




**Client** Staffordshire Crystal Ltd.  
 Unit 14 Pedmore Road Ind. Estate  
 Brierly Hill  
 West Midlands  
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**Part 1: Executive Summary**

**Report for the Periodic Monitoring of Emissions to Air.**

<b>Site</b>	Brierly Hill
<b>Plant</b>	Furnace Chimney
<b>Sampling Date</b>	15th October 2014
<b>Report Date</b>	14th January 2015
<b>Job Number</b>	2p71962
<b>Permit Number</b>	PB/98 Variation 200839393

<b>Report Prepared by:</b>	<b>Print</b>	Graham Rowley
	<b>MCERTS No.</b>	MM 03 148      Level 2 TE: 1,2,3,4

<b>Report Approved by:</b>	<b>Sign</b>	
	<b>Print</b>	Emily Buffam
	<b>MCERTS No.</b>	MM 04 502      Level 2 TE: 1,2,3,4



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## Contents

Page 1	<b>Part 1: Executive Summary</b>
Page 2	Contents
Page 3	Monitoring Objectives
Page 3	Special Monitoring Requirements
Page 4	Summary Of Methods
Page 4	Summary Of Results
Page 5	Operating Information
Page 5	Comments On Monitoring Procedures
Page 6	<b>Part 2: Supporting Information</b>
Page 7	<b>Appendix 1</b>
Page 8	Emission Monitoring Procedures and Instrumentation
Page 9	Sampling Personnel
Page 9	Equipment References
Page 9	Subcontracted Analysis
Page 10	<b>Appendix 2</b>
Page 11	Preliminary Velocity Traverse & Moisture Data
Page 12	Total Particulate Matter - Sampling Data
Page 13	Total Particulate Matter - Emission Results
Page 14	Lead - Sampling Data
Page 15	Lead - Emission Result
Page 16	Lead - Field Blank Emission Result
Page 17	<b>Appendix 3</b>
Page 18	Diagram of Sampling Location
Page 19	Generic Calculations
Page 20	Flow Calculations
Page 21	Concentration Calculation
Page 22	Uncertainty Estimate Calculations - Manual Techniques
Page 23	<b>Appendix 4</b>
Page 24	Uncertainty Estimates:- Total Particulate Matter
Page 25	Uncertainty Estimates:- Lead

## Monitoring Objectives

The monitoring was undertaken to check compliance with authorised emission limits.

All monitoring procedures were carried out to the MCERTS requirements under the REC Environmental Monitoring quality system to ISO 17025: 2005.

Monitoring was undertaken for the listed emissions from the following sampling positions:

Sampling Location	Emission
Furnace Chimney	Particulates Lead

## Special Monitoring Requirements

There were no special requirements for this monitoring campaign.

## Summary Of Methods

Emission	Method number	Method standard
Particulate	TPM/04	BS EN 13284 - 1 : 2002
Gas velocity	TPM/01	BS EN 13284 : 2002
Water vapour	TPM/37	BS EN 14790 : 2005
Lead	TPM/06b	BS EN 14385 : 2004

## Summary Of Results

The table presents the atmospheric emissions from the tests undertaken on behalf of **Staffordshire Crystal Ltd.** The results were measured from the sample positions downstream of the arrestment plant.

Emission at Brierly Hill Furnace Chimney	Sampling Time			Emission Result mg/m <sup>3</sup> *	Authorised Limit mg/m <sup>3</sup> *	Uncertainty +/- mg/m <sup>3</sup> *	Detection Limit mg/m <sup>3</sup> *	Mass Emission g/h
	Date	Start	End					
Particulate	15/10/14	10:39	11:19	24.2	20	16.8	5.90	13.9
s Lead	15/10/14	11:57	12:37	14.2	5	9.67	0.01	6.29

* at reference conditions	Stack Gas Weight	0 °C	Dry Gas
	29.00 Kg/kmol	101.3 kPa	Oxygen 13 %

Where applicable Oxides of nitrogen results are expressed as nitrogen dioxide  
TOC results are expressed as total carbon

Throughout Report: \* Reference conditions (see above) Nm<sup>3</sup> 273 K, 101.3 kPa  
\*\* Analysis not required # - UKAS accredited only  
ND Non detectable ## - Not Accredited  
s - Subcontracted laboratory analysis N/A Not applicable

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a 95% confidence level. The uncertainty evaluation has been carried out in accordance with UKAS requirements.



All tests included in this report are accredited under UKAS and MCERTS accreditation schemes unless otherwise stated. Opinions and interpretations expressed herein are outside the scope of MCERTS and UKAS accreditation.



## Operating Information

The tables below shows details of the operating information on each sampling date for: **Furnace Chimney**

Date	Process type	Process duration	Fuel	Feedstock	Abatement	Load
15/10/2014	Glass Furnace	Batch	Nat. gas	Glass	None	Normal operation

There are no CEMs currently installed on this process for the determinands being monitored.

## Comments & Monitoring Deviations

A waste gas homogeneity test to BS EN 15259:2007 (MID) is not required:-  
The homogeneity test is not applicable to non-combustion processes.  
The homogeneity test is not applicable to duct areas less than 1m<sup>2</sup>.

All monitoring was performed in accordance with the relevant procedures.

Sampling could only be undertaken from the one port available and of limited points as a result of insufficient platform size and restricted access.

The particulate monitoring was within the required 95 to 115 % isokinetic rate as stated in BS EN 13284-1: 2002

The velocity and temperature profile at the sampling location met the requirements of BS EN 13284-1: 2002.

When the results are expressed as non-detected the mass emissions are calculated from the detection limit and therefore they are worst case results.



**Part 2: Supporting Information**

**Report for the Periodic Monitoring of Emissions to Air.**

<b>Client</b>	Staffordshire Crystal Ltd.
<b>Site</b>	Brierly Hill
<b>Plant</b>	Furnace Chimney
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<b>Report Approved by:</b>	<b>Sign</b>		
	<b>Print</b>	<b>Emily Buffam</b>	
	<b>MCERTS No.</b>	<b>MM 04 502</b>	<b>Level 2 TE: 1,2,3,4</b>

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## APPENDIX 1

## Emission Monitoring Procedures And Instrumentation

### Gas velocity and temperature

Documented in-house procedure TPM/01 to the main procedural requirements of BS EN 13284:2002. Velocity and temperature measurements are performed using a calibrated Pitot tube, as described in BS ISO 10780:1994 and a calibrated thermocouple. Velocity and possible flow deviation measurements are carried out at selected, representative points in the gas stream.

### Water vapour

Documented in-house procedure TPM/37 to the main procedural requirements of BS EN 14790:2005. A measured volume of gas is extracted from the gas stream through a moisture trapping unit. The mass gain of moisture trapped is divided by the volume of gas sampled to determine the mass concentration of water vapour. For water saturated stacks the temperature of the gas stream is measured and the water vapour concentration is determined using liquid-gas equilibrium tables. Sampling points are selected in accordance with the findings of any BS EN 15259 assessment.

### Total particulate matter

Documented in-house procedure TPM/04 to the main procedural requirements of BS EN 13284-1:2002. Stack gases are extracted from representative sampling points at isokinetic flow rates through a sharp-edged nozzle. Particulate matter is collected on a pre-weighed filter conditioned at 180°C. Deposits upstream of the filter are also recovered and weighed. The increase of mass of the filter and mass collected upstream of the filter is divided by the volume sampled to determine the mass concentration.

### Lead

Documented in-house procedure TPM/06b to the main procedural requirements of BS EN 14385:2004 - substantial metered volume of gas sampled isokinetically through a sharp edged nozzle dedicated heated probe, filter, and chilled impinger train containing appropriate hydrogen peroxide/nitric acid and sulphuric acid/potassium permanganate solutions, and subsequent Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) analysis.



## Sampling Project Personnel Competency And Expiry Dates

		MCERTS No	Level 1	Level 2	TE1	TE2	TE3	TE4
Report prepared by:	Graham Rowley	MM 03 148	-	30/11/2018	30/11/2018	31/03/2015	31/10/2019	31/03/2020
Report authorised by:	Emily Buffam	MM 04 502	-	30/06/2016	30/06/2016	31/08/2016	31/08/2016	31/08/2016
Team leader:	Graham Rowley	MM 03 148	-	30/11/2018	30/11/2018	31/03/2015	31/10/2019	31/03/2020
Technician:	Tom Clarkson	MM 02 120	31/12/2018	-	-	-	-	-

## Equipment References

Equipment	Reference Number
Analyser	CA03
Probe	P48
Probe Thermocouple	TP48
Stack Thermocouple	TS48
Control Box	CU13
Timer / Stopwatch	CU13/8
Barometer	WS04
Pitot	PT113
Callipers	CV17
Hot Box	HB23
Impinger Thermocouple	TV34
Sample Rate Calculation Equipment	Laptop
Balance	BL19
Weights	W35, W36

## Subcontracted Analysis

REC Environmental Monitoring has, with your approval, used the following sub-contracted laboratories for the laboratory analyses referenced below:

Laboratory:	Scientific Analysis Laboratories
Parameters:	Heavy Metals - Internal method ICPMS BS EN 14385
Accreditation:	UKAS Accredited testing laboratory number 1549

## APPENDIX 2

Date	15/10/2014
Time	09:15
Pitot Cp	0.85

Barometric pressure	98.7	kPa
Duct static pressure	0.04	kPa
Stack Area	0.126	m <sup>2</sup>
Oxygen	20.4	%

Stack Diameter (circular)	0.40	m
		%

Traverse Point	Traverse Line	Depth cm	ΔP mmH <sub>2</sub> O	T °C	Angle °	velocity m/s	Traverse Line	Depth cm	ΔP mmH <sub>2</sub> O	T °C	Angle °	velocity m/s
1	A	5.0	40.0	35	<15	22.5	B	5.0				
2	A	5.0	39.5	35	<15	22.4	B	5.0				
3	A	5.0	39.0	35	<15	22.2	B	5.0				
4	A	7.1	41.0	35	<15	22.8	B	7.1				
5	A	10.0	39.0	35	<15	22.2	B	10.0				
6	A	14.2	37.5	35	<15	21.8	B	14.2				
7	A	25.8	38.0	35	<15	22.0	B	25.8				
8	A	30.0	33.0	35	<15	20.5	B	30.0				
9	A	32.9	33.5	35	<15	20.6	B	32.9				
10	A	35.0	22.0	35	<15	16.7	B	35.0				
11	A	35.0	21.0	35	<15	16.3	B	35.0				
12	A	35.0	23.0	35	<15	17.1	B	35.0				

Average Pitot DP	33.44	mmH <sub>2</sub> O
Average Temperature	308.2	K
Average Velocity	20.6	m/s
Average volumetric flow rate	2.59	m <sup>3</sup> /s at stack conditions
Average volumetric flow rate	2.24	m <sup>3</sup> /s (wet STP)
Average volumetric flow rate	2.22	m <sup>3</sup> /s (dry STP)
Average volumetric flow rate	0.08	m <sup>3</sup> /s (dry, STP, reference oxygen concentraion)

#### Sampling plane requirements Re: BS EN 13284-1:2001 5.2

a	Angel of gas flow less than 15° with regard to duct axis	YES
b	No local negative flow	YES
c	Minimum pitot greater than 5Pa	YES
d	Ratio of highest to lowest local gas velocity less than 3:1	YES
	Minimum local gas velocity	16.3
	Maximum local gas velocity	22.8
	Ratio of highest to lowest local gas velocity	1.40

#### Moisture Determination BS EN 14790:2005

	Volume m <sup>3</sup>	Temp °C	Pressure mbar
Meter start	7.712	22	987
Meter end	8.986	28	987
Meter Yd	1.002		
Gas volume	1.139		

Impinger	1	2	3	4	5
Mass start (g)	741.0	688.3	566.9	958.6	
Mass End (g)	674.7	738.7	579.0	971.2	
Total Mass collected (g)	8.8				

Water vapour content (% v/v)	1.0
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If water droplets are present in the gas, the water vapour content is calculated using BS EN 14790 Annex A

N/A % v/v



Blank Filter Weight		Date of analysis	After (g)	Before (g)	Collected (g)	% of Filter Tare Weight
Filter No	X11377	24/10/2014	0.74529	0.74531	-0.00002	
Washings	10403	20/10/2014	48.65142	48.65093	0.00049	0.1

Filter Weight Test 1		Date of analysis	After (g)	Before (g)	Collected (g)	% of Filter Tare Weight
Filter No	X11378	24/10/2014	0.75079	0.74951	0.00128	
Washings	10404	20/10/2014	48.72602	48.72569	0.00033	0.2

Sample Number	Hopper Or Filter No	Total weights (g)			Control Blank Corrected	Comments
		After	Before	Collected		
Blank	X11377	49.39671	49.39624	0.00047	0.00091	
Test 1	X11378	49.47681	49.47520	0.00161	0.00205	

Washings Control Blank Weight Variance	-0.00044	Acetone Residue Weight	<1ppm
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Particulate emission results	Blank	
Detection Limit	5.90	mg/m <sup>3</sup> *
Particulate Emission	10.74	mg/m <sup>3</sup> *

Reference Gas Details			Test 1		
Species	Units	Value	Cylinder Reference		
Nitrogen	%	99.999	VCEB633		
Oxygen	%	20.90	Dry Ambient		
Calibration Details		Initial Time	10:15	Final Time	12:45
	Units	Initial Zero	Initial Span	Final Zero	Final Span
Oxygen	%	0.00	20.90	0.03	20.98

Particulate Emission Results	Test 1	
Detection Limit	5.90	mg/m <sup>3</sup> *
Particulate Emission	24.20	mg/m <sup>3</sup> *

### Total Particulate Matter - Emission Results



Date	15/10/2014
Start time	11:57
Finish time	12:37
Sample volume Nm <sup>3</sup> (dry gas)	1.234

HEAVY METALS	Impinger mass	
Impinger 1,2 & wash	303.6	g
Impinger 3 & wash	222.2	g

Measured moisture concentration	0.91	% v/v
Measured oxygen concentration	20.56	%

HEAVY METALS	Filter Analysis 2p71962/21	Particulate Phase Emission	Impinger 1 & 2 Analysis 2p71962/22	Vapour phase Emission Impinger 1 & 2	Impinger 3 Analysis 2p71962/23	Vapour phase Emission Impinger 3	Detection Limit	Efficiency % Trapped In impinger 3	Total Emission
Units	µg	mg/m <sup>3</sup> *	µg/l	mg/m <sup>3</sup> *	µg/l	mg/m <sup>3</sup> *	mg/m <sup>3</sup> *	%	mg/m <sup>3</sup> *
Lead (Pb)	920	13.63702	61	0.27451	97	0.31948	0.00975	2.24	14.231021

TOTAL HEAVY METALS Particulate Phase & Vapour Phase	Total Emission mg/m <sup>3</sup> *	Detection Limits mg/m <sup>3</sup> *	Total Emission As % ELV
Total heavy metals, Pb	14.23102	0.00975	284.6

Numbers in bold indicate detection limits

Reference Gas Details					
Species	Units	Value	Cylinder Reference		
Nitrogen	%	99.999	VCEB633		
Oxygen	%	20.90	Dry Ambient		
Calibration Details		Initial Time	10:15	Final Time	12:45
	Units	Initial Zero	Initial Span	Final Zero	Final Span
Oxygen	%	0.00	20.90	0.03	20.98

Metals excluding Mercury

Laboratory	SAL	
Method N° & Accreditation Status	ICPMS BS EN 14385	UKAS
Date of analysis	29/10/2014	

## Lead - Emission Result

Date	15/10/2014
Start time	11:57
Finish time	12:37
Sample volume Nm <sup>3</sup> (dry gas)	1.234

HEAVY METALS	Impinger mass	
Impinger 1,2 & wash	236.4	g
Impinger 3 & wash	197.1	g

Measured moisture concentration	0.91	% v/v
Measured oxygen concentration	20.56	%

HEAVY METALS	Filter Analysis 2p71962/18	Particulate Phase Emission	Impinger 1 & 2 Analysis 2p71962/19	Vapour phase Emission Impinger 1 & 2	Impinger 3 Analysis 2p71962/20	Vapour phase Emission Impinger 3	Detection Limit	Efficiency % Trapped In impinger 3	Total Emission
Units	µg	mg/m <sup>3</sup> *	µg/l	mg/m <sup>3</sup> *	µg/l	mg/m <sup>3</sup> *	mg/m <sup>3</sup> *	%	mg/m <sup>3</sup> *
Lead (Pb)	<b>0.50</b>	0.00000	<b>0.30</b>	0.00000	<b>0.30</b>	0.00000	0.00934	N/A	0.000000

TOTAL HEAVY METALS Particulate phase & Vapour phase	Total Emission mg/m <sup>3</sup> *	Detection Limits mg/m <sup>3</sup> *	Total Emission As % ELV
Total heavy metals, Pb	0.00000	0.00934	0.0

Numbers in bold indicate detection limits

Metals excluding Mercury

Laboratory	SAL	
Method N <sup>o</sup> & Accreditation Status	ICPMS BS EN 14385	UKAS
Date of analysis	29/10/2014	



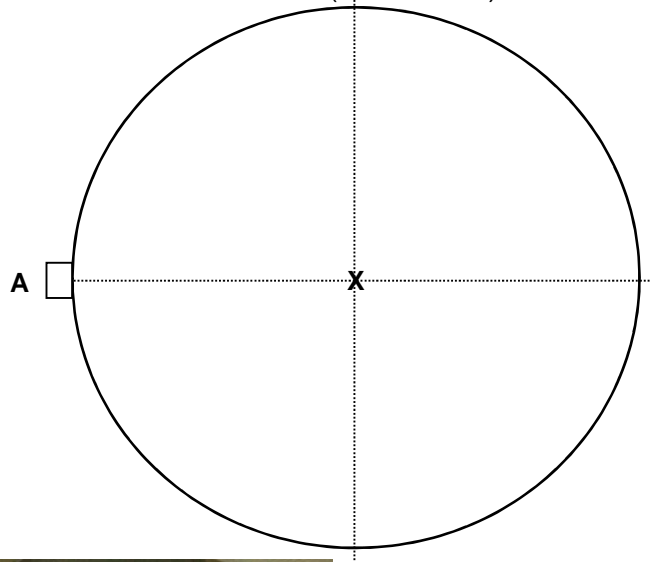
## APPENDIX 3

## Diagram Of The Sampling Location

Diagram of sampling points across the cross section of the duct (not to scale).

Traverse length = 0.40 m

Point	% of D	Location cm
1	50.0	20.0



## General Calculations

### Stack area:

$$\text{Area of a circle} = \frac{\pi \cdot D^2}{4}$$

D = Diameter (m)

$\pi$  = 3.142

### Pressure conversion:

1mmH2O = 0.00980665 kPa

1mmH2O = 9.80665 Pa

1 mar = 0.1 kPa

### Water vapour concentration:

From reference calculations (taken from BS EN 14790):

$$V_{WC(\%)} = \frac{\frac{m_{WC} \cdot V_{mol(std)}}{M_w}}{\frac{m_{WC} \cdot V_{mol(std)}}{M_w} + V_{m(std)}} \times 100$$

WVC (%) = Water vapour content on wet basis, in volume % (m<sup>3</sup> of water vapour in m<sup>3</sup> of wet gas)

Vm(std) = Dry gas volume measured, corrected to standard conditions (m<sup>3</sup>)

mWC = Mass of water collected in the impingers (g)

Mw = Molecular weight of water, 18.01534 rounded to 18 (g/mol)

Vmol(std) = Molar volume of water at standard conditions = 0.0224 (m<sup>3</sup>/mol)

### Gas meter volume at standard conditions (STP)

From reference calculations (taken from BS EN 14790):

$$V_{m(std)} = y_d \times (V_2 - V_1) \times \frac{T_{std}}{T_m} \times \frac{P_m}{P_{std}}$$

Vm(std) = Dry gas meter volume at standard conditions (m<sup>3</sup>)

yd = Gas meter calibration coefficient

(V2-V1) = Dry gas meter volume at actual conditions (m<sup>3</sup>)

Tm = Actual Temperature (K)

Tstd = Standard temperature (273 K)

pm = Absolute pressure at the gas meter (kPa)

pstd = Standard gas pressure (101.3 kPa)

### Isokenetic Ratio (%):

From reference calculations (taken from EA TGN M2):

$$\text{IsokineticRatio}(\%) = \frac{\text{Velocity at the sampling nozzle}}{\text{Velocity of the stack gas}} \times 100$$

### Estimating Measurement Uncertainty

Uncertainty estimates are calculated using the general rule of uncertainty propagation. Guidance is taken from publications including UKAS document M3003 and ISO 20988:2007.

## Flow Calculations

### Velocity:

From reference calculations (taken from ISO 10780):

$$\bar{v} = KC \sqrt{\frac{T_s \Delta p}{p_e M_s}}$$

$\bar{v}$  = Average velocity (m/s)

C = velocity calculation constant = 129

$T_s$  = Average stack temperature (K)

$M_s$  = Molar mass of gas; assume 29 kg/kmol unless the molar mass is < 27 kg/kmol or > 31 g/kmol

K = Pitot calibration coefficient

$p_e$  = Absolute gas pressure (kPa)

$\Delta p$  = Average pitot tube pressure differential (kPa)

### Volume flow rate

From reference calculations (taken from ISO 10780):

$$q_{va} = \bar{v}A$$

$q_{va}$  = Average flow rate (m<sup>3</sup>/s)

$\bar{v}$  = Average velocity (m/s)

A = Stack cross-sectional area (m<sup>2</sup>)

### Volume flow rate corrected for moisture

From reference calculations (taken from BS ISO 9096):

$$q_m = q_{va} \frac{(100 - H_a)}{(100 - H_m)}$$

$q_m$  = Corrected volume flowrate (m<sup>3</sup>/s)

$q_{va}$  = Volume flow rate at actual conditions (m<sup>3</sup>/s)

$H_a$  = Moisture at actual conditions (%volume)

$H_m$  = Reference moisture (%volume)

### Volume flow rate corrected for temperature and pressure

From reference calculations (taken from BS ISO 9096):

$$q_m = q_{va} \frac{(T_m p_a)}{(T_a p_m)}$$

$q_m$  = Corrected volume flowrate (m<sup>3</sup>/s)

$q_{va}$  = Volume flow rate at actual conditions (m<sup>3</sup>/s)

$T_a$  = Temperature at actual conditions (K)

$T_m$  = Reference Temperature (K)

$p_a$  = Absolute gas pressure at actual conditions (kPa)

$p_m$  = Reference pressure (kPa)

### Volume flow rate corrected for oxygen

From reference calculations (taken from BS ISO 9096):

$$q_m = q_{va} \frac{(20.9 - O_{2,ref})}{(20.9 - O_{2,m})}$$

$q_m$  = Corrected volume flowrate (m<sup>3</sup>/s)

$q_{va}$  = Volume flow rate at actual conditions (m<sup>3</sup>/s)

$O_{2,m}$  = Actual oxygen concentration (%)

$O_{2,ref}$  = Reference oxygen concentration (%)

## Concentration Calculations

### Concentration:

From reference calculations (taken from BS EN 13284-1):

$$c = \frac{m}{V}$$

$c$  = Concentration  
 $m$  = Mass of substance  
 $V$  = Volume sampled

### Mass Emission

$$\text{Mass emission} = c \times q_m$$

$c$  = Concentration  
 $q$  = Volume flow rate

### Concentration corrected for oxygen:

From reference calculations (taken from BS ISO 9096):

$$c_m = c_a \times \frac{20.9 - O_{2,ref}}{20.9 - O_{2,a}}$$

$cm$  = Concentration at reference conditions  
 $ca$  = Actual concentration  
 $O_2, ref$  = Reference oxygen (%)  
 $O_2, a$  = Actual Oxygen (%)

### Concentration corrected for moisture:

From reference calculations (taken from BS ISO 9096):

Convert wet gas to dry gas

$$c_{dry} = c_{wet} \times \frac{100}{100 - H_a}$$

Convert dry gas to wet gas

$$c_{wet} = c_{dry} \times \frac{100 - H_a}{100}$$

$c_{wet}$  = Concentration wet gas  
 $c_{dry}$  = Concentration dry gas  
 $H_a$  = Water vapour content (%vol)

### Conversion of parts per million (ppm) to mg/m<sup>3</sup>

From reference calculations (taken from EA TGN M2):

$$\text{Concentration}(\text{mg} / \text{m}^3) = \frac{\text{Concentration}(\text{ppm}) \times \text{molecular weight}(\text{g})}{\text{molar volume}(\text{l}) \text{ at a given temperature}}$$

molar volume at 273K = 22.4 litres

### When Converting TOC

$$\text{Concentration}(\text{mg} / \text{m}^3) = \frac{\text{Concentration}(\text{ppm}) \times \text{molecular weight of carbon in span gas}(\text{g})}{\text{molar volume}(\text{l}) \text{ at a given temperature}}$$

molar volume at 273K = 22.4 litres

## Calculation of Uncertainty Estimates - Manual Monitoring Techniques

$$C_m = \frac{Q_m}{V_{std}}$$

$$V_{std} = V_{T.p} \times \frac{T_{std}}{T} \times \frac{p}{P_{std}}$$

Where:

$C_m$	=	the measured concentration	in	mg/m <sup>3</sup>
$Q_m$	=	mass concentration collected in absorber solution and filter	in	mg
$v_s$	=	the volume of the sample solution	in	l
$V_{std}$	=	volume sampled at standard conditions	in	m <sup>3</sup>
$T_m$	=	mean temperature of gas meter	in	K
$T_{std}$	=	standard temperature	=	273K
$p = p_{rel} + p_{atm}$	=	absolute pressure = gas meter pressure + atmospheric pressure	in	kPa
$P_{std}$	=	standard pressure	=	101.325 kPa
$V_{T.p}$	=	volume sampled as indicated by the gas meter	in	m <sup>3</sup>

Expression for calculation of the combined uncertainty of the measured concentration

$$\frac{u^2(C_m)}{(C_m)^2} = \frac{u^2(Q_m)}{(Q_m)^2} + \frac{u^2(v_s)}{(v_s)^2} + \frac{u^2(V_{std})}{(V_{std})^2}$$

Expression for calculation of the combined uncertainty of the gas volume

$$V_{std} = V_{T.p} \times \frac{T_{std}}{T_m} \times \frac{p}{P_{std}}$$

Assuming that uncertainties associated with the standard quantities  $T_{std}$  and  $P_{std}$  are negligible

Expression for calculation of the combined uncertainty of the measured concentration

$$\frac{u^2(C_m)}{(C_m)^2} = \frac{u^2(Q_m)}{(Q_m)^2} + \frac{u^2(v_s)}{(v_s)^2} + \frac{u^2(V_{T.p})}{(V_{T.p})^2} + \frac{u^2(T)}{(T)^2} + \frac{u^2(p_{rel})}{(p)^2} + \frac{u^2(p_{atm})}{(p)^2}$$

$$u(C_m) = \sqrt{\left( \frac{u^2(Q_m)}{(Q_m)^2} + \frac{u^2(v_s)}{(v_s)^2} + \frac{u^2(V_{T.p})}{(V_{T.p})^2} + \frac{u^2(T)}{(T)^2} + \frac{u^2(p_{rel})}{(p)^2} + \frac{u^2(p_{atm})}{(p)^2} \right)} \times (C_m)$$

Overall expanded uncertainty ( $k = 2$ )

$$U(C_m) = u(C_m) \times k$$

Uncertainty of the measured concentration at oxygen reference concentration

$$u(C_{m,O_2,ref}) = \sqrt{\left( \frac{u^2(Q_m)}{(Q_m)^2} + \frac{u^2(v_s)}{(v_s)^2} + \frac{u^2(V_{T.p})}{(V_{T.p})^2} + \frac{u^2(T)}{(T)^2} + \frac{u^2(p_{rel})}{(p)^2} + \frac{u^2(p_{atm})}{(p)^2} + \frac{u^2(O_{2,meas,dry})}{(21 - O_{2,meas,dry})^2} \right)} \times (C_{m,O_2,ref})$$

Where:

$u(C_{m,O_2,ref})$	=	uncertainty associated with the mass concentration at O <sub>2</sub> reference concentration	in	mg/m <sup>3</sup>
$C_{m,O_2,ref}$	=	mass concentration at O <sub>2</sub> reference concentration	in	mg/m <sup>3</sup>
$O_{2,meas}$	=	O <sub>2</sub> measured concentration	in	% volume
$u(O_{2,meas,dry})$	=	uncertainty associated to the measured O <sub>2</sub> concentration	in	% (relative to O <sub>2,meas</sub> )

## APPENDIX 4

## Uncertainty Estimate For The Measurement Of Total Particulate Matter BS EN 13284 - 1

### Total Particulate Matter Test 1

Symbol	Mass concentration of TPM	Units
$C_m$	1.78	mg/m <sup>3</sup>
$C_m$ at O <sub>2</sub> ref	24.20	mg/m <sup>3</sup>

Filter	1.28	mg
Washings	0.33	mg

Symbol	Reference Oxygen	Units
O <sub>2,ref</sub> (0=No Correction)	13	%

Symbol	Daily emission limit value	Units
DELV	20.0	mg/m <sup>3</sup>

#### Mass of Particulate

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	$c_i$	$U_i$	
$u(\text{calBal})$	Calibration	0.1180	mg	Normal	2	1	0.0590	
$u(\text{repBal})$	Repeatability Filter	0.0110	mg	Normal	1	2	0.0220	
$u(\text{repBal})$	Repeatability Washings	0.0300	mg	Normal	1	2	0.0600	
$u(\text{driftBal})$	Drift	0.0312	mg	Rectangular	$\sqrt{3}$	1	0.0180	
$u(\text{resBal})$	Resolution	0.0050	mg	Rectangular	$\sqrt{3}$	1	0.0029	
$u(\text{aceBal})$	Residual acetone	0.0400	mg	Normal	2	1	0.0200	
$u(\text{buoBal})$	Air buoyancy	0.0015	mg	Normal	1	1	0.0015	
$u(\text{mass})$	Combined Uncertainty	-	-	Normal	-	-	0.0911	
$u(\text{mass})/\text{mass}$	Relative	2.050	mg	-	-	-	0.0511	
							$u(\text{mass})^2/\text{mass}^2$	0.002616

U(Wm)	Expanded Combined Weighing Uncertainty As Percentage of DELV k=2	±	0.91	%

#### Volume of sampled gas

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	$c_i$	$U_i$	
$u(\text{calV}_{T,p})$	Calibration	0.0056	m <sup>3</sup>	Normal	2	1	0.0028	
$u(\text{repV}_{T,p})$	Repeatability	0.0006	m <sup>3</sup>	Normal	1	1	0.0006	
$u(\text{driftV}_{T,p})$	Drift	0.0031	m <sup>3</sup>	Rectangular	$\sqrt{3}$	1	0.0018	
$u(\text{resV}_{T,p})$	Resolution	0.0002	m <sup>3</sup>	Rectangular	$\sqrt{3}$	1	0.0001	
$u(V_{T,p})$	Combined Uncertainty	-	-	Normal	-	-	0.0034	
$u(V_{T,p})/V_{T,p}$	Relative	1.151	m <sup>3</sup>	-	-	-	0.0030	
							$u(V_m)^2/V_m^2$	0.000009

#### Temperature of the DGM

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	$c_i$	$U_i$	
$u(\text{calT}_m)$	Calibration	1.0	K	Normal	2	1	0.5000	
$u(\text{calT}_m)$	Calibration	1.0	K	Normal	2	1	0.5000	
$u(\text{resT}_m)$	Resolution	0.1	K	Rectangular	$\sqrt{3}$	1	0.0577	
$u(\text{driftT}_m)$	Drift	1.0	K	Rectangular	$\sqrt{3}$	1	0.5774	
$u(T_m)$	Combined Uncertainty	-	-	Normal	-	-	0.9147	
$u(T_m)/T_m$	Relative	298.1	K	Normal	-	-	0.0031	
							$u(T_m)^2/T_m^2$	0.000009

#### Atmospheric Pressure

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	$c_i$	$U_i$	
$u(P_{\text{atm}})$	Metrological Office	300	Pa	Normal	$\sqrt{3}$	1	173	
$u(P_{\text{atm}})$	Combined Uncertainty	-	-	Normal	-	-	173	
$u(P_{\text{atm}})/P$	Relative	98700	-	Normal	-	-	0.0018	
							$u(P_{\text{atm}})^2/P^2$	0.000003

#### Relative DGM Pressure

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	$c_i$	$U_i$	
$u(P_{\text{rel}})$	DGM Pressure	40	Pa	Normal	1	1	40	
$u(P_{\text{rel}})$	Combined Uncertainty	-	-	Normal	-	-	40	
$u(P_{\text{rel}})/P$	Measured pressure	99722	-	-	-	-	0.0004	
							$u(P_{\text{rel}})^2/P^2$	0.0000002

#### Oxygen reference concentration

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	$c_i$	$U_i$
$u((\text{O}_2, \text{meas})_{\text{dry}})_{\text{rel}}$	Measurement of oxygen	0.28	%	Normal	1	1	0.2819
	Uncertainty of oxygen correction	-	-	-	-	-	0.4787
	Measured Oxygen	20.4	%	-	-	-	0.115841

#### Measurement uncertainty

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	$c_i$	$U_i$
$u(C_m)$	Combined Standard Uncertainty				±	0.13	mg/m <sup>3</sup>
$u(C_m)$ at ref O <sub>2</sub>	Combined Standard Uncertainty				±	8.42	mg/m <sup>3</sup>

#### Expanded uncertainty expressed with a level of confidence of 95%, k=2

Symbol	Expanded Combined Uncertainty	k = 2	±	0.26	mg/m <sup>3</sup>
U(Cm)	Expanded Combined Uncertainty	k = 2	±	14.5	%
U(Cm,rel,ELV)	Expanded Combined Uncertainty	k = 2	±	1.3	%

#### Expanded uncertainty at oxygen reference conditions expressed with a level of confidence of 95%, k=2

Symbol	Expanded Combined Uncertainty	k = 2	±	16.84	mg/m <sup>3</sup>
U(Cm) at ref O <sub>2</sub>	Expanded Combined Uncertainty	k = 2	±	945.5	%
U(Cm,rel) at ref O <sub>2</sub>	Expanded Combined Uncertainty	k = 2	±	84.2	%

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor (k = 2), providing a level of confidence of approximately 95%

The uncertainty evaluation has been carried out in accordance with UKAS requirements.



## Uncertainty Estimate For The Measurement Of Heavy Metals BS EN 14385 - Lead

## Total Mass Concentration Of Metals

Symbol	Total mass concentration of Lead	Units
Cm	0.77826	mg/m <sup>3</sup>
Cm at O2 ref	14.23102	mg/m <sup>3</sup>

## Mass of heavy metals in filter digest

	Qmf (mg)	LODmf	u(Qmf) % (k = 2)	u(Qmf)/Qmf	u(Qmf) <sup>2</sup> /Qmf <sup>2</sup>
Lead (Pb)	920.000	0.500	23.000	0.115	0.013

## Concentration of heavy metals absorption solution

	Qm (mg/l)	LODm	u(Qm) % (k = 2)	u(Qm)/Qm	u(Qm) <sup>2</sup> /Qm <sup>2</sup>
Lead (Pb)	61.000	0.300	20.500	0.103	0.011

## Volume of sampled gas

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	ci	Ui
u(calVT.p)	Calibration	0.0028	m3	Normal	1.000	1.000	0.003
u(driftVT.p)	Drift	0.0027	m3	Rectangular	$\sqrt{3}$	1.000	0.002
u(resVT.p)	Resolution	0.0002	m3	Rectangular	$\sqrt{3}$	1.000	0.000
u(VT.p)	Combined Uncertainty	-	-	Normal	-	-	0.003
u(VT.p)/VT.p	Relative uncertainty	1.234	m3	-	-	-	0.003
						u(Vm) <sup>2</sup> /Vm <sup>2</sup>	0.000007

## Temperature of the DGM

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	ci	Ui
u(calTm)	Calibration	1.0	K	Normal	2.000	1.000	0.500
u(calTcm)	Calibration	1.0	K	Normal	2.000	1.000	0.500
u(resTm)	Resolution	0.5	K	Rectangular	$\sqrt{3}$	1.000	0.289
u(Tm)	Combined Uncertainty	-	-	Normal	-	-	0.764
u(Tm)/Tm	Relative uncertainty	302	K	Normal	-	-	0.003
						u(Tm) <sup>2</sup> /Tm <sup>2</sup>	0.000006

## Atmospheric Pressure

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	ci	Ui
u(Patm)	Metrological Office	300	Pa	Normal	1.000	1.000	300
u(Patm)	Combined Uncertainty	-	-	Normal	-	-	300
u(Patm)/P	Relative uncertainty	98700	-	Normal	-	-	0.003
						u(Patm) <sup>2</sup> /P <sup>2</sup>	0.000009

## Relative DGM Pressure

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	ci	Ui
u(Prel)	Manometer	40	Pa	Normal	1.000	1.000	40.000
u(Prel)	Combined Uncertainty	-	-	Normal	-	-	40.000
u(Prel)/P	Relative uncertainty	99804	-	Normal	-	-	0.0004
						u(Prel) <sup>2</sup> /P <sup>2</sup>	0.0000002

## Volume (mass) of Absorption Solution

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	ci	Ui
u(repsv)	Repeatability	0.13	g (ml)	Normal	1.000	1.000	0.130
u(calvs)	Calibration (Tare)	0.10	g (ml)	Rectangular	1.000	1.000	0.100
u(drsv)	Drift	0.10	g (ml)	Rectangular	1.000	1.000	0.100
u(resvs)	Resolution	0.05	g (ml)	Rectangular	$\sqrt{3}$	1.000	0.029
u(vs)	Combined Uncertainty	-	-	-	-	-	0.194
u(vs)/vs	Relative uncertainty	304	-	Normal	-	-	0.0006
						u(vs) <sup>2</sup> /vs <sup>2</sup>	0.0000004

## Oxygen reference concentration

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	ci	Ui
u(O <sub>2</sub> ,meas)dry)rel	Measurement of oxygen	0.28	%	Normal	1	1	0.282
	Uncertainty of oxygen correction	-	-	-	-	-	0.6443
	Measured Oxygen	20.6	%	-	-	u(Orel) <sup>2</sup> /O <sup>2</sup>	0.091695

u(Cm)rel	Overall Combined Uncertainty	mg/m3	Total Lead	±		0.1199
U(Cm)rel	Expanded Combined Uncertainty	mg/m3	Total Lead	k = 2	±	0.2399
U(Cm,rel)	Expanded Combined Uncertainty	% of ELV	Total Lead	k = 2	±	4.8
u(Cmrel) at ref O2	Expanded Combined Uncertainty	mg/m3	Total Lead	k = 2	±	9.671
U(Cm,rel)	Expanded Combined Uncertainty	% of ELV	Total Lead	k = 2	±	4.8

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor (k = 2), providing a level of confidence of approximately 95%.

The uncertainty evaluation has been carried out in accordance with UKAS requirements.