 ppm. The method specified for HF dates from 1975 and the published method does not include details on validation data. For VOCs, the use of an FID is specified as the standard reference method. Working Group 4 of the CEN Technical Committee 246 has nearly completed work on a standard reference method for VOC. This will become a standard in Germany as soon as the CEN standard is published - see Section 3.7.

### 3.3.3 Performance criteria and QA/QC procedures for continuous monitors

The performance criteria and QA/QC for continuous monitors in Germany have been described in detail in earlier published studies on large combustion plant and waste incineration process <sup>(Ref. 1.1, 1.2)</sup>. The requirements for facilities covered by the minerals sector are similar and are based on:

- the use, where possible, of a continuous emission monitor system which has undergone suitability tests for the specific industry sector;
- a full calibration according to VDI 3950 Part 1 - derivation of the analysis function using SRMs;
- annual independent function checks;
- re-calibration every three years or following a major process change.

In practice very few continuous emission monitor systems have type approval specifically for processes in the minerals sectors. Those that exist include: Erwin Sick

and Durag equipment for particulate measurement at cement works; Bran & Luebbe Sensimeter and Ecometer for glass manufacture; and OPSIS for phenol and formaldehyde measurement at mineral fibre plants. In general, the licensing authorities will accept the installation of SO<sub>x</sub> and NO<sub>x</sub> continuous emission monitors with approval for LCPs and/or waste incinerator at plants in the minerals industry. There is a reluctance on the part of continuous emission monitor suppliers to incur the high costs involved in obtaining process-specific approvals.

#### 3.3.4 Data-logging and processing

All data from approved continuous emission monitors must be processed using an approved data-logging and process system. These systems are also subject to type approval testing. The reporting formats for the data are specified in a guidance note published in the GMBI in 1988.

Thirty-minute and 24-hour average values should be recorded. Each 30-minute average should be classified into one of 22 concentration classes. This classification system is a means of simplifying the storage and reporting of emission data, that is, the number of values falling within a certain concentration range is stored rather than every actual average value. Classes 1-20 should be chosen to ensure that the limit value is in Class 20. Class 21 should start at the limit value and end with the limit value plus the tolerance interval derived during the calibration tests.

The 24-hour averages should be stored in one of three classes. Class 1 should contain all the values which are less than the limit value. Class 2 should contain all the values greater than the limit value but less than the limit value plus the confidence interval. Class 3 should contain all the values greater than the limit value plus the confidence interval.

In all cases, both the original data and back-up chart recorder strips must be maintained on site for a minimum of three years.

#### 3.3.5 Performance criteria for controlled process measurements

There are no statutory performance criteria for process measurement systems applicable to the minerals sector. However there is a wide range of standards, guidance material and specifications published in Germany for temperature measurement, pressure, flow etc.

### 3.4 The Netherlands

#### 3.4.1 Legislation

Industrial plants in the Netherlands require a licence to operate under various pieces of environment legislation including the Air Pollution Act, the Waste Substances Act, and the Environmental Management Act. Emissions to air are usually licensed by the local municipality, while emissions to controlled waters are the responsibility of the Rijkswaterstaat.

The licence conditions for emissions to air - both emission limits and monitoring requirements are described in NER 92 - Netherlands Emission Regulations (NeR)<sup>(3,21)</sup>. The NeR is structured in a similar manner to TALuft 1986 and describes general release concentrations for a number of organic and inorganic substances, to be applied above a

threshold mass flow. Specific sectoral guidance is also provided in a number of cases, for example mineral fibres, glass production among others. No specific guidance is provided for cement or lime works – there is only one cement works in the Netherlands.

Chapter 4 of the NeR deals specifically with inspection and monitoring and provides guidance on:

- selection of the appropriate inspection and monitoring regime;
- selection of the measurement method – manual and continuous emission monitor;
- measurement planning;
- processing of results, calibration, measurement uncertainty and reporting.

The NeR specifies five different inspection and monitoring regimes for industrial plant, ranging from Regime 0 (no fixed inspection regime) to Regime 4 (monitoring of "emission relevant process parameters" and/or continuous emission monitors). The licensing authority should specify the regime for each plant based on a rather complex scoring system which involves dividing the permitted mass-flow of a pollutant in kg/hr by a mass flow check value for the relevant pollutant. The check values for specific pollutants and pollutant categories are tabulated in Annex 6 of the NeR. For example, continuous emission monitor should be considered for particulate mass-flow in excess of 5 kg/hr.

#### 3.4.2 Standard reference methods

Annex 5 to the NeR provides a list of recommended standard reference methods for flue gas measurements. The methods recommended are those published by ISO, VDI, NPR or USEPA. The list was published in 1992. As new ISO standards are adopted and CEN standards are developed and become mandatory, these are added to the list.

#### 3.4.3 Performance criteria and QA/QC procedures for continuous emission monitors

The Dutch have not published their own performance criteria for continuous emission monitors or any standard methodology for continuous emission monitor verification and QA/QC. Continuous emission monitor systems which have obtained German suitability test approvals are widely accepted in the Netherlands and where ISO has published performance standards, for example ISO 10155 for particulate and ISO 7935 for SO<sub>2</sub>, these are specified by the licensing authority. The NeR recommends that the licensing authority requires that any installed continuous emission monitor system is *"calibrated and checked for correct operation by an institution approved by the licensing authority as soon as the installation in question is put into operation"*. The calibration should be repeated at least every five years and after any substantial change in the process.

#### 3.4.4 Data-logging and processing

The NeR requires that continuous emission monitor data adjusted to reference values and recorded at 30-minute averages. It recommends that the data are stored as a frequency distribution over at least 20 concentration classes. The operator is given the benefit of a two-sided 90 per cent confidence interval when reporting the data.

Compliance with the emission limit is defined as (for a period of four successive quarters):

- all daily averages to be below the emission limit;
- 97 per cent of all 30-minute averages to be below 1.2-times the limit;
- all values to be below twice the limit value.

### 3.5 France

#### 3.5.1 Legislation

In France, industrial facilities within the minerals sector require a licence to operate from the Department Environment Office under the control of the Ministry of the Environment in Paris according to legislation dating from the mid-1970s. The contents of licences, in terms of emissions and monitoring, are by local negotiation. However, in 1993 the Ministry of the Environment published a draft regulation - *Arrêté du 1er mars 1993 relatif aux prélèvements et à la consommation d'eau ainsi qu'aux rejets de toute nature des installations classées pour la protection de l'environnement soumises à autorisation* - which attempted to standardise emission limits for air, water and land across France. This draft was successfully resisted by the French chemical industry and has not been adopted. The Ministry is now redrafting the regulation and it is expected to be published in 1998. However in the meantime the draft from 1993 has become a de-facto standard - widely used by both the local environment offices and industry when setting new standards.

The draft regulation is structured in a similar way to TALuft 1986 and provides both general guidance on emission limits in terms of allowable concentrations for polluting substances (above specified mass-flow thresholds) and also provides specific guidance for a small number of specific industries.

Chapter VI of the regulations provides guidance on the monitoring of emissions to both air and water. For emissions to air, continuous monitoring is recommended for certain substances above a specified mass-flow threshold. Table 3.1 compares these threshold values with those given in TALuft.

**Table 3.1 Thresholds for continuous monitoring**

Pollutant	TALuft 1986	France - 1993
Particulate	> 5 kg/hr - continuous gravimetric between 2 and 5 kg/hr - opacity	>50 kg/hr - continuous gravimetric 5 to 50 kg/hr - opacity measurement
SO <sub>x</sub>	> 50 kg/hr	>150 kg/hr
NO <sub>x</sub>	>30 kg/hr	>150 kg/hr
CO	>5 kg/hr for combustion efficiency >100 kg/hr in all other cases	>50kg/hr
Inorganic fluorides (as HF)	>0.5 kg/hr	> 5 kg/hr
Inorganic chlorides (as HCl)	>3 kg/hr	>20 kg/hr

Pollutant	TALuft-1986	France - 1993
Organic compounds	>1kg/hr - class I >10 kg/hr - sum of class I - III	>2 kg/hr - organic substances listed in Annex III to the regulation >20kg/hr for other (non-methane organics)

### 3.5.2 Standard reference methods

Annex Ia of the 1993 draft regulation specifies the French standard measurement methods to be used for both emissions to air and water. For emissions to air, methods are identified for particulate, SO<sub>2</sub>, CO, HCl, total hydrocarbons and odour, for example NF X43309 for HCl.

### 3.5.3 Performance criteria and QA/QC procedures for continuous emission monitors

There is currently no type approval system for continuous emission monitors in France. A number of French equipment suppliers have sponsored site testing of continuous emission monitors carried out by EXERA and some performance data for individual French-made systems is available.

No information is available on calibration or verification on installed continuous emission monitor systems.

### 3.5.4 Data-logging and processing

The 1993 draft regulation does not provide guidance on data-logging or processing.

## 3.6 The USA

### 3.6.1 Legislation

A knowledge of the regulatory environment in which processes operate is necessary to understand the requirements for Continuous Monitors in the US from minerals processes. Unfortunately, the US regulatory system is particularly complex. This section therefore attempts to clarify the legislation and regulations affecting the monitoring requirements for this sector.

As has been noted in previous reports, regulations controlling emissions to air operate at both federal and state level in the US. States are obliged to enforce federal regulations, but have the freedom to impose more stringent local limits. In reality those set at the federal level tend to be limited and fairly weak, with the majority of emissions controls being applied by state authorities.

Added to the twin level of environmental regulations are the numerous Acts and related regulations used to introduce new emission standards and monitoring requirements. This creates a somewhat confusing regulatory regime.

#### Legislative framework

Acts are passed in Congress, and these generally set the overall legislative framework for subsequent regulations. It is these regulations which provide the technical details to the legislation. This process is similar to the framework directives of the EU which are

then followed by daughter directives, and, for example, the Environment Act in the UK, the details of which are contained within and updated by means of Statutory Instruments.

In the US the majority of emission controls for industrial sources refer back to two legislative Acts: the Clean Air Act (CAA first passed in 1970) and subsequent amendments (CAAA - amended in 1970, 1975, 1977 and 1990), and the Resource Conservation and Recovery Act (RCRA). The CAA's main purpose is to control emissions to air. The RCRA, on the other hand, is principally concerned with hazardous waste management but includes emissions controls for the burning of hazardous wastes. As mentioned above, though, the regulations through which both Acts are promulgated appear in the Code of Federal Regulations, Title 40 <sup>(Ref. 3.22, 3.23, 3.24)</sup>.

### ***Relevant features of the CAA***

The CAA plus amendments contains 11 separate titles, each one covering a different aspect of emissions control and permitting procedures. As far as emissions levels and monitoring compliance are concerned, the following titles are most relevant:

#### **Title I Attainment of Air Quality Standards (for new and existing sources) - promulgated in 40CFR70.**

This sets local air quality limits for NO<sub>x</sub>, SO<sub>x</sub>, Particulates, VOC and CO. The aim is to bring all areas into attainment with the National Ambient Air Quality Standards (NAAQS) which were introduced under the CAAA 1990. The emission limits for these substances are therefore set in relation to the local air quality conditions, and thus vary across the country and even within the same state. In the same way, monitoring requirements will vary depending on the contribution of emission sources to the local air quality levels. Very rarely - indeed none were encountered throughout this research - are continuous monitors required for measuring releases from these regulated sources.

With the exception of cement processes, which must comply with federal emission limits for CO, HC and O<sub>2</sub>, under combustion regulations (BIF regs - see Part 266 <sup>(Ref. 3.23)</sup> below) and the associated monitoring requirements, emissions controls for all other minerals processes are thus set by the local permitting authority. In many instances, no limits are applied at all for processes that would fall under IPC or LAAPC in the UK, because the local area is within compliance.

The emission limits applied to specific processes depend not only on whether the area is in compliance with NAAQS, but also on the scale of the emission. The regulations make the distinction between major and non-major sources, where "major sources" emit over a certain threshold of releases. There are detailed descriptions of what constitutes a major source, but these are not considered relevant for this report.

For plants emitting NO<sub>x</sub>, SO<sub>x</sub>, VOCs, Particulates and CO in non-attainment areas, Reasonable Achievable Control Technology (RACT) must be applied to control releases.

#### **Title III Releases of Air Toxics (Hazardous Air Pollutants) (promulgated in 40CFR63)**

This describes 189 Hazardous Air Pollutants (HAPs), the majority of which are VOC-based substances. As with the NAAQS substances, emission standards are set by the

local permitting authority using a threshold principle for major and non-major sources. The most important feature of HAP-emitting processes is that, if a process is defined as a "major" source, then it is required to comply with **Maximum Achievable Control Technique (MACT)** standards. These MACT standards include emissions levels and operating and monitoring requirements, and apply to existing facilities. To date, few MACT standards have been formalised, but a number of drafts have been produced- in particular the one for cement processes.

New processes emitting HAPs must employ what is referred to as **BACT (Best Achievable Control Techniques)**. The concept is equivalent to the UK's IPC new plant standards. For new major sources emitting HAPs in areas which do not comply with NAAQS ambient levels, a further requirement is imposed, called **LAER (Lowest Achievable Emission Rate)**, which must be implemented regardless of cost.

#### **Title V Permitting (promulgated in 40CFR70)**

Title V differs from the other titles in that it acts as an umbrella, stipulating general permitting requirements for all emission sources.

#### **Existing environmental regulations**

The definitive, legal versions of all environmental regulations are contained within a part of the US Code of Federal Regulations (CFR). This vast series of documents contains every regulation on all possible subjects, of which the environment is only a small part. Title 40 of the CFR deals with environmental protection, which includes details of emission limits as well as compliance and monitoring requirements.

Title 40 itself is divided into 16 volumes, comprising over 790 separate parts. These parts are then further divided into sub-parts, the level at which regulations are defined for different industry sectors. The most relevant parts of Title 40 (environmental protection) for emissions control and monitoring for minerals processes are:

**Part 60<sup>(Ref 3.24)</sup>: Standards of Performance for New Stationary Sources (NSPS)** - This contains numerous sub-parts each relating to different industry sectors and, in Annex A, 28 standard reference methods for monitoring and testing. Within this part separate regulations are set out for portland cement plants (sub-part F), lime plants (sub-part HH), and wool fibreglass insulation manufacturing plants (sub-part PPP). These performance standards apply to *new sources*, defined as those coming into operation after the date for which standards have been proposed. Since most standards were introduced a number of years ago - sometimes up to 25 years - most standards apply to plants currently in operation.

The NSPSs will gradually be superseded by the MACT standards which are currently being developed.

**Part 266: Boiler and Industrial Furnaces (BIF)** - CFR 266 deals with large combustion processes and in particular those burning hazardous wastes. Cement kilns burning hazardous waste are thus covered by these regulations. Part 270 is a related regulation which stipulates trial burn requirements, and includes compliance monitoring during this process.

Prior to being entered into the CFR, all proposed regulations are published in the Federal Register. This is a daily publication of all government offices and acts as the



avenue through which new or the latest drafts of proposed regulations are made available for consultation.

### 3.6.2

#### Standard reference methods

**Part 60: Standards of Performance for New Stationary Sources (NSPS)** contains numerous sub-parts each relating to different industry sectors and, in Annex A, 28 standard reference methods for monitoring and testing.

US federal legislation on incinerator emissions is very specific on the SRMs to be used both for compliance monitoring and the evaluation of continuous emission monitor performance. The methods to be used are published in 40 CFR 60 Appendix A and are summarised in Table 3.5. As can be seen, there are no recommended continuous monitoring methods.

Performance characteristics are given for some of the methods in terms of detection limit and method standard deviation. Of particular interest is the standard for HCl, EPA Method 26. This standard, which is relatively recent, has a claimed standard deviation of 6.2 per cent at a concentration of 3.9 ppm and 3.2 per cent at 15.3 ppm. The SRM for TOC is also based on FID technology. There is no manual method for this measurement.

**Table 3.5: Standard reference methods for incineration processes**

Parameter	USA	
	Recommend manual method	Recommended continuous method
Particulate	USEPA Method 5	-
HCl	USEPA Method 26	-
HF	USEPA Methods 13A and 13B	-
CO		-
SO <sub>2</sub>	USEPA Method 6	-
NO <sub>x</sub>		-
TOC		-
Heavy Metals	USEPA Method 5	-
PCDD + PCDF	USEPA Method 23	-

### 3.6.3

#### Performance criteria and QA/QC procedures for continuous monitors

There is no type approval system for continuous emission monitors in the US. Both federal and state legislation calls for the site certification of installed systems to ensure that they comply with defined minimum performance criteria. The certification testing can be carried out by consulting companies or the operators themselves with a full report, including system description and test results submitted to the appropriate permitting authority.

The USEPA has published performance criteria for SO<sub>2</sub>, NO<sub>x</sub>, CO, O<sub>2</sub> and continuous opacity monitors. These are reproduced in 40 CFR 60 Appendix B.

Following installation, commissioning and debugging of a continuous emission monitor, the operator of a facility must notify the permitting authority that certification is being sought. He must then carry out a series of tests on the installed system to

demonstrate compliance with the given performance criteria. The characteristics tested are:

- seven-day calibration error test;
- linearity check;
- relative accuracy test audit (RATA);
- bias test;
- cycle time/response time test

#### 3.6.4 Data-logging and processing

Both NSPS sub-parts and RCRA contain sections on reporting requirements and data averaging values for continuous emission monitoring data. The complete system, including the data processing system, is subject to certification

#### 3.6.5 Performance criteria for controlled process measurements

The federal legislation contains no specific guidance on temperature measurement with the exception of the nomination of US standards for thermocouples. Performance standards are given for CO and O<sub>2</sub> continuous emission monitors in Appendix B to 40 CFR 60.

#### 3.6.6 Cement

##### **Regulatory context**

There are some 100 cement plants in the US, comprising a mixture of wet, semi dry and dry kilns. Very few use the semi wet process. There is no limit to the amount of waste fuels that can be burned in a cement kiln, and some kilns use wastes for up to 100 per cent of the kiln's energy requirements.

The key regulations affecting cement kilns in the US are the Boiler and Industrial Furnace (BIF) regulations. They are imposed for hazardous waste burning kilns only, and establish the following key environmental requirements:

##### *Particulate:*

The US does not use a gravimetric unit for expressing dust emissions. The units used are either the number of grains per cubic foot, or percentage attenuation of a light beam. The BIF regulations impose a limit of 0.08 grains per dry standard cubic feet. Broadly this is equivalent to around 150mg/m<sup>3</sup>. The limit of attenuation for a light beam is usually set at either 20 or 40 per cent.

##### *SO<sub>x</sub>, NO<sub>x</sub> & Chlorides:*

The BIF regulations do not include any limits for these substances. These are controlled under the NSPS rules.

### *CO & HCs*

The main emphasis of the BIF regulations is to ensure complete combustion of hazardous compounds in furnaces and boilers. To do this the main components regulated are CO and HCs. BIF provides various means of compliance, either CO emission limit of 100ppm at seven per cent oxygen (if less than this limit then no limits applied for HC), or, if CO emissions are higher than 100ppm@, an HC limit of 20ppm at seven per cent oxygen, and a CO limit determined during compliance testing. Kilns with organics in the raw materials may be allowed separate limits, based on material analyses undertaken during compliance testing.

### *Other organics*

- 99.99 per cent DRE on POHCs (Persistent Organic Hydrocarbons);
- 99.9999 per cent DRE on POHCs if dioxin listed wastes are burned.

### *Metals*

Metal emission limits are based on site-specific risk analysis. This is a complex process in which emission limits are calculated based on an analysis of dispersion patterns and human health risks at the site boundary.

Numerous operating requirements are also imposed to ensure the process is operated correctly. These include production rates, waste feed rates, process temperature, and parameters relating to the operation of any abatement equipment, for example pressure drops across bag filters or KVA for EPs.

Many current operators in the US believe that the BIF regulations are inappropriately applied for cement kilns in that most HCs in the system arise from the feed materials, and are volatilised in the pre-heater precalciner stages of a dry kiln. Emission levels thus have very little to do with the combustion performance which is the focus of the BIF regulations. The EPA's view is that this should not prevent efforts to measure actual emissions coming from the process.

### **Monitoring requirements for cement processes**

Only opacity (not PM), HCs, CO and oxygen are to be monitored continuously in the BIF regulations. In neither the BIF regulations nor any other federal environmental legislation, is there a requirement to monitor continuously for any other substance. Some companies will undertake continuous monitoring on their own initiative but rarely is this a regulatory requirement. Extensive initial testing is carried out during compliance testing, in which the worst possible operating conditions are set up in the kiln. Metals are "spiked" to simulate high metal inputs and emission tests are made.

### **Future monitoring requirements**

The proposed MACT standard for cement kilns proposes new emission limits and the use of continuous emission monitors for :

- PM
- HCs
- CO
- Mercury
- Semi-volatile metals (SVMs - lead and cadmium)
- Low-volatile metals (LVMs - antimony, arsenic, beryllium, chromium)
- HCl and chlorides

Note that SO<sub>x</sub> and NO<sub>x</sub> limits are still excluded. However, the general view from the industry is that there is little technical difficulty in monitoring these substances continuously.

The proposal for this projected MACT standard, however, seems to exceed the capabilities of monitoring technology in the US, and indeed elsewhere in the world. No continuous emissions monitors for PM, chlorides and mercury or metals have yet been proven to work to US performance standards.

### 3.6.7

#### **Mineral fibres**

##### **Regulatory context**

Mineral fibre processes in the US are regulated under sub-part PPP of 40CFR60 which stipulates emissions requirements for new plants (New Source Performance Standards). These federal regulations only require monitoring for particulate matter using USEPA standard reference methods. There is no federal requirement for continuous emission monitors, although most plants will operate opacity meters to determine percentage obscuration.

MACT standards (see earlier) may be applied by the state EPA for NO<sub>x</sub> and SO<sub>x</sub> if the plant is in an air quality non-attainment area. In practice, though, there is little evidence of any such limits being applied to mineral fibre processes. There is no limit for CO applied to mineral fibre plants.

However, in common with all other regulated processes, mineral fibre plants are required to report total annual emissions of hazardous air pollutants (HAPS), of which there are over 100 categories, for the Toxic Release Inventory (TRI). This requirement is stipulated under the SARA (Superfund Amendments and Re-authorisation) regulations number 313. HAPs relevant to mineral fibre processes include:

- phenol

- formaldehyde
- methanol
- ammonia
- metals arising from erosion of the refractory furnace lining (Ni, Cr, Cd)

These emissions need only to be estimated - using "best judgement" - and do not require accurate monitoring. Estimates are accepted by the EPA. US operators do not generally use continuous emission monitors to measure these substances on an ongoing basis.

MACT standards for mineral wool processes have been prepared and issued by the USEPA. The final version, published in July 1998, specifies emission limits and monitoring requirements for PM, CO and formaldehyde. It is proposed that formaldehyde is used as a proxy for the other main pollutants of phenol and methanol. No limits are proposed for ammonia.

The standard does not require continuous emission monitors but stipulates the need to monitor process parameters such as:

- cupola production rates;
- bag leak detection - a bag leak detection system must be capable of detecting PM emissions at 1 mg/m<sup>3</sup>;
- free formaldehyde in each resin batch;
- incinerator operating temperature - for cupola and curing oven releases;
- periods over which incinerator temperatures were less than the required level.

### 3.7 The European Union

#### 3.7.1 Legislation

There are no EU Directives or regulations that specifically cover the monitoring of emissions from industries in the minerals sector. However, the Hazardous Waste Incineration Directive (94/67/EC) which came into force in 1994 will have an impact on the minerals sector in two specific areas.

The first impact is on those cement works that use more than 40 per cent thermal input of secondary fuels classified as hazardous wastes. In such cases the monitoring requirements, including a requirement to install continuous emission monitors for particulate, HCl, SO<sub>2</sub> and organic carbon, as described in the Directive, will apply.

The second impact is due to the mandate given to Comité Européen de Normalisation (CEN) by the Commission, following the adoption of the Hazardous Waste Incineration Directive and the Solvent Directive. Their aim is to develop a set of European standard measurement methods for the pollutants controlled by the Directives and reference methods for the calibration of continuous emission monitors. This work, carried out by

Technical Committee 264 (TC264) of CEN, is applicable to a wide range of emission sources, including incineration and hazardous waste, and is particularly concerned with the standardisation of calibration and validation for continuous emission monitors methodologies across Europe.

The activities of TC264 were reported in an earlier joint ETSU/HMIP study on continuous monitors for incineration processes in 1994 <sup>(Ref. 1.10)</sup>. More current information was obtained from discussions with the Source Testing Association (STA), members of whom hold key positions on the CEN working groups. The status of standards and appropriate references, as outlined below, were obtained during this discussion (draft standards cannot be referenced in this study, as they are not in the public domain).

### 3.7.2 Standard reference methods

#### **Workgroup (WG)1: An SRM for dioxin/furan measurement**

Work is now complete and the standard has been published as:

EN 1948 Dioxin measure, sampling and analysis.

#### **WG 3: SRM for HCl**

Work is now complete and the standard has been published as:

EN 1911 Manual methods for determination of HCl.

#### **WG 4: Total gaseous organic carbon**

The final report from this working group will be published in three stages, each of which focuses on a different aspect of monitoring:

- i. VOC monitoring by Flame Ionisation Detection (FID);
- ii. chemical speciation; and
- iii. high-level FID.

Only the first of these reports is currently being debated.

#### **WG5: Total dust, low concentrations**

Owing to the difficulties in sampling techniques, this report has been the subject of much debate. However, the draft standard has now reached the "enquiry" stage of development, for voting as an EN standard.

#### **WG8: Mercury emissions**

The working group will soon issue a draft report on this subject, in conjunction with ISO.

### Other working groups

WG10, concerned with stack methods for metals, and WG16, considering NO<sub>x</sub>, SO<sub>x</sub>, CO, O<sub>2</sub> and H<sub>2</sub>O monitoring, are currently working towards developing further standard monitoring methods and procedures.

### 3.7.3 Performance criteria and QA/QC procedures for continuous emission monitors

#### **WG9: Quality assurance of automated measurement systems.**

WG9 became a formal working group in 1996 following earlier work on an ad hoc basis. CEN has been issued with a formal mandate to develop the QA procedures from the EU. However the draft terms of reference and working methods have already been agreed as well as an indicative programme of field tests due to commence before the end of 1997. The WG will consider QA for continuous emission monitors for incinerators in line with the general mandate given to CEN as a result of the Hazardous Waste Incineration Directive. However the results should be applicable to all AMS systems for stationary sources.

The original ad hoc group examined QA for continuous emission monitors on three levels:

- minimum requirements for continuous emission monitors;
- installation, calibration and verification;
- continuous quality assurance and annual function tests.

Consideration of level 1 QA has now been transferred to SC4 of ISO TC 146. This is due to resistance by a number of EU countries to the need for formal (and mandatory) standards which specify minimum continuous emission monitor requirements when any continuous emission monitors installed must also conform to level 2 standards - compliance with level 2 implies minimum compliance with level 1 etc. The adoption of an ISO standard is not mandatory.

SC4 of ISOTC 146 has published a draft of the relevant standard and comments have been invited. The deadline for comments is November 1997 for consideration at the next meeting of the committee, scheduled for January 1998. If no major disagreements arise from the comments or meeting, a vote on the draft may take place before the end of 1998.

WG9 of CENTC 246 has commenced work on level 2 and 3 QA. Level 2 will consider aspects of on-site calibration of continuous emission monitors, for example - the establishment of the "analysis function". The work may be heavily influenced by VDI 3950, although there is some resistance to this. Some countries favour the approach described in ISO 7935 - "integral performance". One problem with the analysis function approach being considered by the WG is whether the "uncertainty" of the SRM should also be considered when deriving the analysis function.

An outline of a draft standard has recently been distributed to members of the WG for comment, and a full draft is scheduled for March 2000.

#### 3.7.4 Data-logging and Processing

Data-logging and processing will not be within the scope of work for the WG.

The 1993 draft regulation does not provide guidance on data-logging or processing.



#### 4. Application of continuous monitoring systems for cement/lime processes

##### 4.1 Cement/lime sector study summary

A summary of continuous monitoring techniques proven to be suitable and available for use in the cement and lime sector is presented in Table 4.1. This is based on experience obtained from international users and suppliers.

**Table 4.1 Continuous monitoring techniques for cement and lime process**

Source	Pollutant	Suitable technique	Comments on best practice
In-kiln	O <sub>2</sub>	Extractive Paramagnetic Electrochemical	<ul style="list-style-type: none"> <li>These techniques have proven to be effective but because of the high temperatures (1000-1300°C), very high dust loading (upto 100g/m<sup>3</sup>) and corrosive conditions (sulphur and nitric acids) the sample train becomes more complicated. Best practice, for example, would incorporate:               <ul style="list-style-type: none"> <li>⇒ the use of water-cooled probes</li> <li>⇒ acid-resistant materials: e.g. ball valves, solenoids for water cooling, not plastic seals; PTFE for pipe fittings</li> <li>⇒ the use of shock chillers to condense out sulphur acids</li> <li>⇒ additional filters to improve performance and reduce cleaning/replacement frequency</li> <li>⇒ housings for analysers and electronics to be kept away from high-temperature areas</li> </ul> </li> </ul>
	CO	NDIR	
	NO <sub>x</sub>	NDUV Chemiluminescence	
Kiln flue exhaust	PM	Cross-duct opacity	<ul style="list-style-type: none"> <li>Cross-duct systems are generally regarded as more accurate than triboelectric devices, and most suitable for kiln flue gases. Back scatter devices have not proven to be successful for these emissions.</li> <li>Opacity measurement should be separate from the monitoring of any other species.</li> <li>Triboelectric techniques are not suitable for this application because of interference from charged particles caused by the EP.</li> </ul>
	O <sub>2</sub>	Paramagnetic/ Electrochemical/ zirconium oxide cell	<ul style="list-style-type: none"> <li>Paramagnetic devices perform best on dry gas streams, and are best suited to dry kiln systems. ZnO devices are better designed for wet kiln exhaust gases.</li> </ul>
	SO <sub>2</sub>	NDIR/NDUV	<ul style="list-style-type: none"> <li>Some NDIR devices have been prone to interference with chlorine, but on the whole this should not preclude the use of CEM techniques for SO<sub>2</sub> and NO<sub>x</sub> measurement</li> </ul>
	NO <sub>x</sub>	NDIR/NDUV	
	HC	Extractive FID	<ul style="list-style-type: none"> <li>The FID technique is well proven although there is still some debate about the best type of sample train. The USEPA considers hot probes to be best practice, although they have caused problems with line blocking and just as reliable results have been obtained by cold probes.</li> <li>FID trials have started in Germany with minor teething difficulties</li> </ul>
	HCl	GCF IR FTIR Ion selective electrode	<ul style="list-style-type: none"> <li>These techniques for continuously measuring HCl are widely used in the incineration sector, but there is little evidence of their application to cement processes. This is due more to their high cost than technical inapplicability. There is no technical reason why these techniques could</li> </ul>

Source	Pollutant	Suitable technique	Comments on best practice
			not be used on the cement processes. An independent French report, for example (see French experience below) concludes the suitability of a GFC IR technique, and other positive experience is taken from Germany.
	Metals	No techniques have been found which can effectively monitor metals on a continuous basis	
Clinker cooler	PM	Cross-duct opacity triboelectric	<ul style="list-style-type: none"> <li>• Triboelectric devices would be the preferred equipment for these emissions because of the lower temperature of the gases than in kiln exhausts, and the generally lower particulate loadings</li> </ul>

The following general comments also apply to the use of CEMs in cement and lime processes:

- either extractive or in-situ devices can be used - there is little identifiable difference in performance between the two approaches. In-situ equipment is more popular in Europe, extractive more so in the US;
- good quality filters are required, and must be changed regularly. Blocking is not an excuse for not using CEM equipment, but it is inevitable that the conditions in cement and lime processes require regular maintenance;
- NDIR systems have, in the past, suffered from span drift requiring recalibration every 12 weeks or less. Best practice would be more frequent calibration. In the US, recalibration is often performed daily using on-site calibration gases;
- multi-component FTIR techniques have been tested on a number of cement plants, particularly in Germany, but could not yet be considered proven, and are more expensive than IR or UV systems;
- a mass balance can be used in the absence of proven techniques for continuously measuring metals and chlorides. This requires regular chemical analysis of inputs (raw materials and fuels) and outputs (clinker and CKD) to determine residual emissions;
- in some cases it is difficult to establish the performance of CEM devices because of the lack of reliability in results of measurements using standard reference methods. One company reported such large variations in standard reference method results on the same sample that it became impossible to determine the accuracy of the CEM equipment.

A more detailed description of user experience is provided below.

## 4.2 User experience

The use of continuous monitoring technology for monitoring of emissions to air of particulate, SO<sub>x</sub> and NO<sub>x</sub> has been widely practised in cement plants around the world.

#### 4.2.1 In-process measurement

On-line measurement of process gases, particularly flue gases, began around the late 1950s or early 1960s. Traditionally, the two parameters with which the cement industry was concerned were "back-end" oxygen and CO. These two measurements were considered essential in maintaining control of combustion within the kiln. An excess oxygen level at the back-end of around two to four per cent coupled with very low, less than 0.2 per cent CO, was an indication that combustion was taking place efficiently. Efficient combustion control ensures both the correct temperature conditions in the kiln and also has a direct impact on process economics – optimised fuel usage. Good combustion control will also have an impact on environmentally significant emissions, for example NO<sub>x</sub>. Generally the lower the oxygen content at the kiln back-end, the less NO<sub>x</sub> is produced. However, this has to be balanced against increases in CO at lower oxygen levels. Therefore the measurement of NO<sub>x</sub> is also used for process purposes as some sites visited during this study reported a direct correlation between NO<sub>x</sub> levels and the free lime content of the clinker.

Process measurement of flue gas concentrations of CO, O<sub>2</sub> and NO<sub>x</sub> often have to be carried out at points within the cement plant which are characterised by high gas temperatures, high dust loading and generally corrosive atmospheres. The kiln exit temperature at a dry system cement kiln can be in the range 1000 – 1300°C with dust loadings of up to 100mg/m<sup>3</sup>. The critical element of any continuous monitoring system operating under these conditions is the sampling system – in-situ measurements are not applicable.

Most in-process systems require very low maintenance, and reliability is such that they can readily be used with computerised expert kiln control systems. The signals which are essential to the operation of the expert system are kiln exit oxygen, carbon monoxide and nitrous oxides.

The type of analysers which have been used for the various process parameters include:

O<sub>2</sub>: paramagnetic, electrochemical

CO: NDIR

NO<sub>x</sub>: NDUV or chemiluminescence

A typical continuous monitoring array would consist of a paramagnetic analyser for O<sub>2</sub>, NDIR for CO and NDUV for NO<sub>x</sub>.

Cement companies have many year's experience with these type of systems. For example, the main cement manufacturing companies in the UK have, over the last two decades, tested and evaluated various types of analysis equipment. Consequently, most companies have standardised their equipment manufacturer/supplier and type. There are obvious cost benefits associated with this approach, notably preferential terms which can be negotiated with suppliers and reduced spares-holding requirements. One further benefit is that it is possible to develop personnel with a high skill level for specific types of equipment who can then be utilised for problem-solving and repairs at various plants, reducing dependence on manufacturers. This last point tends to be less relevant nowadays as equipment becomes more reliable and, more often than not, maintenance contracts with manufacturers are a financially attractive option.

Continuous monitoring systems are also used for process safety. Control of CO is critical in cement and lime kilns when electrostatic precipitators (EPs) are used for particulate abatement. Because of the danger of explosions, CO concentrations must be kept well below the lower explosive limit of 0.5%v/v. If CO levels rise to close to this level, power to the EPs is tripped to eliminate the explosion risk. A number of in-situ, cross-duct systems for CO measurement have been used for this application. The cross-duct systems have the advantage of rapid speed of response. For example, the Erwin Sick GM 950 - Fast CO sensor system for process applications - may be particularly suitable for monitoring fast CO concentration changes. If a dangerous rise in CO concentration can be detected in time, then process intervention can be used to reduce the CO level before a CO-induced EP trip is initiated. This means fewer trips. A trip leads to an unabated release from the kiln.

#### 4.2.2 Kiln flue emission measurement

The monitoring of emissions to atmosphere for permit compliance purposes is usually carried out after the flue gas treatment system - baghouse or EP - where gas conditions are more benign than earlier in the process train. For emissions from the kiln, the main parameters measured on a continuous basis are particulates, NO<sub>x</sub>, SO<sub>2</sub> and O<sub>2</sub>, standardised to a reference oxygen level. In S2 3.01 the reference conditions specified are "for combustion gases - dry, temperature 273K (0° C), pressure 101.3 kPa (1 atmosphere), 11% v/v oxygen" (Ref 1.1).

##### *Particulate matter*

For particulates, the use of cross-duct opacity meters has become an industry standard with equipment from Erwin Sick being used extensively at British and European cement works. In the US only light beam attenuation is used, with no calibration to absolute concentrations. The cross-duct systems can be calibrated by direct comparative tests to relate the extinction measured by the opacity meter to the actual mg/m<sup>3</sup> of particulate in the flue gas. These type of systems have proved to be reliable and robust and, if properly positioned and calibrated, have no difficulty in supervising the type of emission limits imposed on cement kilns - typically 30-50 mg/m<sup>3</sup>. Extractive continuous monitoring systems for particulate, for example the beta-ray systems or light scatter systems, have not been widely used due to their reported lower accuracy (+/- 50 per cent).

Triboelectric techniques, such as that offered by PCEME, have been found not to be suitable for the measurement of particulates in kiln exhaust gases. This is because the charge carried on the particles having passed through the EP interferes with the functioning of the triboelectric probe, which works on the principle of electrostatic charge.

Continuous monitoring technology is also used to monitor particulate emissions from other process areas, for example clinker or raw material mills. Opacity meters have successfully been used in these applications although lower costs systems, for example triboelectric systems, have also successfully been applied. Triboelectric systems in these applications do not suffer from charge interference from electrostatic precipitators, as they do when measuring kiln exhaust gases.

### *SO<sub>2</sub> and NO<sub>x</sub>*

For SO<sub>2</sub> and NO<sub>x</sub> measurement, both extractive and in-situ systems have been widely used without difficulty. In Germany in particular, a UV in-situ system from Erwin Sick – the GM31 is used at around half of all plants. In the UK, a system from Procal has been used for multi-component analysis. Extractive systems based on sampling probe, sample-conditioning NDIR/NDUV analysers are also used, and are particularly common in the US. Providing that general good practice in sample handling and conditioning is employed, extractive devices offer suitable levels of performance. There is little difference in technical performance between in-situ and extractive systems, with the choice dependent more on the site's own experience with continuous monitoring technology and the type of devices offered by suppliers familiar to the user.

### *Hydrocarbons*

FID technology has been successfully applied to measure hydrocarbon emissions in several cement kiln flue gases. This has become especially important where waste-derived fuels have been used – solvent-based waste or municipal waste pellets. Under many licensing systems, where these fuels are used to any great extent, separate emission limits are applied to HCs. In the US emission limits for HC are imposed together with CO to ensure complete combustion of waste fuels. Many of the problems associated with the use of FIDs at incineration plants also apply when used at cement kilns.

### *Metals*

No techniques have been found which can effectively monitor metals on a continuous basis. Metals will be emitted to atmosphere following abatement in solid particulate form and do not have any useful interaction (absorbance or fluorescence) with infra-red, visible or ultra-violet light. If, however, the metals form a reasonably constant proportion of the total particulate emission, then continuous particulate measurement is an effective surrogate for metals monitoring.

Trials in the US have attempted to measure mercury continuously but the results were inconclusive. This is partly due to the manner in which the trials were conducted rather than the technology itself. As a result, it is not possible to recommend a suitable continuous technique for metals analysis at this time.

### *HCl*

GFC IR, FTIR and ion selective electrode systems are commonly used to continuously monitor HCl emissions from the incineration sector. The fact that they have not widely been used on cement processes is more due to their high cost than any technical difficulties. Continuous monitoring of chlorides is only required if greater than 40 per cent of hazardous waste fuels are burned. Few kilns actually use this amount of hazardous waste fuels, hence there has not been a need for this equipment.

New multi-component analyser technology has been trialed at a number of kilns in particular where the measurement of HCl continuously has become an issue. FTIR technology, for example, has been used at a cement kiln in Germany – the CEMAS system from Hartman & Braun. Experience with single component analysers – for example systems from Bodenseewerk (potentiometric), Woesthoff (sample solution conductivity) and Perkin Elmer (IR GFC) appears to be limited.

## 4.2.3

## UK experience

Many cement and lime manufacturers have extensive experience of continuous monitoring, and tend to test several systems before selecting the best option. In summary, the following techniques have proven successful at several plants and could hence be regarded as "proven":

- PM flue                      Cross-duct opacity systems, for example Erwin Sick, for post-EP kiln gases. Triboelectric devices are better suited to PM measurement from other areas of the plant;
- SO<sub>x</sub>, NO<sub>x</sub>                Cross-duct and extractive NDIR and UV systems.

The UK market for continuous monitoring instrumentation for cement and lime processes is dominated by a few major manufacturers, who regard it as an important sector. These manufacturers also feature prominently in the supply of CEMs to the power and incineration sectors. There are obvious cost benefits associated with this approach, notably preferential terms which can be negotiated with suppliers and reduced spares-holding requirements. One further benefit is that it is possible to develop personnel with a high skill level for specific types of equipment who can then be utilised for problem-solving and repairs at various plants, reducing dependence on manufacturers. This last point is increasingly less relevant as equipment becomes more reliable and, more often than not, maintenance contracts with manufacturers are a financially attractive option.

There is widespread experience with dust monitors for kiln and clinker and cooler emissions, for example Erwin Sick RM41. The main process problems associated with the equipment is "blinding" of the optical equipment. Although blowers are fitted for automatic cleaning, the condition of the flue gas affects the efficiency of this system and hence the frequency of manual cleaning required. For one company, manual cleaning is carried out three times per week; for another, only once per fortnight.

Other CEMs are used to monitor:

- kiln exhaust gas, using IR (for example Procal 240LR) to monitor CO, H<sub>2</sub>O, SO<sub>2</sub>, and NO (for NO<sub>x</sub>) where problems with channel drift have been encountered (due to cross-sensitivities);
- O<sub>2</sub> to measure combustion efficiency and control fuel addition, for in-kiln control (for example H&B extractive system), in which the acidic nature of the gas has caused problems with acid attack of equipment.

## 4.2.4

## German experience

Information on CEMs in the German cement processes was collected from European equipment suppliers, and visits to one German cement plant and the German Cement Research Institute. Details of the visits are contained in the Confidential Annex to this report. In summary, the information gathered revealed the following key points on the use of CEMs in German cement manufacturing:

- CEM devices have been used successfully in the German cement industry for many years, with around half of plants now fitted with these devices to measure PM, CO,

SO<sub>x</sub> and NO<sub>x</sub>. Other than usual teething problems the systems can be said to work satisfactorily;

- the most common type of systems are NDIR and UV. The major supplier is Erwin Sick providing in-situ, cross-duct. About half of installed systems in the cement industry are these devices;
- a problem of interference from chlorides was noticed in one NDIR system on kiln exhaust gases when attempting to measure SO<sub>2</sub> and NO<sub>x</sub>;
- there is no predetermination of choice of extractive or in-situ system. The choice of system seems to depend more on which supplier is chosen - some only provide either in-situ or extractive systems - rather than on the technical or cost merits of each design;
- multi-component systems are now being used more and more;
- CEMs for NH<sub>3</sub> now becoming required due to SNCR for NO<sub>x</sub> abatement on some cement plants;
- FTIR has been being tested at a number of works, but is not yet proven on a continuous basis.

#### 4.2.5

##### French experience

Emission SA, the largest domestic supplier of such systems, manufactures a range of emission and air quality analysers at a plant in Poissy, near Paris. The range includes beta-gauge particulate measurement system, a dilution probe system, a sampling and sample conditioning system based on permeation dryers, a MIR 9000 multi-component infra-red GFC analyser and ambient air analysers.

The company has supplied continuous monitoring systems to approximately 80 per cent of cement plants operating in France and claims its to be the biggest domestic manufacturer of continuous monitoring equipment. According to September 1997 reference list, it has supplied up to 33 MIR 9000 systems to cement plants. The other main suppliers are Hartmann & Braun, Siemens and Erwin Sick.

The main cement companies in France are Ciments Francais, Lafarge Ciments, Groupe Origny and Vicat. Up to 20 cement works in France are licensed to incinerate solvents and other secondary fuels.

Emission SA typically supplies to a cement plant with a turn-key continuous monitoring system. For a plant which does not burn hazardous waste, the system is based on a sample probe/permeation dryer, a MIR 9000 for three components - SO<sub>2</sub>, NO<sub>x</sub>, CO<sub>2</sub> and an O<sub>2</sub> and particulate continuous monitoring according to the requirements of the customer. For a plant burning hazardous waste, HCl, HC and CH<sub>4</sub> can be added to the MIR 9000.

There are no type approvals systems in France. Emission SA does not sell equipment in Germany due to the cost of obtaining a German type approval. The only independent test data available for the MIR 9000 are contained in a report completed in 1992 by SIREP-WIB-Exera. This describes a laboratory and site-testing programme which

concentrated on the continuous monitoring's HCl measurement capability. The measurement range tested was 0 - 300 mg/m<sup>3</sup>. The results appear to indicate satisfactory performance.

The MIR9000 must be supplied with a dry sample of gas. Emission SA uses a permeation dryer rather than a condensing dryer to achieve this. The permeation dryer functions by the migration of water molecules from the sample gas across a membrane to a counter-current flow of very dry instrument air. In theory, this should not lead to loss of the pollutants in the sample gas. However this technology has not been successfully utilised at incineration applications in Germany, where wet scrubbing of the flue gas is used, due to unacceptable HCl loss in the dryer system.

Emission SA claims that its permeation dryer does not result in unacceptable HCl loss. However no test data were provided by the company to confirm this.

#### 4.2.6

#### US experience

##### General appraisal of performance of continuous monitors for cement processes

##### *Opacity monitors*

In the US only light attenuation systems measuring percentage obscuration of a light beam are used. These devices are not technically challenging and consequently few problems are reported. Clearly, though, the system must be set up correctly with appropriate path length. A shorter path length will give a higher reading for the same PM density as one reading over a longer distance.

##### *CO monitors*

Few problems are experienced with these. They are regarded as standard pieces of analytical equipment, with NDIR being prevalent.

##### *HC monitors*

The critical point with HC monitors is the type of sample train used: hot wet or cold dry. The US BIF regulations require the use of hot wet to avoid any sample loss in the train and measure as accurately as possible the true nature of the gas stream. Industry maintains that the hot wet system is problematic to use on wet kilns due to the high moisture (33-35 per cent) and particulate levels in the gases. Fewer problems are encountered on dry kilns.

Cement plant operator's experience is that in the hot wet system the moisture levels cause blocking and corrosion inside the sample lines and the FID itself, requiring frequent maintenance. Cold spots in the sample line are regular problems. Industry also claims that less than five per cent of the HC sample is lost in the condenser on a cold system prior to the FID (see Continental visit report). The EPA, on the other hand, does not accept that the problems with hot wet FIDs are as severe as the operators make out, and says that with suitable impingers blocking problems could be overcome. Moreover, the EPA claims to have seen hot and cold sampling systems working on the same gas stream with a 10-15 per cent difference in readings. This is, however, thought to have been an incinerator, and thus may have had different HC species present. The matter is as yet unresolved.



### *Mercury continuous monitors*

The USEPA conducted a series of trials to test the performance of H<sub>g</sub> continuous monitors at Holnam's long wet kiln in South Carolina. In short the conclusion is that the technology is not able to meet the required continuous monitoring performance specifications, that is, variability in the continuous monitoring readings compared with the standard reference method (based on the Relative Accuracy (RATA) methodology exceeded the maximum acceptable level – 700 per cent errors were experienced.

Similarly, poor performance of Hg continuous monitors was experienced from an incinerator trial, although in these tests fewer than the required nine RATA samples had been run.

### *Metals*

No continuous monitors capable of measuring metals accurately are known to be in operation. This subject is still very much at the research stage.

### *Chlorides*

No cement plant in the US has a continuous monitoring installed to measure chlorides, although the proposed MACT standard for the cement industry proposes to introduce this requirement.

### *SO<sub>x</sub> and NO<sub>x</sub>*

Cement plants in the US tend to measure SO<sub>x</sub> and NO<sub>x</sub> for the purposes of process control, rather than for regulatory compliance. The main techniques used are infra-red and chemiluminescence, both of which are considered accurate and reliable.

## 4.3

### **Supplier review**

In the UK most companies ( some of which are multi-national) have chosen to select continuous monitoring systems from single suppliers. Most of these suppliers are also the major suppliers to the power generation and incineration sectors. Continuous monitoring equipment suppliers and their portfolio are presented in the appendices to the report.

## 5. Application of continuous monitoring systems for mineral fibre processes

### 5.1 Mineral fibre sector study summary

In assessing the application of CEMs in mineral fibre processes it is necessary to distinguish between different types of processes, for example rock fibre and continuous filament processes, and stages within in each process, for example furnace, forming and curing. The suitability of CEMs also depends on the configuration of the waste gas ducting and the type of abatement systems used. A summary of CEM techniques for use in the mineral fibre sector is presented in Table 5.1. This assesses CEM techniques according to stages in the process: furnace (glass wool and rock wool) and forming/curing areas.

**Table 5.1 Summary of CEM techniques in the mineral fibre sector**

Source	Pollutant	Technique	Comments on best practice
<b>Furnaces</b>			
Glass wool and continuous filament (gas and oil fired)	PM	<ul style="list-style-type: none"> <li>Cross-duct IR</li> <li>In-situ triboelectric</li> </ul>	<ul style="list-style-type: none"> <li>Where pure glass furnace gases with dry abatement techniques are monitored, both cross-duct and triboelectric devices should work satisfactorily.</li> <li>Where wet scrubbing techniques are used, or gases are ducted with emissions from forming and curing areas, the use of CEMs becomes more problematic. Triboelectric devices, for example, have exhibited difficulties, where gases are moisture laden following wet scrubbing for particulate removal.</li> </ul>
	CO, O <sub>2</sub>	IR, zirconium oxide, paramagnetic	<ul style="list-style-type: none"> <li>There is little difficulty in using these devices on glass furnaces.</li> </ul>
	SO <sub>x</sub> , NO <sub>x</sub>	IR, UV (in-situ and extractive)	<ul style="list-style-type: none"> <li>No furnaces currently use these techniques, but measuring off-gases both in situ and extractively should not pose insurmountable problems.</li> <li>The main difficulty is if gases are measured where the temperature is above the melting point of glass. In this case, in-situ systems will not function well, and extractive systems will suffer from condensing particles in the sample lines and loss of sample if water is present. In most situations, though, gases should be measured at well below this temperature following dry particulate filtration.</li> <li>As above combining gases with those from other parts of the process introduces substantial difficulties for CEMs.</li> </ul>
Continuous filament glass furnace only	HF	None currently used	<ul style="list-style-type: none"> <li>No continuous monitors are currently used to measure HF, but reading across from other sectors,</li> </ul>

Source	Pollutant	Technique	Comments on best practice
			for example incineration, suggests that it is technically feasible. Two TUV-approved HF CEMs are available, both based on the ion-selective electrode principle. With HF being highly reactive gas, great care needs to be taken in gas sampling and conditioning.
Rock wool cupolas	PM	None currently used	<ul style="list-style-type: none"> <li>Although there is no direct experience of CEMs on these furnaces, all proven CEMs for particulate monitoring should work effectively providing wet scrubbing devices are not used.</li> </ul>
	H <sub>2</sub> S		<ul style="list-style-type: none"> <li>Continuous H<sub>2</sub>S measurement is not widely practised on rockwool furnaces.</li> </ul>
<b>Forming and curing (combined forming and curing /furnace emissions)</b>			
Glass and rock wool processes	General	In-situ and extractive systems	<ul style="list-style-type: none"> <li>Forming gases are heavily saturated with water droplets. This causes great difficulty with all CEM techniques. The only examples where CEMs have been successfully used is after sophisticated abatement systems using wet EPs to remove fine particulates and water droplets. This has been tried and approved by TUV in Germany using the OPSIS cross-duct technique to measure phenol and formaldehyde.</li> <li>Without wet EPs CEM techniques are not considered viable.</li> </ul>
	PM	Opacity	<ul style="list-style-type: none"> <li>With wet EP pre-treatment, opacity devices for absolute measurement are reported to work effectively in Germany.</li> </ul>
	Phenol, formaldehyde	OP SIS cross-duct UV	<ul style="list-style-type: none"> <li>Following a wet EP this device has been used with reported success in Germany.</li> </ul>
	Urea, NH <sub>3</sub> , VOCs		<ul style="list-style-type: none"> <li>No device has been used to continuously measure these substances, even after a wet EP.</li> <li>FTIR systems have been used intermittently with good results in the US - but their use on a continuous basis is not considered practicable because of the high degree of maintenance and operator involvement required.</li> </ul>

The following general comments also apply to the use of CEMs in mineral processes:

- there should be no reason why CEM techniques could not be used for measurement of common waste gases, for example CO, O<sub>2</sub>, PM, SO<sub>x</sub> and NO<sub>x</sub> from glass furnaces, providing wet scrubbing techniques are not used;
- the saturated characteristics of forming area emissions create substantial difficulties for CEM techniques. Only where sophisticated abatement systems designed to remove fine particles and water droplets are used can CEM techniques be deployed. Even under these conditions, though, the monitoring device needs regular maintenance;
- because triboelectric techniques are less prone to interference from water droplets it may be possible to use these for *indicative* monitoring on forming area emissions. UK experience, where these devices have suffered from fouling and have not performed well, conflicts with that in Germany where they have been used with some degree of success for indicative purposes. Triboelectric devices would not be considered for absolute measurement on these gases;
- the advanced technique of FTIR is an effective means of measuring inorganic and speciated organic compounds from complex gas streams, for example combined furnace and forming area emissions. Its application though is difficult in practice, requiring a high degree of operator input and maintenance, and at present would not be considered suitable for use on a continuous basis;
- the continuous nature of glass fibre manufacturing processes lends themselves well to the application of predictive monitoring techniques. These use sophisticated computer software to establish mathematical relationships between process outputs, such as product quality characteristics and emissions, and input parameters. One system is being trialed in the US, and has shown encouraging results to date. The accuracy of these systems is reportedly to be at least as good as, if not better than, CEM devices already available;
- with regard to the measurement of ammonia from forming areas, there is an important issue concerning the interpretation of emissions measurements over short periods of time. On all wool fibre lines, the off gases from the forming area pass through a wash water spray. This wash water both absorbs and releases ammonia and thus ammonia concentrations in the outlet gases can vary as a result of changing inlet and outlet conditions;
- where an extractive system is used to measure forming area emissions, there is the risk of reactions taking place on the heated filter in the sample train. Since this is held at > 250°C some phenol/formaldehyde resin will be cured on the filter surface, with the potential to release formaldehyde into the sample;
- a final consideration is the need to avoid reactions occurring in the sample lines. Gases from the forming area may contain urea, urea formaldehyde, phenol, formaldehyde, ammonia, and water. Formaldehyde and ammonia can react to form hexamethaline tetramine ("hexa"). This reaction can be reversible at high temperatures. At around 125°C, the temperature of the sample lines, the reaction to form hexa is dominant, but should there be higher temperature spots there is the risk that this reaction could reverse, giving unrepresentative readings of formaldehyde or ammonia. Best practice is to ensure that the possibility of reversible reactions is limited by keeping the sample lines and residence times in the lines as short as possible;

## 5.2 User experience

### 5.2.1 In-process measurement

Furnace control is critical for both control of product quality and environmental performance of the process. For effective combustion control and heating, mineral fibre processes usually continuously monitor CO, oxygen and temperature. The general techniques used are similar to those used on other small process combustion equipment and have been described in earlier reports <sup>(Ref. 1.9, 1.10)</sup>

Monitoring of O<sub>2</sub> and CO is usually carried out after flue gas treatment and following cooling of the flue gases. High temperature measurement is made difficult by the presence of partly molten dust particles in the gas stream.

### 5.2.2 Emission measurement

The two main release points for emissions to air from mineral fibre processes are the furnace flue gases and releases from the forming/curing/cooling areas.

For glass fibre production, glass melting furnaces can be oil, gas or electrically heated. For a typical 50,000 tonnes a year facility using gas or oil, the furnace would produce approximately 20,000 Nm<sup>3</sup>/hr of flue gas. A typical flue gas would contain particulate, NO<sub>x</sub>, SO<sub>x</sub> (if oil-fired) and possibly low levels of HF – although low levels of chlorides may be generated in optical fibre processes <sup>(Ref. 1.7)</sup>. The mass flow of pollutants from these furnaces has in the past not been considered significant enough to require continuous measurement in countries such as France and Holland, and the study did not reveal any instances where these parameters are continuously monitored. The only partial exception to this is where some companies have installed opacity monitors after electrostatic precipitators or bag filters, which are used for particulate control. The opacity monitors are reported to be used for filter-check purposes rather than reporting emissions to atmosphere.

Mineral wool production uses cupola furnaces with coke as a fuel. These furnaces operate at low excess air levels to achieve the high temperatures required. This may result in high CO levels and possibly the formation of H<sub>2</sub>S. Flue gas treatment is based on after-burning followed by a bag filter. H<sub>2</sub>S limits might be applied in many cases, although, the study did not reveal any plants where H<sub>2</sub>S is continuously monitored.

The second major source of emissions to atmosphere is from the forming, curing and cooling. Vent gases from these areas are sometimes treated and vented separately, or various combined venting arrangements are used. A typical example would be where forming area gases are treated and vented separately from the combined curing and cooling area vents.

The large volume of forming area vent gas – typically around 300,000 Nm<sup>3</sup>/hr for a 50,000 tonne/year production facility – has resulted in low pressure drop flue gas treatment systems being commonly employed, for example simple water injection followed by cyclone separators. Gas flows from the other areas are much lower – for example 50,000 Nm<sup>3</sup>/hr of combined curing and cooling vents – and this permits the installation of highly efficient scrubbing systems such as venturi scrubbers. Therefore emissions from the forming area tend to be wetter and to contain high levels of water droplets in addition to phenols, formaldehyde, urea, NH<sub>3</sub> and other VOCs.

In Europe, emission limits are usually specified for particulate and phenol/formaldehyde and occasionally  $\text{NH}_3$  and VOCs. In the USA the only parameter generally controlled is particulate. The continuous monitoring of these parameters is extremely difficult due to the nature of the carrying gas and there is limited experience available of the use of continuous monitoring techniques at operating facilities.

In Germany, the OPSIS cross-duct continuous monitoring - 602 Z - has been TUV type approved for the simultaneous measurement of phenol and formaldehyde with measurement ranges of 0–20  $\text{mg/m}^3$  in both cases (Ref: TUV 936/804002/02 from September 1994). One international mineral fibre company has installed OPSIS to monitor both parameters in the vent gases from the forming area at its facility in Germany. The detection limit for formaldehyde is reported to be 2.5 per cent of full scale deflection and the measurement cycle time is up to 90 seconds. The budget cost for the OPSIS system is approximately £ 110,000.

At this particular plant in Germany the standard gas treatment system of water injection followed by a cyclone has been supplemented by the addition of a wet electrostatic precipitator (wet EP) which reportedly removes water droplets from the gas sufficiently to enable effective functioning of the cross-duct monitoring system. The company has reported good operating experience with the OPSIS system and this is now used for compliance monitoring purposes. The same company has tried OPSIS at other mineral fibre plants in Europe for the same application. However the trials were not successful due to the fact that these plants had not been equipped with wet EPs.

Sites in the UK and France have tested triboelectric systems for particulate measurement. In the UK, experience reported from one site indicated that the system suffered drift and problems of fouling. These systems are no longer used. In Germany and France, on the other hand, one company has reported encouraging trial results with a UK-manufactured triboelectric system in an indicative capacity. It has carried out a number of calibration tests which compared the results recorded by the continuous monitoring with manual SRM tests. Good correlation was noted, but the company has no immediate plans to install the system at any of its sites for compliance monitoring purposes.

In the USA a number of sites have installed opacity continuous emission monitors for the forming curing area vent gases. As the regulatory emission limit is expressed in terms of opacity rather than  $\text{mg/m}^3$  of particulate, it is presumed that any free droplets will be recorded by the opacity meter and will be reported as opacity. No CEMs are currently used; although FTIR and predictive monitoring systems have been investigated. These are discussed later in this section.

### 5.2.3

#### UK experience

In the UK, one company had installed triboelectric PM systems at each of its two sites at a cost of £3,000 each (including data-logger). At one of the sites the off-gas from the cupola was abated via a cyclone prior to passing through a PM arrestment to atmosphere via a 25m stack. The exhaust gas was high in water vapour and approximately 150°C. At the other site the process off-gas was abated via a venturi scrubber. The exhaust gas was high in water vapour and approximately 60°C.

Both systems encountered problems with drift occurring soon after re-calibration. This was believed to have been due to the build-up of dust between the probe and the stack with the stack, acting as an extension of the probe.

The equipment supplier offered poor after-sales service to the company, which felt that the continuous monitoring was not "fit for purpose". The continuous monitors are no longer used.

Another company also reported poor experiences with continuous monitors, with inadequate performance against standard reference method BS3405 <sup>(Ref. 3.1)</sup>. As a result, the company had insufficient confidence in the equipment to rely on it for compliance testing, and uses it instead for trends. The principal problem appears to be the high moisture content of the flue gas affecting both operation and calibration.

#### 5.2.4

#### US experience

In the US, a site with broadly similar configurations to those in the UK and the rest of Europe had a relatively simple exhaust system with little abatement. The main abatement device on furnace emissions was a bag filter. Forming area emissions are treated by a sequence of wash water sprays followed by cyclones and a "penthouse" - the purpose of which is to drop out any water droplets by slowing down the air flow rate. Oven and cooling area emissions are ducted to an oxidiser. The oxidised waste gases are then combined with the forming area emissions in a single duct. The resulting gas stream has a temperature of around 160-170°F and seven to nine per cent moisture. This is above the dew point, hence no water droplets should be present.

#### Current monitoring activities

As previously mentioned, most mineral fibre plants in the US are only regulated for PM. These emissions are monitored continuously but only using percentage obscuration, not a direct PM measuring device. There is currently no US standard method for PM continuous emission monitors. The USEPA's recent thinking has been that there is no accurate means of measuring particulate continuously, given the difficulties with regular calibration, and that obscuration provides a reasonable indication of the trends in particulate release levels.

Two transmissometers are used at one site in the US:

- on cooling area gases, where readings are in the region of 10-15 per cent. The main purpose for these devices is to monitor process efficiency, and they require frequent adjustment to account for varying levels of moisture in the gases;
- on bag filters from furnace area emissions at various plants to check the efficiency of the filter. PM from ovens and cooling area are considered to be negligible and not worth measuring.

A recent review by the company on the applicability of PM to mineral fibre processes concluded that there were no techniques available which are capable of adequately measuring particulate in such a humid atmosphere. Water interference is the main difficulty.

Although not required by authorisations, NO<sub>x</sub> and SO<sub>x</sub> are measured periodically, mainly for process efficiency and to estimate emissions for the TRI. The preferred technique for NO<sub>x</sub> is chemiluminescence rather than the wet method described in USEPA method 7. SO<sub>x</sub> is measured for the same reasons. When required, contractors are called in for one or two days at a time. They use UV/NDIR which are verified against USEPA Methods 6 and 8.

Metals can be emitted from the erosion of the refractory linings of the kilns, and are measured periodically. Some states require measurements of metal emissions to ensure ambient air quality levels are not exceeded. Monitoring information is also required for internal purposes. The main measurement techniques used are USEPA method 29 and CARB method 429.

VOCs are given off in various forms from the forming and oven/cooling areas. Species include phenol, formaldehyde, methane and a range of other oils in the binders.

The extraction point for the VOC monitoring was on the forming area emissions prior to mixing with those from the cooling area. No problems were reported in sampling at this point in spite of the "difficult" gas stream. The performance of both the FID and FTIR were compared. The FID used was a JUM 109A. The main result was that the FID measuring total VOCs consistently read around 60-70 per cent lower than the FTIR measuring separate components of phenols, formaldehyde and methanol. The reason for this is that the FID is normally calibrated in terms of methane, and its response is different for different types of organic compound. For example, its response is much reduced if the organic compound is unsaturated, or contains oxygen, nitrogen or chlorine. In the presence of such compounds the conversion of the FID response directly to  $\text{mg/m}^3$  carbon does not accurately represent the emission of VOCs in terms of  $\text{mg/m}^3$  carbon <sup>(Ref. 1.10)</sup>.

### 5.3 Supplier review

In the UK a range of continuous monitoring techniques have been trialed on mineral fibre processes. The suppliers, however, appear to concentrate their efforts on the larger more lucrative markets, for example power generation, incineration and cement manufacture. Nevertheless, several companies are building up a reasonably sized customer base within this sector for example PCEME in the UK and OPSIS in Germany.

### 5.4 Developing techniques

#### 5.4.1 Predictive emission monitoring

The PEM system has been developed by Pavilion Technologies (PT) based in Austin, Texas. A PT PEM system has been commissioned at one mineral fibre facility in the US, with the system set up only to provide emissions readings for particulate. Later developments are expected to extend its performance range to include other substances, and measurement of product quality.

The basis principle of a predictive emissions monitoring system is to calculate outputs from a process - these can be emissions but also include a range of product variables - based on a knowledge of current operating conditions and a large body of experimental data relating changes in inputs and operating variables to changes in outputs. Through non-linear regression analysis the system establishes individual non-linear functions relating changes in each input variable to changes in outputs.

In 1996 the USEPA published a set of protocols and performance specifications for PEM software. The performance specification stipulates the general approach to be used when installing and operating a PEM system. Consistent with other monitoring techniques the specification requires a nine-test run - a relative accuracy test audit



(RATA). From the trials conducted to date the installed PEM system has performed well within the required 20 per cent RATA test limits.

The main strength of a PEM system is its ability to relate both product quality and emissions to changes in input variables. This allows more optimum control of the process to maximise product quality and yield and minimise emissions. With regard to emissions alone, a PEM is effectively a process control device and so it can be used to minimise the total impact of a group of emissions where they are interrelated. For example, emissions of NO<sub>x</sub> and CO are generally inversely related, and the optimum process operating condition is one in the centre of the range which achieves the lowest overall levels of releases. By correlating CO and NO<sub>x</sub> emissions, a PEM system can identify quite accurately the most efficient operating range.

A further advantage is the accuracy of the system. Pavillion, for example, claims that in some cases the accuracy of the PEMs system is better than conventional continuous emission monitors (derived from tests comparing variability in emission measurements from two continuous emission monitors and the PEM). Typically, the system is capable of achieving relative accuracy results of less than five per cent, which is considerably below the required maximum of 20 per cent.

Another advantage of PEMs is that once the system has been set up it does not require regular calibration, as do conventional continuous emission monitors. Savings are achieved through lower materials (for example calibration gas) and labour requirements.

The main drawback of a PEM system is its cost and the time and effort associated with setting it up. The front-end calibration phase is necessarily comprehensive and requires the involvement not only of the equipment supplier and a key operator but also of other process engineers familiar with the process.

To accurately monitor the input variables, considerably more comprehensive process sensors are required. These would measure, for example, material feed rates, furnace temperatures, glass pull rates etc at various stages in the process.

Actual operating data have been charted correlating actual and predicted emissions and they illustrate a high degree of accuracy with an  $r^2$  correlation coefficient of 0.93 (Ref. 5.1). No monitoring has been done for substances other than particulate.

The costs of the system installed at the US plant are given in Table 5.2.

**Table 5.2 Installed costs of the PEM system**

Item	Cost (1997)
Main software package ("process insights") - including a 266MHz Pentium PC	\$60,000
Bespoke software to interface with site control system	\$30,000
Process sensors (not typical as installed more than required)	\$550,000
CEM costs	\$185,000

Item	Cost (1997)
Special sampling of furnace parameters	\$50,000
Sensor validation system	\$7,000
Internal staff time to set up system (four person years @ \$50,000 per person / year)	\$200,000
Total set-up costs	\$1million

These costs are for one line out of six and thus include a number of non-recurring costs. The costs of implementing on to the other five lines at the plant are estimated at around \$300-350,00 per line. This was still considered high by the company involved.

The other main limitation to a PEM system is that it can only operate within steady-state conditions and is unable to predict emissions under, for example, start-up or shut-down. Under steady-state operation, though, emissions should be predictable under all possible conditions.

This is not necessarily a major limitation, as most mineral fibre process plants are designed for continuous steady-state operation, and hence the PEM system is valid for the majority of the plant's operating time. The system is, however, under continuing development to operate under unsteady-state conditions with the intention that the software will track changes in the process parameters.

#### 5.4.2

#### FTIR

##### *Introduction*

A company has been using FTIR to measure emissions from mineral fibre processes for a number of years. It is not used continuously but has been operated for periods of up to a couple of months. The main purpose of the FTIR equipment has been to calibrate a predictive emissions monitoring systems currently being installed, although the information is also useful for monitoring process efficiency.

FTIP calibration is the most expensive method, but it is considered the only achieves the accuracy necessary for the PEM system to operate as required.

##### *System description*

The FTIR system used is an extractive system, and has been employed on emissions from all stages of the process. The device used was a Nicolet 550, which uses liquid nitrogen for cooling the mercury cadmium telluride detector. This liquid cooling provides a more accurate reading by an order of a factor of 10 over non-liquid cooled FTIR devices.

The gases measured by the FTIR unit were extracted from the combined waste gas streams arising from the forming and oven/cooling areas. More recently, some tests have been done on gases coming directly from the forming area, but no data have been provided.

The configuration used is similar to most other extractive systems, including a heated ceramic filter followed by a flow meter, analyser and a pump. An ambient temperature membrane filter can be placed in between the ceramic filter and the flow meter, but this is not used by the company.

The extraction system needs regular maintenance as it is applied continuously to the forming area emissions which contain a high moisture content as well as sticky resinous particulate. The filters require replacing every 12 hours or so. Should the filter plug up as for example, might occur during start-up or shut-down, the pump is then switched off. A heated line is used to maintain the integrity of the sample. As a guide a maximum of .50ft is used to reduce the risk of cold spots. In addition to the regular replacement of the filters, the liquid nitrogen is added manually every 12 hours. As yet there are no FTIR devices which have automatic liquid nitrogen feeding.

### *Calibration*

The FTIR analyser is a sensitive instrument and requires comprehensive checks before it is able to operate. These checks cover hardware, analytical methods and sampling system and line losses. Calibration is usually completed once prior to a week's trial, although zero calibration is performed daily during continuous running. The mirrors in the FTIR analyser accumulate deposits but this interference shows up in background reading and the system can be adjusted to allow for build-up on the mirror surface providing it is re-calibrated frequently. Attending to the position, alignment (required to achieve correct IR path length) and cleanliness of the mirrors is the main aspect of calibrating an FTIR analyser.

When operating continuously the FTIR is calibrated daily using N<sub>2</sub> as the calibration gas (to test for a zero reading). As noted above, resetting to allow for deposits on the mirrors does not cause too much of a problem, although when the background levels introduce too much noise the mirrors are then removed and cleaned.

The site has two sets of mirrors, one of which can be removed and cleaned while the other is in operation. Periodically the mirrors may be sent away for recoating.

### *Results*

The FTIR system can be used to measure the concentrations of a variety of components in a gas mixture. The aim of using the FTIR was to speciate VOC compounds in emissions from wool fibre processes, in particular ammonia, phenol and methanol. The overall performance of the FTIR analyser is considered good by the company, with reasonable margins of error. Typical errors from standard reference methods using Method 5 sample trains are:

- methanol     10-15 per cent
- phenol        40-50 per cent            (typical levels: 0.5 - 1 ppm)
- ammonia      < 10 per cent

The higher level of error for phenol is due to the very low concentrations measured - < 5mg/m<sup>3</sup>.

Errors can occur at various points in the FTIR analysis: sampling, analytical and mathematical. Sampling errors are typically of the order of five to 10 per cent for most substances, although this can rise to 20 per cent for phenol, for the above reason. This sort of variability is seen in continuous readings provided every five minutes over 35 minutes.

Analytical errors are affected by the presence of interfering compounds, mainly water. This is particularly a problem with the measurement of phenol at such low levels, where an increase in moisture increases the FTIR reading. An experienced FTIR operator should however, be able to identify the phenol spectra by subtracting known spectra from the broad pattern.

The presence of water, however, is generally a problem when measuring low concentrations due to the increase in background noise. Moreover, as the required sensitivity of the FTIR analyser is increased then the range over which readings act linearly reduces. Temperature can also have a large effect on readings, particularly on the background signal from water. To avoid this the sampling and analytical system must be operated at above dew point. The problems of the build-up of deposits on the mirrors in the FTIR cell are largely overcome with daily recalibration, although a small amount of error does creep in during the running period as deposits build up on the mirror. Such errors, though, are very small.

In the FTIR technique identified, spectra are subtracted from the frequency response and these mathematical calculations can introduce some error, but again this is negligible. Only highly qualified operators provide this level of competence.

#### *Application of FTIR to continuous filament processes*

The FTIR analyser was also used at the company's continuous filament plants to measure HCl and SO<sub>2</sub> on emissions from the glass furnace. The standard impingement method was used for HF. Emissions from the glass furnace are emitted directly to atmosphere through a stack above which is situated a shroud that allows significant air dilution. The extraction point for the analyser had to be in the cooled section (700°F compared to 1400°F in the lower stack) to avoid the hot glass particles condensing on and coating the sample lines.

#### *Results*

The FTIR system worked satisfactorily, showing emission levels of 60-70ppm HF, 5-10ppm HCl and 60ppm SO<sub>2</sub>. However, no comparisons were made using emissions spiked with calibration gases because no gases were available at the time of the tests. Across all these compounds the FTIR gave readings at around 20 per cent of those of the impingement method.

The main disadvantage with using FTIR on gases with such high levels of HF present is the damage caused on the glass mirrors inside the analyser. The mirrors had to be replaced on these tests after three days.

At the beginning of 1998 the USEPA issued a draft proposal on a standard method for the measurement of emissions using extractive FTIR - Method 318. This will be introduced in the forthcoming MACT standard for mineral fibre processes.

The draft method 318 included in its scope measurement of carbon monoxide, carbon disulphide (rock wool processes only), formaldehyde, methanol and phenol. A more recent draft is soon to be published and this is expected to exclude all compounds other than formaldehyde. This will tie in with the forthcoming MACT standard for mineral wool processes which will only set limits for formaldehyde. Cost data for an FTIR system is given in Table 5.3.

**Table 5.3 Costs of an FTIR system**

Item	Cost (1997)
<b>Non-recurring costs</b>	
Nicolet 500 Analyser + one 10ft + one 50ft line	\$186,000
Transformer	\$5,000
Packaging and transport	\$6,000
<b>Total</b>	<b>\$197,000</b>
<b>Recurring costs</b>	
Maintenance (labour) . (10% of contract value)	\$18,600 pa
Mirrors: one new set per year (5-10 reconditions @ \$500 each)	\$5-10,000 pa
<b>Total</b>	<b>\$23,600-28,600 pa</b>

Operator time is also an important consideration in using FTIR, in that analysing the spectra can take a significant amount of staff time. Using the system frequently requires around one or two people per year for this task. As noted above the people involved would need to be highly qualified.

## 6. Application of continuous monitoring systems for frit processes

### 6.1 Frit sector study summary

A summary of suitable CEM techniques studied for use in the frit industry is shown in Table 6.1.

**Table 6.1 Summary of CEM techniques for frit processes**

Source	Pollutant	Technique	Comments
Flue gas from kiln	PM	In-situ opacity Triboelectric	<ul style="list-style-type: none"> <li>After abatement, flue gas conditions are undemanding and in-situ devices can work effectively.</li> </ul>
	HF	Extractive Electrochemical	<ul style="list-style-type: none"> <li>The most widely used system on the market, is the Bran &amp; Luebbe Ecometer. This is TUV approved for a measurement range of 0-5 mg/m<sup>3</sup>. Severn Science/CERAM research also offers continuous HF monitoring equipment based on the same principle. Both makes of systems have worked satisfactorily.</li> <li>Sample lines need to be made from chemically resistant PTFE and fully heated to avoid loss of sample in any condensed moisture. Proprietary sampling probes and a heated particulate filter help ensure the system is able to cope with the potential corrosive conditions.</li> </ul>
	NO <sub>x</sub>	Extractive NDUV Chemiluminescence	<ul style="list-style-type: none"> <li>Little difficulties have been experienced in operating these devices.</li> <li>NDUV is the most common technique in this industry - based on German experience - although there is no technical reason why other designs could not be employed.</li> </ul>

The kiln temperature is normally monitored continuously. This is to ensure effective operating conditions, and has been done as a product quality feature rather than for emissions control purposes. This area has not been investigated.

## 6.2 User experience

### 6.2.1 Emissions measurement

The main source of emissions to air from frit processes is the flue gas from the melting kilns. The kilns operate on a batch basis, although several kilns on a particular site may be vented to a common vent header system. The kilns may be fired with oil or gas and many plants use pure oxygen instead of air for combustion. This reduces heating costs and also reduces the amount of flue gas that requires treatment.

The main contaminants in the flue gas include particulate matter, metals (Pb, Cd), HF and NO<sub>x</sub>. Many kiln systems are equipped with particulate and HF abatement.

The gas flow rate from the kilns tends to be low – in particular those systems which use pure oxygen rather than air. In addition, flue gas treatment systems for the control of particulate and HF emissions result in low gas concentrations. Therefore, in many

countries, the mass flow of these parameters is below the threshold which require continuous monitoring. Consequently, continuous monitoring technology has not been widely used in the industry to date.

#### *Particulate measurement*

Both opacity and triboelectric systems have been used successfully on gases following abatement with a bag filter or electrostatic precipitator.

#### *Hydrogen fluoride*

The principle CEM system for HF monitoring is based on ion selective electrode technology. The main difficulties with HF monitoring are ensuring the integrity of the sample and avoiding corrosion of sampling equipment. These difficulties can be overcome by using chemically resistant materials such as PTFE in the sample lines, and maintaining temperatures in the sample lines above HF dew point.

#### *Oxides of nitrogen*

For NO<sub>x</sub> monitoring there is a wide range of NDUV, chemiluminescence and other multi-component analysers currently available. During the study only plants in Germany appear to continuously monitor NO<sub>x</sub>, with most plants using an extractive NDUV system. The systems have all worked successfully.

#### *Metals*

There are no systems currently on the market which can continuously monitor heavy metals at frit processes.

### 6.2.2 UK experience

Two sites in the UK employed PCME DT770 systems with data-loggers, with satisfactory results. One of the sites had also tested an optical system but had encountered problems - initially the windows needed cleaning every one or two months (due to moisture from the kiln), but the system then needed even more frequent calibration.

PCME was providing good technical support and service contracts to both companies. Calibration at both sites was carried out by external emissions testing organisations. One of the sites had encountered rain ingress through the stack during periods of shut-down, giving PM readings.

Only one of the sites had experience outside that of PM continuous monitoring. That experience was restricted to HF monitoring using a Severn Science/CERAM Research electrochemical system. Severn Science had a service contract to overhaul the instrument on a six monthly basis. The site technical manager calibrated the instrument fortnightly. Experience was good and the company decided to undertake a trial whereby the HF emission level 4-20mA signal was used to control the lime feed rate for abatement purposes.

### 6.2.3 German experience

A plant in Germany had had more experience of continuous monitoring than the two sites in the UK.

This plant had installed, at a cost of over DM 200,000 DM, continuous monitoring equipment to monitor HF and NO<sub>x</sub> emissions from the main stack. The monitoring equipment was located downstream of the abatement equipment consisting of a primary bag filter to reduce dust loading and then a dry-lime acid scrubbing system involving injection of CaOH<sub>2</sub>. This investment was carried out at the same time the abatement equipment was installed. Continuous monitoring was not required in the site licence: the main reasons given for installing the continuous emission monitor system were to provide a continuous check on the operation of the new scrubbing system, and to build up a record of emissions to be used in any discussions/ disagreement with the licensing authority. CEM equipment was anticipated to be a regulatory requirement in the near future.

The equipment used was:

HF monitoring: Ecometer AC85 from Bran & Luebbe (measurement range: 0-5 mg/m<sup>3</sup>)

NO<sub>x</sub> monitoring: Unor 600 NO<sub>2</sub>, NDUV analyser with converter (NO-NO<sub>2</sub>) from Maihak (measurement range: 0-3000 mg/m<sup>3</sup>)

O<sub>2</sub> monitoring: Oxor 600 Paramagnetic analyser from Maihak (measurement range : 0-21%)

The analysers were situated in an air-conditioned analyser room near the base of the stack. The sampling point was located 25m up in the stack.

The flue gas conditions at the sampling point were relatively undemanding:

- temperature: 130° C
- dew point: < 50° C
- particulate: < 10 mg/m<sup>3</sup>
- HF: << 5 mg/m<sup>3</sup>

The Ecometer was supplied with its own proprietary heated sampling probe which includes a heated particulate filter and approximately 30m of teflon-lined heated sampling line which delivered the sample gas without cooling/condensation directly to the analyser.

The separate sampling systems for the NO<sub>x</sub>/O<sub>2</sub> analysers consisted of an unheated sampling probe with an externally mounted and heated particulate filter. A heated sample line passed sample gas to a cooler and then to a catalytic converter to convert NO to NO<sub>2</sub>.



The Ecometer was contained within its own housing. The Unor 600 and the Oxor 600 analysers were in a single factory-fitted 19inch rack cabinet which also contained the flue gas cooler, fine filter, pressure and moisture alarms and gas switching systems for the introduction of span and zero gas.

### **Data processing**

The 4-20 mA signals from the three analysers were connected to a MEAC A/D converter, also supplied by Maihak, which was connected to a standard PC loaded with data processing software.

### **Calibration and verification**

As the installation of continuous emission monitors was not a licence requirement, the continuous emission monitors system was not subject to official calibration according to VDI 3950.

The Ecometer was subject to a twice-yearly maintenance contract with Bran & Luebbe when the zero and span settings were checked. Regular span and zero checks were carried out every 24 hours according to a pre-programmed sequence using test solutions. No span or zero gases were used. The UNOR and Oxor analysers were zero and span checked by plant personnel every three to four weeks using bottled zero and span gases.

### **Availability, maintenance and costs**

The continuous emission monitors have displayed good availability and reliability since installation and the company appears satisfied with performance. Regular maintenance for the Ecometer consisted of:

- a daily function check - carried out by plant personnel;
- recharging the absorption and analysis solutions every three or four weeks - carried out by plant personnel;
- a maintenance contract with Bran & Luebbe at a cost of DM 8,000 per year - two site visits and the costs of all replacement parts subject to regular wear and tear (for example tubing, seals etc.).

The cost in terms of plant personnel time was estimated at an average of two or three hours per week.

The Unor and Oxor analysers were checked every day, in particular the sampling system - the cause of most problems encountered - and zero and span checks every three or four weeks.

The total investment cost was in the region of DM 200,000 with approximately DM 100,000 for the Ecometer and sampling system.

**6.3****Suppliers review**

In the UK a range of continuous monitoring techniques have been trialed. The suppliers appear to concentrate their efforts on the larger, more lucrative markets such as power generation, incineration and cement manufacture. However several companies are building up a reasonably sized customer base within this sector, for example PCME.

## 7. Application of continuous monitoring systems for asbestos processes

### 7.1 Asbestos sector study summary

The suitability of techniques to monitor the main emissions from asbestos processes are presented in Table 7.1.

**Table 7.1 Summary of CEM techniques for asbestos processes**

Source	Pollutant	Technique	Comment
Various sources	Particulate matter	In-situ riboelectric, Opacity	<ul style="list-style-type: none"> <li>Current practice is to use triboelectric devices to measure particulates as a surrogate measure for asbestos fibre.</li> <li>Opacity devices are also likely to operate effectively but triboelectric devices are somewhat and have been favoured by most operators.</li> </ul>
	VOCs	No experience in asbestos processes	<ul style="list-style-type: none"> <li>CEMs have not been used but that does not mean that they are not suitable. Continuous FIDs are used in other sectors and there should be little technical difficulty in applying them to asbestos processes.</li> </ul>
	Phenol, formaldehyde	No experience in asbestos processes	<ul style="list-style-type: none"> <li>There are currently no monitors which could be said to offer continuous monitoring of these substances in asbestos processes, although read-across from the mineral fibre sector, where the OPSIS system has been effectively employed, would suggest this is technically feasible.</li> </ul>
	Ammonia	No experience in asbestos processes	<ul style="list-style-type: none"> <li>As above, CEMs are not currently applied but that does not mean they are necessarily unsuitable for asbestos processes.</li> <li>Difficulties which need to be overcome include heated lines greater than 300°C where sulphur compounds are present. This is needed to prevent formation of ammonium sulphate and bisulphate.</li> <li>Bearing this in mind, conventional NDIR and ion selective electrode-based techniques should be capable of continuously monitoring for ammonia.</li> </ul>

## 7.2 User experience

### 7.2.1 Emissions measurement

#### *Particulates and fibres*

Operator experience of continuous monitoring for emissions to atmosphere is limited to particulate matter. The industry and bodies such as the HSE have investigated asbestos fibre measurement, but efforts have focused on personal dosimetry and to date there are no recognised continuous monitoring techniques for emission monitoring purposes.

Triboelectric monitoring systems are employed throughout the industry for continuous monitoring of particulate matter - both for absolute measurement and indicative to identify bag failure - and with appropriate calibration is accepted as a suitable surrogate technique for asbestos fibre measurement. The Control of Asbestos in the Air Regulations 1990 require asbestos emissions to air to be monitored at six monthly

intervals. There are two options for monitoring emissions, either by fibre counting or gravimetrically. The reference method for determination of fibres is BS6069 Section 4.2:1991. The specifications to be met if the gravimetric method is selected are detailed in the Annex to Directive 87/217/EEC. Section 2 of the Note recommends the use of continuous monitoring for PM. If continuous monitoring of PM is carried out, the continuous monitors should be calibrated regularly using BS3405 or equivalent.

#### *Phenol and formaldehyde*

Formaldehyde and phenol are emitted from asbestos processes, but continuous monitoring of these pollutants is not carried out in the UK. Cross-reading between sectors could mean that techniques DOAS (German experience in mineral fibre application) could be suitable. FTIR is capable of accurately measuring ammonia and organic compounds, but its use under continuous operation is still not proven, requiring substantial operator input and maintenance.

#### *Ammonia and amines*

Ammonia is also emitted to atmosphere from asbestos processes. Again, continuous monitoring is not carried out. However, available techniques for continuous monitoring of ammonia include electrochemical cell, Chemiluminescence, NDIR, ion mobility spectroscopy and NDUV. There are no recognised techniques for suitable continuous monitoring techniques for amines.

#### *VOCs*

VOCs emitted could be monitored continuously by a range of techniques including FID, GC-PID, NDIR and PID, all of which are recognised in continuous applications.

Due to the undemanding nature of the abated emission from asbestos processes it is likely that all of the techniques listed above for the pollutants emitted to atmosphere would be suitable.

### 7.2.2

#### UK experience

One site in the UK employed several PCME DT200 continuous monitors, both for absolute and indicative monitoring to identify bag leakage. The company had four year's experience with the equipment, with PCME undertaking trials at the site ahead of purchase. The triboelectric continuous monitors were chosen rather than optical devices on the basis of cost. Experience has so far been good. Annual calibration is carried out by an external emissions testing organisation.

The only problems encountered related to PM measurements during downtime when it was raining or snowing. The company rectified this by fitting cowl to the points of emission on the site.

## 8. Application of continuous monitoring systems for ceramic processes (fletton brick)

### 8.1 Ceramic sector study summary

Table 8.1a presents a summary of suitable techniques studied:

Source	Pollutant	Technique	Comments
Combined waste kiln gases	Particulate matter, SO <sub>x</sub> , NO <sub>x</sub> , CO, CO <sub>2</sub> , VOCs and halogen components	No experience in the UK	<ul style="list-style-type: none"> <li>Initial difficulties of stack access and sample line blockage should be able to be overcome.</li> <li>Once access is gained there is substantial read-across between the continuous monitoring of emissions from Fletton brick processes and other industrial emissions.</li> <li>Compared to other emissions there is little water vapour present and inorganic compounds can be readily measured by cross-duct and extractive techniques using NDIR or UV analysis.</li> <li>With appropriate filter replacement VOCs should be measurable on a constant basis by FID techniques.</li> </ul>

### 8.2 User experience

#### 8.2.1 Emissions measurement

Pollutants emitted to atmosphere include particulate matter, SO<sub>x</sub>, NO<sub>x</sub>, oxides of carbon, VOCs and halogen compounds. Hanson Brick is the only UK company operating Part A IPC-prescribed ceramic processes, and the Hoffman kiln process operated by Hanson Brick is unique to the UK.

To date no monitoring has been carried out on these kilns other than on an intermittent basis. This is as a result of initial monitoring campaigns which found difficulties with filters blocked by particulate matter. This was caused in part by the use of portable equipment in these tests.

Other difficulties in applying CEM techniques on UK Hoffman brick kilns include:

- access to the stack interior, caused by thick brick walls. Assess ports with a large diameter, sometimes up to nine inches, are required because of the need to maintain the correct NPL relative dimensions on pitot tubes for gas flow measurement.
- particulate loadings are also slightly higher than other mineral industry emissions, with a benchmark release level of 50mg/Nm<sup>3</sup> compared to 20 or 30 in other mineral processes. This imposes a slightly higher loading on the front end filter on the gas sampling train. This is evidenced by recent campaigns at Hanson Brick for the monitoring of hydrogen fluoride using an electrochemical system (Severn Science).

Probe blockage problems have also arisen. As with most monitoring campaigns sampling problems can be overcome by regular filter changes, although at a cost;

- in-situ cross-duct IR and UV equipment, as used in a wide variety of other mineral and non-mineral processes, offers an alternative to extractive systems, and can be used for a wide range of inorganic compounds;
- efflux velocities tend to be lower than in other IPC minerals processes, for example cement/lime. This increases the risk of air ingress into the stack under windy conditions, which can upset the homogeneity of pollutant distribution inside the stack.

These practical issues, however, are not considered insurmountable and further perseverance with CEMs, in particular in-situ systems, should be investigated. In the German brick industry it is normal practice to employ continuous monitoring for O<sub>2</sub>, CO<sub>2</sub> and CO. There is no evidence to show that these techniques suffer from any consistent problems.

## 9. Conclusions

### 9.1 General

The general conclusions of the study are as follows.

- The vast majority of prescribed substances likely to be released from mineral processes are released to air, and the experience of CEMs has focused on this application.
- Many of the difficulties associated with CEMs in the minerals sector are similar to those in other process sectors and centre on:
  - ⇒ interference from water droplets (forming gases from mineral fibre plants);
  - ⇒ line and filter blockage from particulate loading.
- In general, CEM technology and its experience is developing quickly with minerals processes taking the lead from other sectors, such as incineration, where CEM devices are being used to monitor for a wide variety of substances in harsh environment.
- In the cement industry the use of CEM technology for measuring SO<sub>2</sub>, NO and CO at the kiln exit is a standard technology for process control with many suppliers offering standardised packages. This equipment is effective and available.
- The use of CEM technology for monitoring emissions from the cement and lime sector for particulates SO<sub>2</sub> and NO<sub>x</sub> is also well proven, with many reliable systems available. Techniques for HCl are not widely employed but systems are used in other industries such as waste incineration, and there should be no technical reason why they could not be applied to cement and lime processes. The study found no evidence of proven use of continuous techniques for monitoring heavy metal emissions.
- The applicability of CEM technology to mineral fibre processes depends on the configuration of the waste gas stream. Where furnace emissions are separated from forming/curing emissions, CEMs can be readily used providing there is suitable particulate abatement and/or temperature reduction. CEMs on forming gas or combined forming/furnace emissions pose greater problems, due to the inherent difficulty of applying CEM technology to cool saturated gases. Only one system appears to have any track record for measuring phenol/formaldehyde emissions (cross-duct UV) and this is only feasible where gas scrubbing equipment (wet EP) has been installed to remove fine particulates and free water droplets from the gas phase. FTIR and Predictive Emissions Monitoring systems for monitoring forming/curing emissions are on the verge of commercial and technical viability.
- CEM technology for frit processes is suitable for PM, NO<sub>x</sub> and HF measurement. The UK has positive experience of PM measurement using triboelectric technology, and in Germany several sites have installed NO<sub>x</sub> and HF monitoring, where they have proven to be effective and reliable. Many different NO<sub>x</sub> systems are available,

although only one system - based on ion selective electrode technology - is available for HF monitoring.

- In the ceramic sector, initial problems of probe fouling and stack access have hindered the application of CEMs to emissions measurement. Neither of these difficulties are insurmountable, however, and proven multi-component techniques capable of measuring PM, CO, SO<sub>x</sub> and NO<sub>x</sub> should be suitable for use on these processes.

## 9.2

### Continuous monitors for the cement/lime processes

The use of continuous monitors for flue gas analysis in the cement industry has a long history and can now be considered to be a standard practice across the sector. All sites referred to have developed a considerable amount of experience with both the selection of CEM systems and their calibration and maintenance. All the major suppliers of CEM equipment have significant cement sector references.

Most of the sites use kiln combustion control systems which rely on data provided by CEM systems measuring at the kiln exit. These systems appear to be overwhelmingly extractive systems for O<sub>2</sub>, CO, NO<sub>x</sub> and SO<sub>2</sub>. The main technologies employed include NDIR for SO<sub>2</sub> and CO, NDUV for NO and paramagnetic or electrochemical cells for O<sub>2</sub>. Many sites reported a development or debugging phase when CEMs were initially installed whereby the particular difficulties facing CEM equipment in the cement kiln atmosphere - high-temperature aggressive gas, dusty work environment etc - have been overcome. The critical issues were materials of construction and maintenance for the sampling system and the analysers. Some suppliers, for example Hartmann & Braun, have standardised the CEM packages for kiln control purposes.

With regard to the use of CEM technology for the monitoring of emissions to air, again the cement sector has many year's experience of the installation of stack particulate monitors. Cross-stack opacity/extinction measurement is the preferred technology in Europe, with Erwin Sick in a dominant market position throughout the continent. A number of companies in the UK have installed particle impingement systems - PCME, Triboace - to monitor other dust sources on the site. These units are cheaper than opacity-based devices, and are most cost-effective for measuring particulates in benign gases from contained sources.

To determine NO<sub>x</sub> and SO<sub>2</sub> emission to atmosphere, separate measurements must be made in the stack. The data from the kiln exit CEMs cannot generally be used due to the change of flue gas as it passes through the preheaters. Again, many different systems are available and there are both cross-stack and extractive systems available as standard packages for cement industry applications. In Germany, the market would appear to be evenly divided between cross-duct and extractive systems with again Erwin Sick - GM 31 combined SO<sub>2</sub>/NO CEM - being the market leader for UK extractive systems. In the US, extractive systems are preferred.

The costs of installing, calibrating and maintaining a complete cross-stack emission monitoring system have been estimated as follows:

Dust monitor:	£5,000
Combined SO <sub>2</sub> /NO:	£20,000
Emission computer:	£13,500



Combined total: £38,500

Maintenance £3,000  
contract plus spares:

The costs for a complete system with extractive SO<sub>2</sub>/NO monitoring would be broadly similar.

A number of new CEM technologies have been applied to cement works. FTIR multi-component technology has been used in at least one cement works in Germany and at a number of sites in the USA. A number of cement works have also successfully used FID technology to measure total organic carbon, in particular those sites using non-standard fuels.

### 9.3

#### Continuous monitors for the mineral fibre processes

Where off-gases from the furnace (or cupola in the case of rock wool plants) are separated from the forming area emissions, CEM devices to measure particulates and combustion products, based either on cross-duct or extractive systems, should work without insurmountable difficulties.

CEM technology has not been widely used with regard to forming and curing area emissions used. Wet scrubbing systems would appear to be universally used to treat the off-gas from these areas for both glass and rock wool production. The main parameters subject to emission limit control are particulate, phenol and formaldehyde. The condition of the off-gas after treatment - water saturated and a high content of free water droplets - places very high demands on extractive sampling systems, and conventional cross-duct opacity/extinction monitors do not work effectively in the presence of free water droplets. CEM devices are only suitable on these processes where abatement systems can reduce fine particulate and free droplets to low levels. Wet EPs at two sites in Germany and France have reportedly produced emissions where cross duct DOAS IR (OPSIS) systems can operate effectively.

One major mineral fibre company has carried out a series of tests of impingement particulate monitors (triboelectric) on post wet EP forming gas emissions. The system appears to be little affected by the presence of remaining water droplets and reasonable results have been reported, albeit on a very limited dataset. It had not been tested against standard reference methods. The company has no immediate plans to install any units at operating sites, and without further testing its use as a suitable technique cannot be endorsed.

FTIR technology has been used in the USA. However the only application was to gather data on a campaign basis for the establishment of a predictive emission monitoring system. The FTIR system is not installed on a permanent basis and its use during the campaigns was associated with very high support costs. The system is expensive with costs around £130,000 including installation. Predictive Emissions Monitoring techniques being trialed in the US during the study appeared to show promising results, to the extent that these could replace conventional stack CEM equipment. The cost of the system viewed was high - of the order of \$1m - but this needs to be set in the context of tighter process control and product quality improvements which these systems are also designed to achieve.

#### 9.4 Continuous monitors for frit processes

The use of CEM systems for emissions to air is standard practice in UK and Germany, whereas experience is limited to particulate monitoring in the UK. The main parameters of interest are particulate, HF and possibly  $\text{NO}_x$ .

Many enamel frit processes in Europe are equipped with a high-efficiency dry scrubbing system. The site in Germany was equipped with a high-efficiency dry scrubbing system which resulted in relatively straightforward conditions for the application of CEM technology. The plant was equipped with an HF CEM from Bran & Luebbe (electrochemical technique) with a measuring range of  $0\text{--}5\text{mg/m}^3$ . According to industry sources, this is the only HF CEM with a significant reference list and any track record.  $\text{NO}_x$  was measured continuously using NDUV and chemiluminescence techniques.

For a complete CEM package including HF,  $\text{NO}_x$  and  $\text{O}_2$  measurement, the costs were quoted at approximately DM 200,000. The installed system is reported to be reliable with a relatively low maintenance cost.

With regard to particulate monitoring, triboelectric devices have been successfully installed at two of the major frit kilns works in the UK. Cross-duct opacity systems suffered from fouling of the beam window, requiring regular maintenance and down time.

#### 9.5 Continuous Monitors for Asbestos Processes

Experience is restricted to particulate matter emission monitoring. All UK sites undertaking continuous emission monitoring employ triboelectric devices as surrogate indicators for fibrous material. Experience has been good and these devices are considered to be effective and are certainly available.

With regard to other emissions from these processes, principally VOCs including phenol and formaldehyde, no experience of the use of CEMs has been identified. That they have not been used, however, does not mean that they are not suitable, nor available. Continuous FIDs, for example for HC measurement, are used in other sectors and there should be little technical difficulty in applying them to asbestos processes. There are currently no monitors which could be said to offer proven continuous monitoring of phenol and formaldehyde on these processes, although read-across from the mineral fibre sector, where the OPSIS system has been effectively employed, would suggest this is technically feasible. The same is true for ammonia where, although no direct experience of CEMs has been found, conventional NDIR and ion selective electrode based techniques should be capable of operating reasonably well.

#### 9.6 Continuous monitors for ceramic processes

Experience of CEMs on Fletton Brick processes in the UK has been very limited, being restricted to periodic trials. The main difficulty encountered was recurrent sample blockage problems in the sample lines and conditioning equipment. This could in part be due to the comparatively low level of abatement applied to emissions from these processes, creating harsh operating environments for CEM techniques. Providing filter blockages issues can be overcome, a range of proven techniques are available for continuously measuring combustion products of  $\text{SO}_2$ ,  $\text{NO}_x$ , CO and VOCs.

## 10. Glossary of terms

Acfm	-	Actual cubic feet per minute
BATNEEC	-	Best Available Techniques Not Entailing Excessive Cost
BOD	-	Biochemical Oxygen Demand
BIF	-	Boilers and Industrial Furnaces
BSI	-	British Standards Institution
CAA	-	Clear Air Act 1990 (USA)
CAAA	-	Clean Air Act 1990 Amendments (USA)
CARB	-	Californian Air Resources Board
CEM	-	Continuous Emission Monitor (relating to releases to atmosphere)
CEN	-	European Body for Standardisation
CFR	-	Code of Federal Regulations (USA)
CIGN	-	Chief Inspector's Guidance Note
CKD	-	Cement Kiln Dust
COD	-	Chemical Oxygen Demand
CRI	-	Chemical Release Inventory
EPA 1990	-	Environmental Protection Act 1990
EP	-	Electrostatic Precipitator
ESRC	-	Engineering and Science Research Council
EU	-	European Union
FID	-	Flame Ionisation Detector
FTIR	-	Fourier Transform Infra-Red
GFC	-	Gas Filter Correlation
HC	-	Hydrocarbon

HMIP	- Her Majesty's Inspectorate of Pollution
HSE	- Health and Safety Executive
IR	- Infra-Red
IPC	- Integrated Pollution Control
ISO	- International Standards Organisation
KVA	- Kilo Volt Amperes
LAAPC	- Local Authority Air Pollution Control
MACT	- Maximum Achievable Control Technology
MCERTS	Monitoring Certification Scheme
NDIR	- Non Dispersive Infra-Red
NDUV	- Non Dispersive Ultra-Violet
NESCAUM	- North-East States for Co-ordinated Air Use Management (USA)
NPL	- National Physics Laboratory
NSPS	- New Source Performance Standard (USA)
PCDD	- Polychlorinated Dibenzo-p-dioxin
PCDF	- Polychlorinated Dibenzofuran
PEM	Predictive Emission Monitor
PID	- Photo-ionisation Detector
PLC	- Programmable Logic Controller
PM	- Particulate Matter
RATA	- Relative Accuracy Test Audit
RCRA	- Resource Conservation and Recovery Act 1976 (USA)
SCR	- Selective Catalytic Reduction
SNCR	- Selective Non-Catalytic Reduction
SRM	- Standard Reference Method

TOC	-	Total Organic Carbon
THC	-	Total Hydrocarbon
TRI	-	Toxic Release Inventory
TSS	-	Total Suspended Solids
TUV	-	Technische Ueberwachungs Vereine Independent Bodies Recognised by the Licensing Authority to Conduct Calibration and Verification Checks, Germany
US EPA	-	United States of America Environmental Protection Agency
UV	-	Ultra-Violet
VDI	-	German Standards Organisation
WG	-	Working Group
BImSchV	-	Federal Air Quality Law (Germany) 1990

## 11. References

### Section 1

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## **APPENDIX I (A)**

# **CONTINUOUS MONITORS FOR EMISSIONS TO AIR: EQUIPMENT SUPPLIER**

**(ALL BUDGET COSTS ARE BASED ON 1997 DATA)**

**Appendix I(a)**  
**SUPPLIERS OF CONTINUOUS MONITORS FOR EMISSIONS TO AIR**

COMPANY	ADDRESS	TEL. NO.	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	TURNOVER (1997)	NO. OF EMPLOYEES
<b>Analytical Development</b>	Pindar Road Hoddesdon Herts EN11 0AQ	01992 469 638	01992 444 567	Manufacture, supply and installation of industrial and laboratory instrumentation	UK	£4 million	21
<b>BHA Group GmbH</b>	Filtrastrasse 5-7 59227 Ahlen- Vorhelm Germany	+49 2528 3100	+49 2528 30100	Replacement parts and services for air polluton control equiptment	USA	120,000K (USD)	800
<b>Bran + Lubbe (GB) Ltd</b>	Scaldwell Road Brxworth Northampton NN6 9UD	01604 880751	01604 882657				50
<b>Blackell Europlacer Ltd</b>	Gas Detection Division Blandford Heights Blandford Dorset DT11 7TE	012258 451 353	012258 480 183		UK		

COMPANY	ADDRESS	TEL. NO.	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	TURNOVER (1997)	NO. OF EMPLOYEES
<b>Codel International Ltd</b>	Station Building Station Road Bakewell Derbyshire DE45 1GRE	01629 814351	01629 814619	Design and manufacture of emission monitors	UK	£3.5 million	40
<b>Enviro Technology Service</b>	Environment House Dudbridge Road Stroud Glos. GL5 3EE	01453 751641	01453 757296	Supplier of a wide range of continuous monitoring systems	Denmark	£4 million	40
<b>Erwin Sick Optic Electronic</b>	39 Hedley Road St Albans Hertfordshire AL1 5BN	01727 831121	01727 856767	Supply, installation and maintainance of flue gas monitoring systems. UK agents for parent company	Germany	£8 million	120
<b>Fisher Rosemount</b>	Heath Place Bognor Regis West Sussex PO22 9SH	01243 863121	01243 876554		Germany		
<b>Foxboro GB</b>	Manor Royal Crawley West Sussex RH10 2SJ	01293 526000	01293 541312		Germany		

COMPANY	ADDRESS	TEL. NO	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	TURNOVER (1997)	NO. OF EMPLOYEES
<b>Hartmann + Braun</b>	Moulton Park Northampton NN3 6TF	01604 646311	01604 491027	Supply and installation of industrial instrumentation. UK agents for parent company	USA/ UK/ Germany	£8 million	55
<b>Hidden Analytical</b>	420 Europa Boulevard Warrington WA5 5UN	01925 445225	01925 416518		UK	£4 million	60
<b>PCME Ltd</b>	Stonehill Huntingdon Cambridgeshire PE18 6EL	01480 455611	01480 413500		UK		
<b>Perkin Elmer</b>	Chalfont Road Seer Green Beaconsfield Bucks HP9 2FX	01494 676161	01494 679279	World leader in the development, manufacture and distribution of analytical instrumentation and life science systems used in environmental technology	Germany	£58 million	570
<b>Procal Analytics</b>	5 Maxwell Road Woodston Peterborough	01700 232495			UK		

COMPANY	ADDRESS	TEL. NO.	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	TURNOVER (1997)	NO. OF EMPLOYEES
<b>Rotork Analysis Ltd</b>	Regal Way Faringdon Oxon SN7 7BX	01367 242660	01367 242700		UK		
<b>Seres</b>	Britwood House 178 Dukes Road Crowthorne Berkshire RG45 6DS	01344 762211	01344 761255	UK sales and service for Seres (France)	France	£10 million	115
<b>Severn Science</b>	4/5 Short Way Thornbury Industrial Estate Thornbury Bristol BS12 2UL	01454 414723	01454 417101		UK		
<b>Signal Instrument Company</b>	Standards House 12 Doman Road Camberley Surrey GU15 3DF	01276 682841/6	01276 691302	Manufacture, sales and service		£5 million	85

COMPANY	ADDRESS	TEL. NO.	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	TURNOVER (1997)	NO. OF EMPLOYEES
Skill Controls	Greenhey Place Selmersdale Lancashire WN8 9SB	01695 714600	01695 714622		UK/ Denmark	£2.5 million	65
Sigrist Instruments Co. Ltd Camberly	Standards House 1 Doman Road Surrey GU15 3DW	01223 860595	01223 861816	Agent for sales of process equipment	Swiss	£300k	5
Testo Ltd	3 Oriel Court Omega Park Alton Hampshire GU34 2QE	01420 544433	01420 544434	Electronic measurement instrumentation of physical values	Germany		14
TQ Environmental Wakefield	Flanshaw Way West Yorkshire WF2 9LP	01924 380700	01924 361700				



## **APPENDIX I(B)**

**CONTINUOUS MONITORS FOR EMISSIONS TO AIR :  
CROSS REFERENCE; COMPANIES : ANALYSER**

**APPENDIX I(b)**  
**CROSS REFERENCE; COMPANIES: ANALYSER SYSTEMS**

Company	SO <sub>2</sub>	NO <sub>x</sub>	PM	HCl	HF	CO <sub>2</sub>	CO	Velocity	O <sub>2</sub>	Water vapour	Organic carbon
Analytical Development	IR	IR		IR		IR	IR				
BHA Group GmbH			Optical								
Bran + Lubbe (GB) Ltd											
Blackell Europlacer Ltd	Electrochemical										
Codel Internatioal Ltd	NDIR	NDIR	Transmissometer, Turbo Electric Probe	NDIR		NDIR	NDIR	YES	NDIR	NDIR	
Enviro Technology Service	UV	Chemiluminescence									
Erwin Sick Optic Electronic	UV	UV		Optical							
Fisher Rosemount	IR	Chemiluminescence				IR					
Foxboro GB	IR	IR									
Hartmann + Braun	Remote sensing	var		IR	Electrochemical					Electrochemical	
Hiden Analytical									Mass spectrometry		
Monitor Labs	IR		Visible light			IR			FID catalytic cell		
PCME Ltd			Scintillation								
Perkin Elmer	IR	IR		IR		IR	IR				
Procal Analytics	IR	IR		IR	IR	IR					
Quantitech Ltd				Ion mobility spectrometer	Ion mobility spectrometer						
Rotork Analysis Ltd	IR	Chemiluminescence				IR	IR				
Seres	UV	Chemiluminescence		FID		IR GFC	IR GFC				

[illegible]

## **APPENDIX I(C)**

### **ANALYSER DETAILS FOR :**

**SULPHUR DIOXIDE  
NITROGEN OXIDES  
PARTICULATE MATTER  
CARBON MONOXIDE  
CARBON DIOXIDE  
HYDROGEN CHLORIDE  
OXYGEN  
WATER VAPOUR  
FLUE GAS FLOW  
MULTI-COMPONENT**

**APPENDIX I(c)**  
**SULPHUR DIOXIDE**

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Analytical Development Company Ltd	Series 7000 rotating filter type. Extractive	POA	0-200 ppm 0-100%		
Analytical Development Company Ltd	Series 7000 Single Beam. Extractive	£1-5k	0-1%		
Blackell Europlacer Ltd	Series 300 330 350 320 and gas Maestro. Extractive. In situ. Remote sensing.	<£1K	0-100 ppm	SIRA BASEEFA	
Codel International Ltd	3000. NDIR	POA			
Enviro Technology Service	Oxydan M1052. Extractive	£10-19.9k	0-3000 ppm		
Enviro Technology Service	Oxydan M1051. Extractive	£10-19.9k	0-3000 ppm		
Enviro Technology Service	Oxydan M1050. Extractive	£5-9.9k	0-3000 ppm		
Erwin Sick Optic Electronic Ltd	GM 31-1. In situ	£10-19k	0-3000	TUV	
Erwin Sick Optic Electronic Ltd	GM 31-2. In situ	>£20k	0-12,000	TUV	
Erwin Sick Optic Electronic Ltd	GM 31-3. In situ	>£20k	0-12,000	TUV	
Erwin Sick Optic Electronic Ltd	GM 31-5. In situ	>£20k	0-1,000 mg/Nm <sup>3</sup>	TUV	
Erwin Sick Optic Electronic Ltd	GM 31-6. In situ	>£20k	0-8,000	TUV	
Fisher Rosemount Ltd	NGA-2000. Extractive	POA	0-200 ppm		

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Foxoboro GB Ltd	UNOR 610/Multor 610. Extractive	£5-9.9k	85 ppm	TUV	
Hartmann + Braun	Extractive	£5-<20k	0-500 ppm	TUV/EPA	
Monitor Labs	SM8160. In situ	>£20k	0-5000 ppm v/v 0-100%	EPA	
Monitor Labs	ML 661. Extractive	>£20	0-3000 ppm	EPA	
Perkin Elmer Ltd	MCS 100 HW. Extractive	POA	0-500 mg/m <sup>3</sup>	EPA	
Perkin Elmer Ltd	MCS 100 CD. Extractive	POA	0.750 mg/m <sup>3</sup>	EPA	
Procal Analytics Ltd	PULSI 200, 400, 500. Extractive, In situ	£10-19.9k	0.1 ppm	EPA	
Rotork Analysis Ltd	EMIRAK. Extractive	>£20k	0-100, 500, 1000, 2500		
Seres UK Ltd	SF 2000 In situ. Remote sensing.	£5k+	1-10 ppm		
Seres UK Ltd	Multi-gas 2000. Extractive. In situ. Remote sensing	£8k+	0-5000		
Signal Instrument Company Ltd	Emirak. NDIR	£7500k	0-100%	None	
Testo Ltd	Testo 350. In situ.	£5-9K	0-500 ppm	TUV	
TQ Environmental Ltd	Stackmaster. Extractive	£9.9k	0-2,000 ppm		

**Appendix I (c)**  
**NITROGEN OXIDES**

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Analytical Development Company Ltd	Series 7000 rotating filter. Extractive	£1-9.9k	0-200 ppm		
Codel International Ltd	3000. Cross-duct NDIR				
Rotork Analysis	EMIRAK. Extractive	>£20	0-1000 ppm		
Testo Ltd	Testo 342. In situ	£1-5k	0-3000 ppm	TUV	
Perkin Elmer Ltd	MCS 100 HW. Extractive	POA	0-200 mg/m <sup>3</sup>	EPA	
Perkin Elmer Ltd	MCS 100 CD. Extractive	POA	0-200 mg/m <sup>3</sup>	EPA	
Erwin Sick Optic Electric Ltd	GM 31-2. In situ	>£20k	0-4,000	TUV	
Erwin Sick Optic Electric Ltd	GM 31-3. In situ	>£20k	0-12,000	TUV	
Erwin Sick Optic Electric Ltd	GM 31-4. In situ	>£20k	0-4,000	TUV	
Erwin Sick Optic Electric Ltd	GM 31-5. In situ	>£20k	0-1,200	TUV	
Erwin Sick Optic Electric Ltd	GM 31-6. In situ	>£20	0-2,500	TUV	
Erwin Sick Optic Electric Ltd	GM 31-7. In situ	8k	0-4,000	TUV	
Seres UK	NOX 2000. Extractive	£5-9.9k	0.1-10ppm	AFNOR	
Seres UK	Multigas 2000. Extractive	£5-9.9k	0-5000		
Signal Instrument	EMIRAK	7500k	0-100%	none	

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Company Ltd	HCLD				
TQ Environmental	Stackmaster. Extractive	£5-9.9k	0-1000 ppm		
Hartmann + Braun		£5-<20k	0-1000 ppm	TUV EPA	
Foxboro GB Ltd	UNOR 610/ Multor 610. Extractive	£5-9.9k	75ppb	TUV	
Enviro Technology Service Plc	Oxydan M1040 No1No. Extractive	£5-9.9k	0-300ppm		
Procal Analytics Ltd	PULSI200, 450, 500. Extractive. In situ	£10-19.9k	0-30ppm	EPA	
Fisher Rosemount Ltd	NGA 200 CLD. Extractive	POA	0-10,000 ppm		
Fisher Rosemount Ltd	NGA 2000 NDIR. Extractive	POA	0-500 ppm		



**APPENDIX I(c)**  
**NITROGEN OXIDES**

<b>COMPANY</b>	<b>MODEL and TYPE</b>	<b>BUDGET COSTS (1997)</b>	<b>RANGES 1) MAX 2) MIN 3) APP</b>	<b>APPROVALS/TESTING</b>	<b>REFERENCES</b>
Analytical Development Company Ltd	Series 7000 rotating filter. Extractive	£1-9.9k	0-200 ppm		
Codel International Ltd	3000. Cross-duct NDIR				
Rotork Analysis	EMIRAK. Extractive	>£20	0-1000 ppm		
Testo Ltd	Testo 342. In situ	£1-5k	0-3000 ppm	TUV	
Perkin Elmer Ltd	MCS 100 HW. Extractive	POA	0-200 mg/m <sup>3</sup>	EPA	
Perkin Elmer Ltd	MCS 100 CD. Extractive	POA	0-200 mg/m <sup>3</sup>	EPA	
Erwin Sick Optic Electric Ltd	GM 31-2. In situ	>£20k	0-4,000	TUV	
Erwin Sick Optic Electric Ltd	GM 31-3. In situ	>£20k	0-12,000	TUV	
Erwin Sick Optic Electric Ltd	GM 31-4. In situ	>£20k	0-4,000	TUV	
Erwin Sick Optic Electric Ltd	GM 31-5. In situ	>£20k	0-1,200	TUV	
Erwin Sick Optic Electric Ltd	GM 31-6. In situ	>£20	0-2,500	TUV	
Erwin Sick Optic Electric Ltd	GM 31-7. In situ	>£20	0-4,000	TUV	
Seres UK	NOX 2000. Extractive	£5-9.9k	0.1-10ppm	AFNOR	
Seres UK	Multigas 2000. Extractive	£5-9.9k	0-5000		

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Signal Instrument Company Ltd	EMIRAK. HCLD	£7500	0-100%	none	
TQ Environmental	Stackmaster. Extractive	£5-9.9k	0-1000 ppm		
Hartmann + Braun		£5-<20k	0-1000 ppm	TUV EPA	
Foxboro GB Ltd	UNOR 610/ Multor 610. Extractive	£5-9.9k	75ppb	TUV	
Enviro Technology Service Plc	Oxydan M1040 No1No. Extractive	£5-9.9k	0-300ppm		
Procal Analytics Ltd	PULSI200, 450, 500. Extractive. In situ	£10-19.9k	0-30ppm	EPA	
Fisher Rosemount Ltd	NGA 200 CLD. Extractive	POA	0-10,000 ppm		
Fisher Rosemount Ltd	NGA 2000 NDIR. Extractive	POA	0-500 ppm		

**APPENDIX I(c)  
PARTICULATE MATTER**

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
PCME Ltd	SC-600. In situ	£1-5k	0-100%		
BHA Group	CPM 2001. Optical LED	DEM 14,000	0-2000 mg/m <sup>3</sup>	13. BlmSchv and TA Luft	
BHA Group	CPM 3000. optical modulated LED	DEM12,000	0-3000mg/m <sup>3</sup>	no	
BHA Group	CPM 1001/5000. Optical modulated LED or laser	DEM 19,000	0-3000 mg/m <sup>3</sup>	13 BlmSch V and TA Luft	
Sick AG	OMD41. Visible transmission opacity extinction	£8.3k	0-100%0-100%0-2	TÜV	
Sick AG	RM210. IR scattered light			TÜV	
Sick AG (Particulates in wet gases)	Heated bypass with RM210. IRscattered light			TÜV	
Sigrist	KTN R. Conductive	£35-50k	0.1mg	TUV	

**APPENDIX I(c)**  
**CARBON MONOXIDE**

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Analytical Development Company	Series 7000 rotating filter. Extractive	POA	0-30 ppm		
Codel International Ltd	3000. Cross-duct NDIR				
Rotork Analysis Ltd	EMIRAK. Extractive	>£20k	0-500 ppm		
Signal Instrument Company Limited	EMIRAK. NDIR	£7500	0-100	none	
Testo Ltd	Testo 342. In situ	£1-5k	0-400ppm	TUV	
Testo Ltd	Testo 350. In situ	£1-9.9k	0-4000 ppm		
Perkin Elmer Ltd	MCS 100 HW. Extractive	POA	0-100 mg/m <sup>3</sup>	EPA	
Perkin Elmer Ltd	MCS 100 CD. Extractive	POA	0-75 mg/m <sup>3</sup>	EPA	
Erwin Sick Optic Electric Ltd	GM910. In situ	£10-19k	0-5000 mg/m <sup>3</sup>	TUV	
Skill Controls Ltd	7030a. Extractive	£1-5k	0-20%		
TQ Environmental	Stackmaster. Extractive	£5-10k	0-10,000 ppm		
Teledyne Analytical Instruments Ltd	9950. Extractive	£5-10k	0-2000 ppm		
Hartmann + Braun	Extractive	£5->20k	0-500 ppm	TUV EPA	
Foxboro	UNOR 610 MULTOR 610. Extractive	£5-9.9k	20 ppm	TUV	

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Monitor Labs	ML 9820. Extractive	£5-9.9k	0-3000ppm	EPA	
Monitor Labs	ML 661. Extractive	>£20k	0.5ppm-0-2%	EPA	
Monitor Labs	CEMcat. Extractive	>£20k	0-2000 ppm	EPA	
Fisher Rosemount	NGA 2000 NDIR. Extractive	POA	0-50ppm		

**APPENDIX I(c)  
CARBON DIOXIDE**

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Analytical Development Company Ltd	Series 7000 rotating filter. Extractive	£1-9.9k	0-10 vpm		
Codel International Ltd	3000. Cross-duct NDIR				
Rotork Analysis Ltd	EMIRAK. Extractive	>£20k	0-20%		
Testo Ltd	Testo 342. In situ	£1-5k		TUV	
Testo Ltd	Testo 350 In situ	£1-9.9k		TUV	
Perkin Elmer Ltd	MCS 100 HW. Extractive	POA	0-25 vol	EPA	
Perkin Elmer Ltd	MCS 100 CD. Extractive	POA	0-20 vol%	EPA	
Skill Controls Ltd	70380 A. Extractive	£1-5k	0-20%		
TQ Environmental Ltd	Stackmaster. Extractive	£5-9.9k	0-10%		
Signal Instrument Company Ltd	Emirak.	£7500	0-15%	none	
Monitor Labs	ML9820. Extractive	£5-9.9k	0-3000 ppm v/v	EPA CE	
Monitor Labs	ML 661. Extractive	>£20k	0-20%	EPA	
Procal Analytics	Pulsi 200, 400, 500.	£10-19.9k	0-20ppm	EPA M-Certs	

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
	Extractive. In situ				
Fisher Rosemount Ltd	NGA 2000 NDIR. Extractive	POA	0-10 ppm		

**APPENDIX I(c)**  
**HYDROGEN CHLORIDE**

COMPANY	MODEL & TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Analytical Development Company Ltd	Series 7000. Extractive	POA	0-200 vpm		
Codel International Ltd	3000.				
Hartmann + Braun	Extractive	£5->20k	0-20%	TUV EPA FM	
Perkin Elmer	MCS 100 HW. Extractive	POA	0-15 mg/m <sup>3</sup>	EPA	
Procal Analytics Ltd	Pulsi 200, 400, 500. Extractive. In situ	£10-20k	0-50ppm	EPA	
Quantitech Ltd	HCL. Extractive	>£20k	0-5 ppm		
Severn Science	HCL. Extractive	£10-19.9k	0.5-1000 mg/m <sup>3</sup>	Test programme with CRE and AEAT	22



**APPENDIX I(c)**  
**HYDROGEN FLUORIDE**

COMPANY	MODEL & TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Hartmann + Braun	Extractive	£5->20k	0-5ppm	TUV EPA	
Procal Analytics	Oulsi 200, 400, 500. Extractive. In situ	£10-20k	0.5ppm	EPA	
Quantitech Ltd	Stackmaster. Extractive	>£20k	0-2 ppm		
Severn Science	HF. Extractive	£10-20k	0.5-1000 mg/m <sup>3</sup>	ETIS programme with Dti	

**APPENDIX I(c)**  
**OXYGEN**

<b>COMPANY</b>	<b>MODEL and TYPE</b>	<b>BUDGET COSTS (1997)</b>	<b>RANGES 1) MAX 2) MIN 3) APP</b>	<b>APPROVALS/TESTING</b>	<b>REFERENCES</b>
Foxboro GB	UNOR 610 MULTOR 610. Extractive	£5-9.9k	0.1	TUV	
Hartmann + Braun	Extractive	£5->20k	0.0025	TUV EPA	
Hitech Instruments Ltd	2125. Extractive	£1-5k	0-100%		
Monitor Labs	ML 661. Extractive	>£20k	0-25%	EPA	
Monitor Labs	CEMat. Extractive	>£20k	0.5%-21%	EPA	
Perkin Elmer	HELOX. Extractive	POA	0-25VOL%	EPA	
Rotork Analysis Ltd	EMIRAK. Extractive	>£20k	0-25%		
Signal Instrument Company Ltd	EMIRAK. NDIR	£7500		none	
Skill Controls	OC2010. In situ	£1-5k	0-95%		
Teledyne Analytical Instruments	9950. Extractive	£5-9.9k	0-25%		

**APPENDIX I(c)**  
**WATER VAPOUR**

<b>COMPANY</b>	<b>MODEL and TYPE</b>	<b>BUDGET COSTS (1997)</b>	<b>RANGES 1) MAX 2) MIN 3) APP</b>	<b>APPROVALS/TESTING</b>	<b>REFERENCES</b>
Analytical Development Company Ltd	Series 7000 rotating filter. Extractive	£1-9.9k	0-500 vpm<0.2% FSD		
Codel International Ltd	3000.				
Hatmann + Braun	Extractive	£5<20k	0-40%	TUV EPA	
Hidden Analytical Lrd	DSMS. In Situ	£10-19.9k	100%-500 ppb	CE	
Perkin Elmer	MCS 100 HW. Extractive	POA	0-40% vol	EPA	
Signal Instruments Company Ltd	Emirak. ZiO2 Oxygen	£7500	0-15%	none	

**APPENDIX I(c)**  
**FLUE GAS FLOW**

COMPANY	MODEL and TYPE	BUDGET/COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Codel International Ltd	502				
Signal Instruments Ltd	Emirak				
Testo Ltd	Testo 350. In situ	£1-10k	1-30m/s		

**APPENDIX I(c)**  
**MULTI-COMPONENT**

COMPANY	MODEL & TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Codel International Ltd	3000.				
Procal Analytics Ltd	Pulsi 200, 400, 500. Extractive. In situ	£10-20k	Pollutant dependent	EPA	

## **APPENDIX II(A)**

### **CONTINUOUS MONITORS FOR RELEASES TO WATER: EQUIPMENT SUPPLIER DETAILS**

**Appendix II(a)**  
**SUPPLIERS OF CONTINUOUS MONITORS FOR RELEASES TO WATER**

COMPANY	ADDRESS	TEL. NO.	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
ABB Kent Taylor Ltd (ABBKT)	Oldens Lane Stonehouse Glos GL10 3TA	01453 826661	01453 826358	Instrumentation manufacturer		800+	£40 million
Applikon Analyzers UK	3 Eelmoor Road Farnborough Business Centre Farnborough GU14 7QN	01252 372303	01252 372628	Supply, installation and service of on-line and laboratory analysers		7	£600k
LTH Electronics	Chaul End Lane Luton Beds LU4 8EZ	01582 593693	01582 598036				
Pollution and Process Monitoring Ltd	Bourne Enterprise Centre Borough Green Sevenoaks Kent TN15 8DG	01732 882044	01732 780190	Water monitoring		16	2 million
Process Measurement and Analysis Ltd	Analysis House 6 Kelvin Park Dock Road Birkenhead Merseyside L41 1LT	0151 6498477	0151 6477211	Analytical instrumentation supplies		13	
Sigrist Photometer	1 Pemm Brooke Avenue Water Beach Cambridge CB5 9QR	01223 860595	01223 861819				

COMPANY	ADDRESS	TEL. NO.	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
Steptech Instruments Ltd	Maxwell Road Stevenage SG1 2EW	01438 312425	01438 312111	On-line water and air quality monitoring contract with R&D		10	£500k



**APPENDIX II(B)**

**CONTINUOUS MONITORS FOR RELEASES TO WATER:  
CROSS REFERENCE; COMPANIES : ANALYSER**

**APPENDIX II(b)**  
**CROSS-REFERENCE; COMPANIES: ANALYSER SYSTEMS**

COMPANY	FLOW MEASUREMENT	EFFLUENT SAMPLING	TEMPERATURE	TOTAL ORGANIC CARBON	SUSPENDED SOLIDS	PH
ABB Kent Taylor Ltd (ABBKT)	masmaste				y	y
Applikon Analyzers UK						
LTH Electronics						y
Pollution and Process Monitoring Ltd	y		y	y		y
Process Measurement and Analysis Ltd	Mag flow			uv	y	y
Sigrist Photometer				tragg	y	
Steptech Instruments Ltd				flourescence	90° light scatter	

## **APPENDIX II(C)**

**ANALYSER DETAILS FOR :**

**FLOW MEASUREMENT  
TEMPERATURE  
TOTAL ORGANIC CARBON  
SUSPENDED SOLIDS  
pH**

**APPENDIX II(c)  
FLOW MEASUREMENT**

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Process Measurement and Analysis	Mag flow	Size-dependent			
Pollution and Process Monitoring Ltd					
ABB Kent Taylor	Masmaste	150mm-£1.5k			

**APPENDIX II(c)**  
**TEMPERATURE**

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Pollution and Process Monitoring Ltd		£1k			

**APPENDIX II(c)**  
**TOTAL ORGANIC CARBON**

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Steptech Instruments	Fluorescence	£10k	0-100mg/l		
Sigist	KFLJ Tragg monitor	£15k	0-500mg/l (ppm)		
Process Measurement and Analysis	UV phot	13k	0-100ppm		
Pollution and Process Monitoring		3.7k			

**APPENDIX II(c)  
SUSPENDED SOLIDS**

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX/ 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Steptech	90° Light Scatter	£2k	0-1000NTS		
Sigrist	CT65	£10-12k	0-1 FTU		
Sigrist	KTS25	£10-12k	y		
Process Measurement and Analysis Ltd	Cosmos	£4k	0-14g/l		
Pollution and Process Monitoring Ltd		£3k			
ABB Kent Taylor	4670	£1.8k	0-2 ntu to 0-1000ftu		

# APPENDIX II(c)

pH

COMPANY	MODEL and TYPE	BUDGET COSTS (1997)	RANGES 1) MAX 2) MIN 3) APP	APPROVALS/TESTING	REFERENCES
Process Measurement and Analysis Ltd	Liquisys	£1-2k	0-14		
Pollution and Process Monitoring Ltd		£2.1K			
LTH	TPD33	£251	0-1pH		
LTH	TPD33	£342	0-1pH		
LTH	TPD23	£416	0-1pH		
LTH	TPD231	£522	0-1pH		
LTH	TPD33	£251	0-1pH		
ABB Kent Taylor	4630	£0.8k	0-14		



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