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HEALTH & SAFETY LABORATORY

Evaluation of portable flue gas analysers for monitoring carbon dioxide in ambient workplace air

HSL/2006/42

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ACKNOWLEDGEMENTS

We are grateful to the instrument manufacturer for loan of the instruments.

CONTENTS

EXECUTIVE SUMMARY

Three types of flue gas analysers (two that calculate carbon dioxide concentration from oxygen concentration and one that measures carbon dioxide concentration) were tested in the laboratory by subjecting them to various carbon dioxide and oxygen mixtures diluted by air, generated from pure gas supplies. Initial carbon dioxide and oxygen test gas mixtures were equivalent to a standard flue gas mixture (as specified in BS EN 50379-1 "Specification for portable electrical apparatus designed to measure combustion flue gas parameters of heating appliances").

An accuracy limit of ± 0.2% v/v was adopted, as specified in BS EN 50379 for flue gas analysers which measure carbon dioxide.

Objectives

To evaluate the accuracy of flue gas analysers which calculate carbon dioxide (CO_2) concentration from oxygen (O_2) concentration for the measurement of *workplace* ambient carbon dioxide levels, particularly around and below the 8-hr WEL of 0.5% (5000 ppm) v/v. Note that this is not the same as indoor air quality measurements.

Main Findings

The instruments were evaluated using standard test gases and not actual flue gas. These results are therefore derived from best case scenarios.

Analyser 1 and Analyser 2, which both calculate carbon dioxide from oxygen, could be used above 0.2% and up to several % carbon dioxide to give a general indication of carbon dioxide levels, provided the only source of carbon dioxide was from a flue gas for which the gas analyser was calibrated.

Both Analyser 1 and Analyser 2 exceeded the ± 0.2% v/v tolerance when measuring carbon dioxide-air mixtures generated from pure carbon dioxide up to concentrations of approximately 2%, ie from a source other than air-diluted flue gas. Note that the dilution of pure carbon dioxide by air results in the greatest degree of inaccuracy for a flue gas analyser which calculates carbon dioxide concentration from the oxygen level based on the combustion of fuel, and which is not applicable for this source of carbon dioxide.

Analyser 3, which measures carbon dioxide, could be used above 0.15% and up to several % carbon dioxide for monitoring carbon dioxide levels from any source.

Analyser 3 was within the ± 0.2% v/v tolerance when measuring carbon dioxide-air mixtures generated from pure carbon dioxide up to concentrations of approximately 2%.

Recommendations

Generally, and notwithstanding the acceptable performance (in the laboratory) of all the analysers tested in *air-diluted, simulated flue gas,* it is preferable to measure carbon dioxide concentrations around and below 0.5% rather than rely on an analyser which calculates carbon dioxide from the oxygen concentration based on a specific combustion reaction. This is because other sources of carbon dioxide may be present which do not arise from a leak/spillage of flue gas or are derived from other combustion reactions for which the flue gas analyser is not calibrated. This would adversely affect the accuracy of the calculated carbon dioxide analyser, which assumes that the carbon dioxide arises solely from oxidation of fuel (eg natural gas) with oxygen from air in a gas appliance.

Flue gas analysers which calculate carbon dioxide concentration are only suitable for measuring ambient carbon dioxide generated from combustion of fuel for which they are calibrated, over the concentration range from several % down to approximately 0.2% carbon dioxide. The lower level may need to be increased because the tests were carried out using cylinder (bottled) gases and not actual flue gas.

Flue gas analysers which measure carbon dioxide concentration are suitable for measuring ambient carbon dioxide, from any source from several % down to approximately 0.2% carbon dioxide.

Ideally, a detection limit of around 10% of the 8-hr WEL (0.5% carbon dioxide) is required for *workplace* air measurements, ie 500 ppm.

When a carbon dioxide measuring analyser is used for workplace air monitoring, the accuracy should be appropriate for measuring around and below the WEL, ie around ±500 ppm. It should be calibrated at an appropriate concentration, eg 0.5% or below, in order to help attain this accuracy; and maintained, checked and recalibrated at regular intervals, all in accordance with the manufacturer's instructions.

1 INTRODUCTION

Carbon dioxide is a very widely occurring gas. It is (a) a product of combustion of carbon-based fuels, respiration in animals and plants, and bacterial decomposition; and (b) commonly used as part of a process, eg brewing, chilling. Carbon dioxide is a colourless, odourless, non-combustible, slightly acidic gas that constitutes about 0.03% v/v of the atmosphere by volume. Exhaled human breath contains about 3.8% v/v and sometimes as much as 5.6% v/v of the gas. It is a toxic gas in addition to being an asphyxiant, and therefore it is incorrect to to consider it to be physiologically inert. A 2% concentration of carbon dioxide is sufficient to cause headache and nausea on mild exertion (Schulte, 1984); the displaced oxygen concentration would, however, still be 20.5% which normally has no effect. Further increases in carbon dioxide concentration lead to a weakly narcotic effect at 3%, giving rise to reduced acuity of hearing and increased blood pressure and pulse. Shortness of breath may be caused by concentrations in excess of 5%. Exposure at 10% causes visual disturbances, tremors, perspiration and unconsciousness, and exposure at 25% results in depression, convulsions, coma and death (Arena and Drew, 1986).

In the UK, the Workplace Exposure Limit (WEL) for carbon dioxide is 0.5% (5000 ppm) for the 8-hr Long Term Exposure Limit and 1.5% (15000 ppm) for the 15-min Short Term Exposure Limit, STEL), as listed in HSE Guidance EH40/2005 (HSE, 2005).

While carbon dioxide is not as toxic as some other fossil fuel combustion products such as carbon monoxide, oxides of nitrogen and aldehydes, it is produced in relatively larger quantities. Further information on these products, particularly relating to gas appliances, can be found in the draft British Standard BS 7967-1 (see refs.), to be circulated for public comment in late 2005. If the combustion products are not extracted effectively from, for example, heating and cooking appliances, then high exposure could result in ill-health effects, including those from carbon dioxide. In addition, the ratio of carbon monoxide to carbon dioxide can provide information on the performance of the appliance; again further information, relating to gas appliances, can be found in the draft British Standard BS 7967-3 (see refs).

The concentration of carbon dioxide (and carbon monoxide) can be measured by various types of instrument including electronic portable flue gas analysers. Such instruments can be useful in reducing risk of exposure to workers and the general public, after ensuring that proper installation and regular maintenance of the appliance(s) are carried out.

Flue gas analysers which calculate carbon dioxide from the oxygen concentration are well proven for determinations in the flue. However, with the potential expansion of the use of such analysers into ambient air monitoring (for both workplace and indoor air quality), the limitations of such an instrument for ambient measurements of carbon dioxide have not been widely understood. This report evaluates, in the laboratory, flue gas analysers which calculate carbon dioxide from oxygen deficiency; and it provides guidance for users in the *workplace*. It should be noted however that instrument manufacturers do not generally recommend such instruments for use as ambient air analysers. Suitable analysers, i.e. instruments which measure carbon dioxide concentrations around and below the WELs and at lower levels for indoor air quality, are now, however, becoming available. These are available as stand-alone monitors or as an integral part of a flue gas analyser.

2 FLUE GAS ANALYSERS

Flue gas analysers (electronic portable combustion gas analysers) are multigas instruments commonly used in the gas industry and domestic premises (eg by British Gas Services and CORGI engineers), and other industries where fuels such as gas or oil are combusted eg food and catering industry. They are primarily employed to check *in situ* the performance of gas appliances, eg cooker, heater etc. Typically, carbon monoxide and oxygen concentrations are measured, then from the oxygen concentration the carbon dioxide concentration is calculated. See Appendix 7.1 for details on how the carbon dioxide concentration is derived using the fuel factor to account for use of the analyser in different fuels. Other gases can also be measured eg nitric oxide (also known as nitrogen monoxide NO).

The sensors used for measurements are typically electrochemical sensors for oxygen (for the calculation of carbon dioxide concentration) and carbon monoxide, and infrared sensors (for the measurement of carbon dioxide). Also, there have been new developments in electrochemical sensors for carbon dioxide.

Electronic portable combustion gas analysers are subject to a performance standard (BS 7927, see refs.) which outlines the tests and requirements for determining the accuracy and other parameters of the analyser. This British standard will be superseded in June 2007 by European standards BS EN 50379-1 and 50379-3 (see refs.).

The original design of flue gas analysers was for analysis of the combustion products, typically in flues. However, they are increasingly being used to monitor carbon monoxide and, to a lesser extent, carbon dioxide in the ambient air arising from leakage/spillage from gas appliances, and possibly other sources. Standards (BS 7967-1, BS 7967-2, BS 7967-3 and BS 7967-4, see refs.), currently in draft form, have therefore been written to provide guidance for the use of electronic portable flue gas analysers for measurement of combustion gases (mainly carbon monoxide but also carbon dioxide) in dwellings and the combustion performance of gas-fired appliances.

The requirements for accuracy of these three standards are summarised in Table 2.1.

Table 2.1 Comparison of measurement requirements for analysers fitted with a carbon dioxide sensor

Parameter	BS EN 50379	BS 7927 Incl. Amend 1 :1999	Draft BS 7967 (dwellings)
Range	0-20% v/v	0-20%	Analyser should conform to BS7967:1998 incl. Amend - ment 1:1999
Test gas range	12.0%, balance nitrogen 9.0%, balance nitrogen 2.5%, balance nitrogen	5 ± 0.2% v/v, balance air 10 ± 0.2% v/v, balance air	
Display resolution	0.1%	0.1%	
Accuracy	± 0.2% v/v	± 5% relative	
Detection limit	0.2%	Not specified	
Response time (t90)	50 s	240 s	

The above standards are of immediate relevance for electronic portable flue gas analysers but it should be noted that the use of toxic gas detectors in the workplace is also covered by the standards BS EN 45544-1, BS EN 45544-2, BS EN 45544-3, and the corresponding guidance for use of these instruments in BS EN 45544-4 (see refs.). The performance criteria for such instruments are specified quite differently and are more complex than the above standards. Brief details are given in Appendix 7.2. All the standards referred to above are minimum performance standards.

An accuracy limit of ± 0.2% v/v was adopted in the following tests, as specified in BS EN 50379 for flue gas analysers which measure carbon dioxide. This concentration is 40% of the 8-hr WEL (0.5 %), ie a high limit. However, in the workplace toxic gas detector standard (BS EN 45544-1, see Appendix 7.2), an overall uncertainty (OU, a defined accuracy parameter) of ±30% (relative) is required for monitors measuring carbon dioxide concentrations between 0.25 - 5.0%. This equates to an OU of ± 0.15% at the 8-hr WEL of 0.5%. An overall uncertainty of ±50% (relative) is required for monitors measuring 0.05 - 0.25% carbon dioxide (ie an OU of ±0.03% and ±0.13% at the extremes). The accuracy/overall uncertainty of the two standards, while, not entirely reconcilable with each other, are of a similar order at the 8-hr WEL.

3 EXPERIMENTAL

Three flue gas analysers (denoted Analyser 1, 2 and 3) were tested by exposing them to standard test gases comprising mixtures of (a) carbon dioxide, oxygen and nitrogen diluted with air, to simulate flue gas emissions; and pure carbon dioxide diluted with air, to simulate other types of leak involving carbon dioxide, eg pure carbon dioxide from gas cylinders. The flue gas test mixtures used were based on those specified in BS EN 50379-1:2002 (see refs.) for test gas mixtures for oxygen and/or carbon dioxide sensors in portable flue gas analysers, ie nominally 5% oxygen, 9.0% carbon dioxide, balance nitrogen; and nominally 16.5% oxygen and 2.5% carbon dioxide, balance nitrogen.

The responses from the flue gas analysers were compared with the responses from reference analysers. The reference analysers used were:

- For carbon dioxide: an infra-red laboratory analyser (ADC Ltd), calibrated at zero using laboratory supplied oxygen-free nitrogen, and at span by a cylinder of standard test gas mixture of 5.74% carbon dioxide and 1260 ppm CO (BOC "Alpha Standard").
- For oxygen: a paramagnetic oxygen meter (Servomex Ltd), calibrated at zero using laboratory supplied oxygen-free nitrogen, and at span using ambient (laboratory) air (20.9%).

Pure oxygen and pure nitrogen from the laboratory supply and pure carbon dioxide (BOC cylinder size VK with vapour withdrawal) were mixed together using mass flow controllers (MFCs) and the output monitored on the ADC and Servomex paramagnetic oxygen meter. The MFCs were adjusted until a concentration of 8.98% carbon dioxide, 5.1% oxygen in nitrogen was obtained.

This mixture was then diluted with clean dry air via two further MFCs at various flow rates, and fed into a series of T-pieces for monitoring the test gas concentration with the ADC and Servomex, sampling the test gas by the analysers, and ensuring that there was an excess of test gas, see Fig. 3.1.

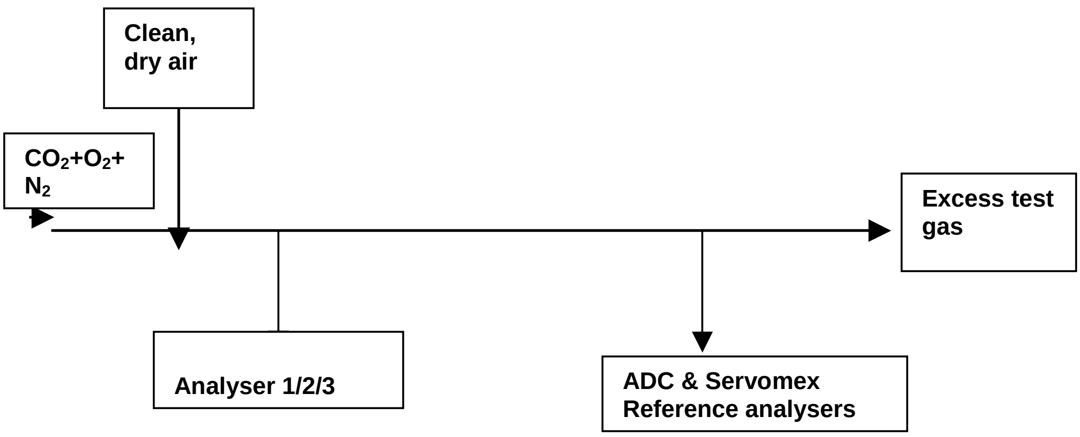

Fig. 3.1 Gas mixing and flow system

4 RESULTS

4.1 FLUE GAS ANALYSER 1

4.1.1 Nitrogen response to determine Fuel Factor F

The analyser was exposed to pure nitrogen, ie containing 0% oxygen, which then generates the maximum value of the carbon dioxide concentration which is equivalent to F (see Appendix 6.1). The analyser was set to two fuels, natural gas (mainly methane) and liquid petroleum gas (mainly propane) and the carbon dioxide reading was noted. The results are shown in Table 4.1.

Table 4.1 Experimentally determined fuel factors for Analyser 1

Fuel Setting	Response (% CO_2)
Natural gas	11.4
LPG	13.7

The value of the fuel factor for natural gas was then used to normalise the readings from the analyser when exposed to various carbon dioxide concentrations. The mixture of 8.98% carbon dioxide and 5.1% oxygen when diluted with air used to test the analyser is equivalent to an F value of 11.9, as derived from formula F1 in Appendix 2 (see § 7.1). Consequently, the readings from Analyser 1 were multiplied by 11.9/11.4 (1.044) in order to adjust for the differing F values of the test gas mixture and the analyser.

4.1.2 Response to carbon dioxide concentrations from simulated flue gas

The response of the analyser to a series of low concentrations, comprising some below the 0.5% 8-hr WEL are shown in Table 4.2.

Table 4.2 Response of Analyser 1 to low flue gas carbon dioxide concentrations

Actual % CO2	Analyser 1 % CO2	Normalised reading % CO2
0	0	0
0.09	0	0
0.15	0.1	0.1
0.23	0.2	0.2
0.26	0.2	0.2
0.33	0.3	0.3
0.46	0.4	0.4
0.52	0.4	0.4
0.57	0.5	0.5
0.63	0.6	0.6
0.72	0.6	0.6
0.82	0.7	0.7
0.9	0.8	0.8
1.14	1	1
1.4	1.2	1.3
1.74	1.6	1.7

If an accuracy of ± 0.2% v/v is taken, as specified in BS EN 50379 for flue gas analysers which measure carbon dioxide (See Table 2.1), then it can be seen that the analyser is within the specification at all concentrations in the table. Typical deviations are less than 0.1%.

The results in Table 4.2 are plotted in Fig. 4.1.

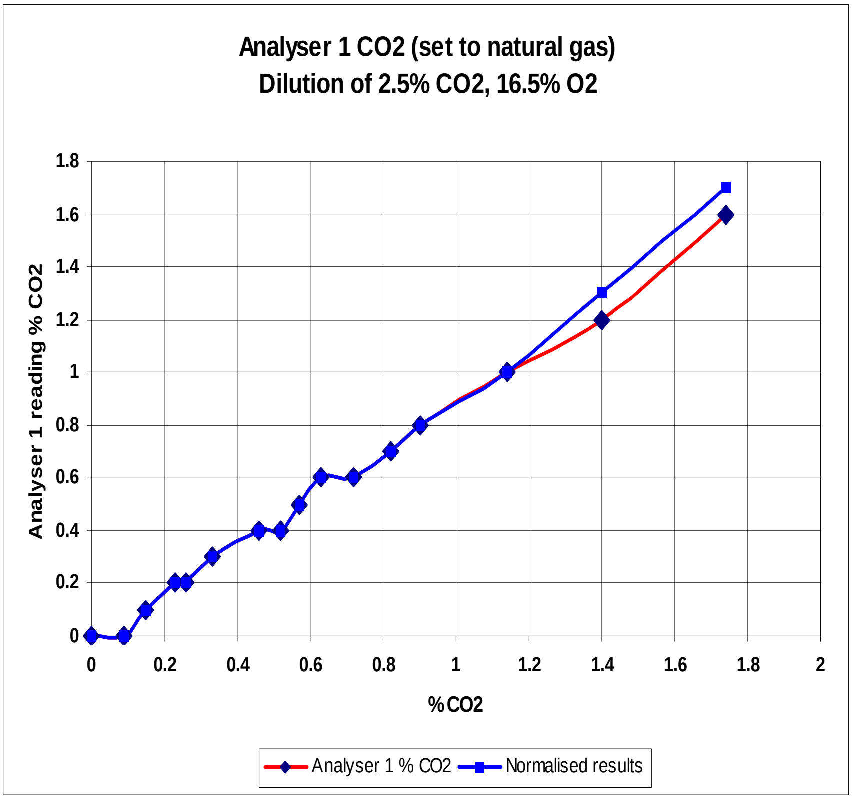

Fig. 4.1 Response of Analyser 1 to low flue gas carbon dioxide concentrations. Note: blue and red datapoints overlap between 0 and 1.14% CO_2 (see Table 4.2).

The response of the analyser to a series of higher flue gas concentrations, including those well above the 0.5% WEL and similar to those found in flues, are shown in Table 4.3.

These results are plotted in Fig. 4.2.

Table 4.3 Response of Analyser 1 to high flue gas carbon dioxide concentrations

Actual % CO2	Analyser 1 % CO2	Normalised reading % CO2
0	0	0.0
0.48	0.4	0.4
0.53	0.4	0.4
0.6	0.5	0.5
0.79	0.7	0.7
0.92	0.8	0.8
1.16	1	1.0
1.3	1.2	1.3
1.56	1.1	1.1
2.07	1.6	1.7
2.71	2.4	2.5
3.69	3.4	3.5
5.3	4.7	4.9

Again , adopting the limit of accuracy as ± 0.2% v/v, the analyser performs within this limit for most concentrations over the range tested but with a few exceedences where the maximum deviation is 0.4%.

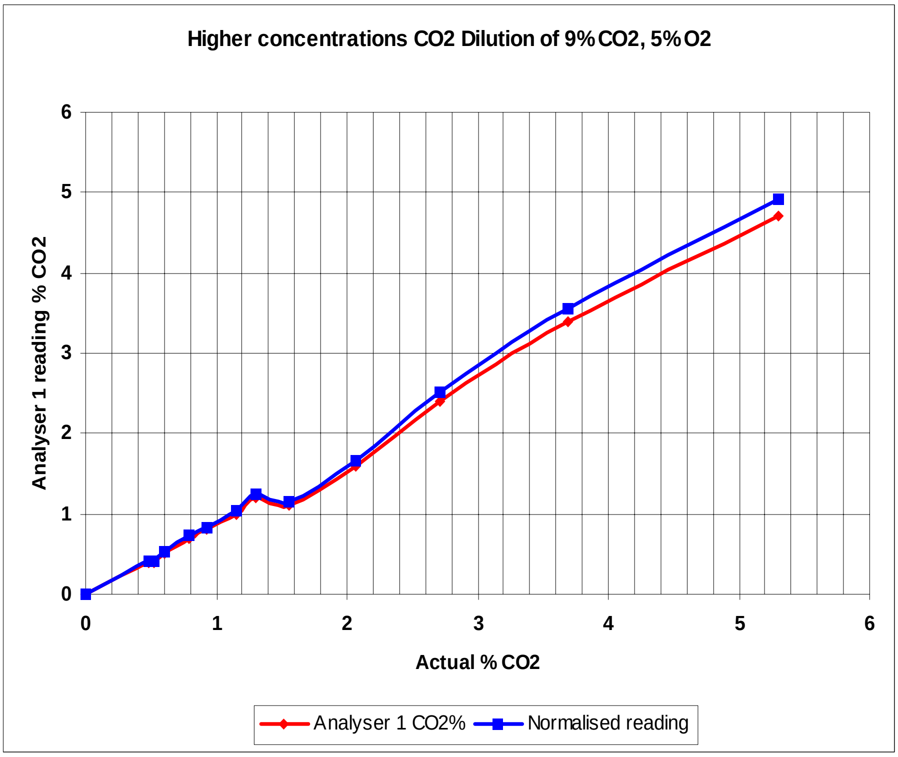

Fig 4.2 Response of Analyser 1 to high flue gas carbon dioxide concentrations

4.1.3 Response to diluted pure carbon dioxide concentrations

The response of the analyser to a source of carbon dioxide other than flue gas exhaust was measured by diluting pure carbon dioxide gas with air. The results are shown in Table 4.4.

Table 4.4 Response of Analyser 1 to air-diluted pure carbon dioxide concentrations

Actual % CO2	Analyser 1 % CO2	Servomex % O2
0.0	0.00	21.0
1.02	0.00	20.8
1.42	0.00	20.7
1.79	0.1	20.7

Analyser 1 gives highly inaccurate readings up to 1.8% carbon dioxide.

4.2 FLUE GAS ANALYSERS 2 & 3

4.2.1 General

Two more flue gas analysers were tested in a similar manner to Analyser 1. Analyser 2 measures oxygen and calculates carbon dioxide, while Analyser 3 measures carbon dioxide and calculates oxygen. Both instruments were set to Natural Gas as the fuel.

4.2.2 Nitrogen response to determine Fuel Factor F

Analyser 2 was exposed to pure nitrogen, ie containing 0% oxygen, which then generates the maximum value of the carbon dioxide concentration which is equivalent to F (see Appendix 6.1). The carbon dioxide reading was then noted. The results are shown in Table 4.5.

Table 4.5 Maximum carbon dioxide reading for Analyser 2

ADC $\%CO_2$	Servomex $\%O_2$	ANALYSER 2	
		$\%CO_2$	$\%O_2$
0.0	0.0	11.9	0.0

The value of F derived for Analyser 2 is approximately equivalent to that for the flue gas mixture (11.9), therefore the results from Analyser 2 do not require normalising.

4.2.3 Response to carbon dioxide concentrations from simulated flue gas

A low flow rate of 2.5% carbon dioxide and 16.5% oxygen was generated from three MFCs in order to dilute the mixture sufficiently enough to achieve a carbon dioxide concentration of around 0.1%. The results are shown in Table 4.6 and plotted in Fig. 4.3.

Table 4.6 Response of Analyser 2 and Analyser 3 to low concentrations of flue gas carbon dioxide

Actual %CO2	Analyser 2	Analyser 3
	%CO2 (Calculated)	%CO2 (Measured)
0.47	0.5	0.5
0.36	0.3	0.3
0.28	0.2	0.2
0.17	0.1	0.1
0.16	0.1	0.1
0.13	- -	0
0.11	- -	0

It can be seen that the analyser which calculates carbon dioxide and the one which measures it have similar accuracy and are both within the BS EN 50379 limit of accuracy of ± 0.2% v/v down to their detection limits of around 0.15% carbon dioxide.

Analyser 2 had a F value equivalent to the flue gas mixture (11.9); if, however, the flue gas mixture was of a different CO_2/O_2 ratio, eg equivalent to an F value of 11.4, say, then this would decrease the values in Table 4.6 by 0.1% carbon dioxide at the maximum. Larger variations in flue gas mixture ratios would induce larger errors although typically F does not vary much outside the above range.

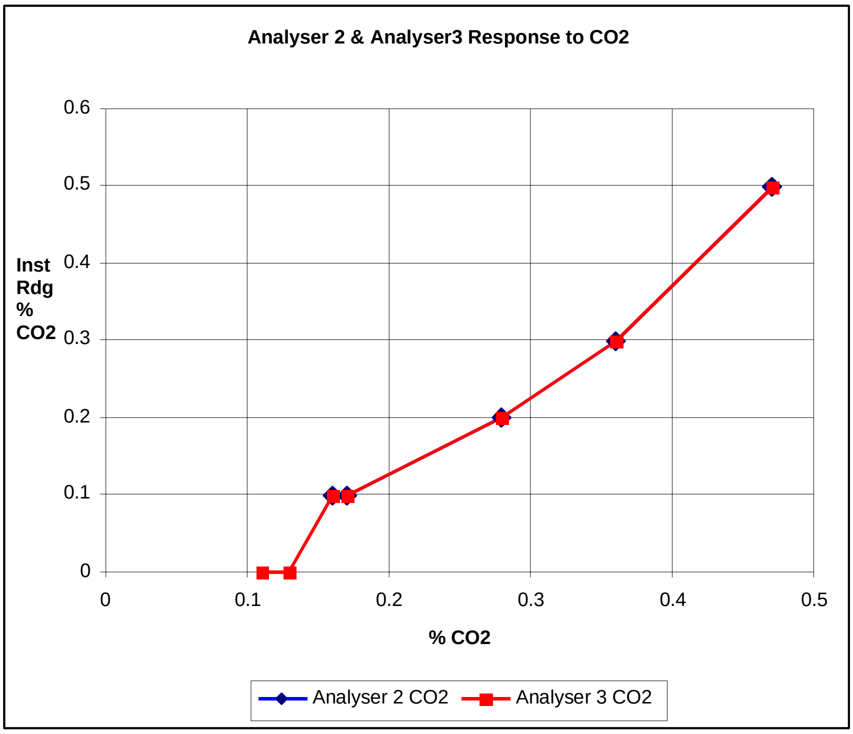

Fig 4.3 Response of Analysers 2 and 3 to low carbon dioxide concentrations. Note: blue and red datapoints overlap at all % CO_2 (see Table 4.6).

The responses of the analyser to a series of higher flue gas concentrations, including those well above the 0.5% WEL and similar to those found in flues, are shown in Table 4.7. The results are plotted in Fig. 4.4.

Table 4.7 Response of Analyser 2 and Analyser 3 to high concentrations of carbon dioxide from simulated flue gas

Actual CO_2 (%)	Analyser 2	Analyser 3
	$\%CO_2$ (Calculated)	$\%CO_2$ (Measured)
0.79	0.6	0.8
1.06	0.8	0.9
1.35	1.1	1.3
1.91	1.5	1.8
3.1	3.1	3.0
4.45	4.6	4.3
4.8	4.9	5.4
6.2	6.1	6.2
7.46	7.2	7.5
8.57	8.2	7.9
9.1	8.9	8.6

Again, in general, acceptable accuracy to BS EN 50379 is attained by both the carbon dioxide calculating Analyser 2 and the carbon dioxide measuring Analyser 3.

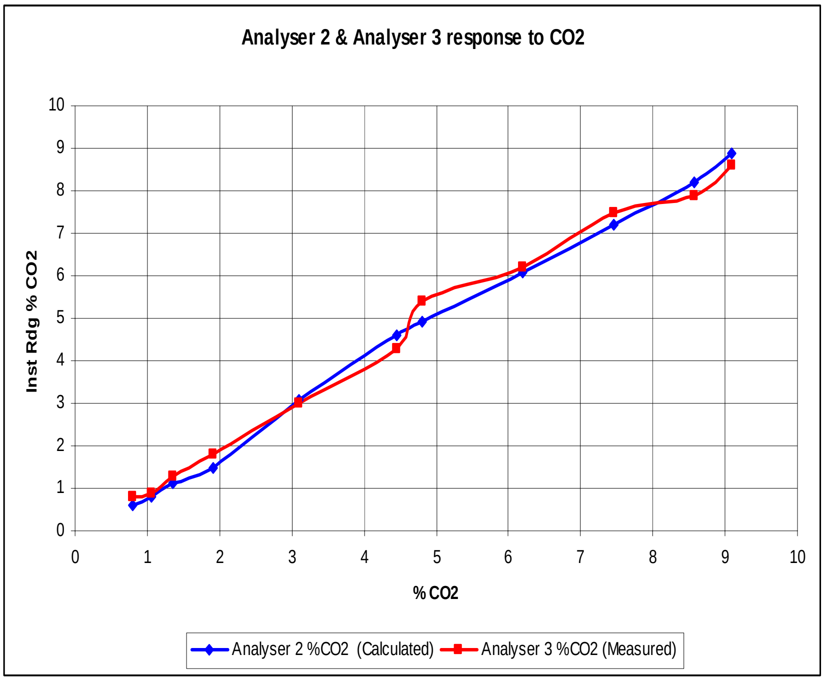

Fig 4.4 Response of Analysers 2 and 3 to high carbon dioxide concentrations

4.2.4 Response of Analyser 2 and Analyser 3 to air-diluted pure carbon dioxide concentrations

The response of the analyser to a source of carbon dioxide other than flue gas exhaust was measured by diluting pure carbon dioxide gas with air. The results are shown in Table 4.8.

Table 4.8 Response of Analyser 2 and Analyser 3 to air-diluted pure carbon dioxide concentrations

Actual % CO_2	Analyser 2 % CO2	Analyser 3 % CO2	Servomex % O2
0.02 (lab air)	--**	0.0 (20.9% O2)*	20.9
1.04	--	1.0 (19.1% O2)	20.7
1.20	--	1.1 (18.9% O2)	20.7
1.72	0.1	1.6 (18.1% O2)	20.6
2.05	0.1	1.9 (17.6% O2)	20.5

* Value of oxygen concentration displayed by the instrument and calculated from the carbon dioxide measurement.
** "—" is symbol shown on display, not "0.0".

Similar results are obtained for Analyser 2 to those for Analyser 1. Analyser 2 gives highly inaccurate readings up to 2% carbon dioxide. Analyser 3, which calculates carbon dioxide, remains within tolerance at all concentrations tested.

5 CONCLUSIONS

Three types of flue gas analysers were tested in the laboratory and subjected to various carbon dioxide and oxygen mixtures equivalent to a standard flue gas mixture (as specified in BS EN 50379-1) diluted by ambient, clean air.

Analyser 1 and Analyser 2, which both calculate carbon dioxide from oxygen, could be used above 0.2% and up to several % carbon dioxide to give a general indication of carbon dioxide levels, provided the only source of carbon dioxide was from a flue gas for which the gas analyser was calibrated.

Both Analyser 1 and Analyser 2 exceeded the ± 0.2% v/v tolerance when measuring carbon dioxide-air mixtures generated from pure carbon dioxide up to concentrations of approximately 2%, ie from a source other than air-diluted flue gas. Note that the dilution of pure carbon dioxide by air results in the greatest degree of inaccuracy for a flue gas analyser which calculates carbon dioxide concentration from the oxygen level based on the combustion of fuel, and which is not applicable for this source of carbon dioxide.

Analyser 3, which measures carbon dioxide, could be used above 0.15% and up to several % carbon dioxide for monitoring carbon dioxide levels from any source.

Analyser 3 was within the ± 0.2% v/v tolerance when measuring carbon dioxide-air mixtures generated from pure carbon dioxide up to concentrations of approximately 2%.

6 RECOMMENDATIONS

Generally, and notwithstanding the acceptable performance (in the laboratory) of all the analysers tested in *air-diluted, simulated flue gas,* it is preferable to measure carbon dioxide concentrations around and below 0.5% rather than rely on an analyser which calculates carbon dioxide from the oxygen concentration based on a specific combustion reaction. This is because other sources of carbon dioxide may be present which do not arise from a leak/spillage of flue gas or are derived from other combustion reactions for which the flue gas analyser is not calibrated. This would adversely affect the accuracy of the calculated carbon dioxide analyser, which assumes that the carbon dioxide arises solely from oxidation of fuel (eg natural gas) with oxygen from air in a gas appliance.

Flue gas analysers which calculate carbon dioxide concentration are only suitable for measuring ambient carbon dioxide generated from combustion of fuel for which they are calibrated, over the concentration range from several % down to approximately 0.2% carbon dioxide. The lower level may need to be increased because the tests were carried out using cylinder (bottled) gases and not actual flue gas.

Flue gas analysers which measure carbon dioxide concentration are suitable for measuring ambient carbon dioxide, from any source from several % down to approximately 0.2% carbon dioxide.

Ideally, a detection limit of around 10% of the 8-hr WEL (0.5% carbon dioxide) is required for *workplace* air measurements, ie 500 ppm.

When a carbon dioxide measuring analyser is used for workplace air monitoring, the accuracy should be appropriate for measuring around and below the WEL, ie around ±500 ppm. It should be calibrated at an appropriate concentration, eg 0.5% or below, in order to help attain this accuracy; and maintained, checked and recalibrated at regular intervals, all in accordance with the manufacturer's instructions.

7 APPENDICES

7.1 APPENDIX 1. CALCULATION OF CARBON DIOXIDE CONCENTRATION FROM OXYGEN CONCENTRATION

The formula used by a flue gas analyser to calculate the carbon dioxide concentration $[CO_2]$ from the measurement of oxygen concentration $[O_2]$ for the combustion of fuel depends upon the fuel type (eg natural gas, LPG) and the concentration of oxygen in the air. When the oxygen concentration is 0%, reduced from the ambient value (the oxygen concentration will be 20.9% of the %air), then the maximum concentration of carbon dioxide is produced. This maximum concentration expressed as a percentage is known as the fuel factor F. The formula is:

$$\%[CO_2] = \{20.9 - \%[O_2]\} \cdot F/20.9 \qquad (F1)$$

The fuel factor is derived from the stoichiometry of the reaction between fuel and oxygen in air. For methane and propane the reactions are given in (R1) and (R2) respectively:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \qquad (R1)$$

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \qquad (R2)$$

If the methane reacts with all the oxygen in the air, then the concentration of methane is equal to half the concentration of oxygen in the air, ie

$$2 \cdot [CH_4] = 0.209 \cdot \{100 - [CH_4]\} \qquad (F2)$$

The (stoichiometric) concentration of methane is therefore 9.5%. From (R1), the maximum concentration of carbon dioxide will be equal to this methane concentration. The flue gas analyser removes water vapour from the sample, therefore the above concentrations need to be quoted on a dry basis. As the concentration of water vapour is twice that of the maximum carbon dioxide concentration, ie 19%, from (R1), then F is 9.5·(100/81), ie 11.73. This is a theoretical value for methane; for natural gas, which is mainly methane but with varying proportions of higher hydrocarbons (and nitrogen), experimental values a little higher than this are invariably used, eg 11.9.

Similar calculations for propane based on (R2) result in a value for F of 13.7. Typical values for F for LPG (propane) are 13.8. For LPG (butane, C_4H_{10}), F is typically 14.1.

7.2 APPENDIX 2. BS EN 45544 (2000) WORKPLACE ATMOSPHERES - ELECTRICAL APPARATUS USED FOR THE DIRECT DETECTION AND DIRECT CONCENTRATION MEASUREMENT OF TOXIC GASES AND VAPOURS

The use of toxic gas detectors in the workplace is covered by the standards BS EN 45544-1, BS EN 45544-2, BS EN 45544-3, and the corresponding guidance for use of these instruments in BS EN 45544-4. The performance criteria for such instruments are specified quite differently and are more complex than the flue gas standards BS 7927 and BS EN 50379.

The standard test gas concentration (STGC) used in the tests is 5000 ppm for carbon dioxide monitors. The lower limit of the measuring range (ie detection limit) is determined as 0.5 times the zero variation for zero variations less than or equal to 0.25 STGC (ie 1250 ppm). The zero variation is determined as part of the tests. The overall uncertainty (OU) is an defined expression of the measurement error or accuracy. OU is the sum of bias and precision (repeatability) of the instrument, expressed as a percentage of the true value, and is concentration range dependent. A requirement of ± 30% applies to measurements in various test gases over the range 2500 – 50,000 ppm (0.25 - 5%) carbon dioxide, and a requirement of ± 50% applies to 500 - 2500 ppm (0.05 – 0.25%) carbon dioxide.

The response time requirement is within 150 sec.

8 REFERENCES

Arena, J.M., and Drew, R.H. (1986)
Poisoning: Toxicology, Charles, C. (ed.)
Thomas Springfield.

BS 7927 : 1998 incl. Amendment 1 : 1999 Heating appliances for domestic applications – Portable apparatus designed to detect and measure specific combustion flue gas products – Requirements.
BSI, London.

BS 7967-1 Carbon monoxide in dwellings and the combustion performance of gas-fired appliances – Part 1: Guide for identifying and managing sources of fumes, smells, spillage/leakage of combustion products and carbon monoxide detector activation.
BSI, London.

BS 7967-2 Carbon monoxide in dwellings and the combustion performance of gas-fired appliances – Part 2: Guide for using electronic portable combustion gas analysers in the measurement of carbon monoxide and the determination of combustion performance.
BSI, London.

BS 7967-3 Carbon monoxide in dwellings and the combustion performance of gas-fired appliances – Part 3: Guide for responding to measurements obtained from electronic portable combustion gas analysers.
BSI, London.

BS 7967-4 Carbon monoxide in dwellings and the combustion performance of gas-fired appliances – Part 4: Guide for using electronic portable combustion gas analysers as part of the process of servicing and maintenance of gas-fired appliances.
BSI, London.

BS EN 45544-1 : 2000 Workplace atmospheres - electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours – Part 1: General requirements and test methods.
BSI, London.

BS EN 45544-2 : 2000 Workplace atmospheres - electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours – Part 2: Performance requirements for apparatus used for measuring concentrations in the region of limit values.
BSI, London.

BS EN 45544-3 : 2000 Workplace atmospheres - electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours – Part 3: Performance requirements for apparatus used for measuring concentrations well above limit values.
BSI, London.

BS EN 45544-4 : 2000 Workplace atmospheres - electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours – Part 4: Guide for selection, installation, use and maintenance.
BSI, London.

BS EN 50379-1 Specification for portable electrical apparatus designed to measure combustion flue gas parameters of heating appliances. Part 1: General requirements and test methods.
BSI, London. To be published.

BS EN 50379-3 : 2004 Specification for portable electrical apparatus designed to measure combustion flue gas parameters of heating appliances. Part 3: Performance requirements for apparatus used in non-statutory servicing of gas fired heating appliances.
BSI, London.

HSE (2005)
EH40/2005 Workplace exposure limits 2005
HSE Books, Sudbury.

Schulte, J.H. (1984)
Sealed Environments in Relation to Health and Disease.
AMA Arch. Environ Health 8, 438-451

Walsh P (2003)
Measurement of oxygen and carbon dioxide in confined spaces.
Toxic Substances Bulletin, Issue 50, Jan 2003.
(http://www.hse.gov.uk/toxicsubstances/issue50.htm).
HSE.

Walsh P, Greenham L (2004)
Carbon dioxide detectors for health and safety applications.
Int. Environmental Technology, 14 (6), November/December 2004.