REC Environmental Monitoring

Client **Staffordshire Crystal Ltd.**
Unit 14 Pedmore Road Ind. Estate
Brierly Hill
West Midlands
DY5 1TJ

Part 1: Executive Summary

Report for the Periodic Monitoring of Emissions to Air.

Site	**Brierly Hill**
Plant	**Wet Arrestor**
Sampling Date	**14th October 2014**
Report Date	**25th November 2014**
Job Number	**2p71962**
Permit Number	**PB/98 Variation 200839393**

Report Prepared by: ***Print*** **Graham Rowley**

MCERTS No. **MM 03 148** **Level 2 TE: 1,2,3,4**

Report Approved by: ***Sign*** EBuffam

Print **Emily Buffam**

MCERTS No. **MM 04 502** **Level 2 TE: 1,2,3,4**

mCERTS THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

ilac-MRA

UKAS TESTING

1783

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Tel: 0845 676 9303
Company Registration No 08343822

a CONCEPT LIFE SCIENCES company

Contents

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
Wet Arrestor	**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 Wet Arrestor	Sampling Time			Emission Result	Authorised Limit	Uncertainty +/-	Detection Limit	Mass Emission
		Date	Start	End	mg/m^3*	mg/m^3*	mg/m^3*	mg/m^3*	g/h
	Particulate	14/10/14	15:24	16:04	1.09	20	0.26	0.71	5.18
s	Lead	14/10/14	14:28	15:08	0.009	5	0.003	0.001	0.044

* at reference conditions	Stack Gas Weight	0 °C	Without correction for moisture
	29.00 Kg/kmol	101.3 kPa	Oxygen No Correction %

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

Throughout Report:

*	Reference conditions (see above)	Nm³	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.

Operating Information

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

Date	Process type	Process duration	Fuel	Feedstock	Abatement	Load
14/10/2014	**Process Extraction**	**Continuous**	**-**	**Glass**	**Water Trough**	**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 $1m^2$.

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.

The impinger efficiency check for lead was not performed because the measured emission was less than 30% of the emission limit value.

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.

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	Print	**Emily Buffam**	
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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^{o}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
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	14/10/2014
Time	13:30
Pitot Cp	0.85

Barometric pressure	98.9	kPa
Duct static pressure	-0.02	kPa
Stack Area	0.302	m^2

Stack Diameter (circular)	0.62	m

Traverse Point	Traverse Line	Depth cm	ΔP mmH_2O	T ^oC	Angle ^{o}	velocity m/s	Traverse Line	Depth cm	ΔP mmH_2O	T ^oC	Angle ^{o}	velocity m/s
1	A	5.0	2.0	16	<15	4.9	B	5.0			<15	
2	A	5.0	2.0	16	<15	4.9	B	5.0			<15	
3	A	7.3	1.5	16	<15	4.2	B	7.3			<15	
4	A	11.0	2.0	16	<15	4.9	B	11.0			<15	
5	A	15.5	2.5	16	<15	5.5	B	15.5			<15	
6	A	22.1	2.5	16	<15	5.5	B	22.1			<15	
7	A	39.9	2.0	16	<15	4.9	B	39.9			<15	
8	A	46.5	3.0	16	<15	6.0	B	46.5			<15	
9	A	51.0	2.5	16	<15	5.5	B	51.0			<15	
10	A	54.7	3.0	16	<15	6.0	B	54.7			<15	
11	A	57.0	4.0	16	<15	6.9	B	57.0			<15	
12	A	57.0	2.5	16	<15	5.5	B	57.0			<15	

Average Pitot DP	2.42	mmH_2O
Average Temperature	289.2	K
Average Velocity	5.4	m/s
Average volumetric flow rate	1.62	m^3/s at stack conditions
Average volumetric flow rate	1.49	m^3/s (wet STP)

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

a	Angel of gas flow less than 15^o 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	4.2
	Maximum local gas velocity	6.9
	Ratio of highest to lowest local gas velocity	1.63

Moisture Determination BS EN 14790:2005

	Volume m^3	Temp ^oC	Pressure mbar
Meter start	5.470	14	989
Meter end	6.188	16	989
Meter Yd	1.002		
Gas volume	0.666		

Impinger	1	2	3	4	5
Mass start (g)	679.9	726.3	754.6	583.3	947.5
Mass End (g)	680.0	728.6	755.5	584.0	951.5
Total Mass collected (g)		8.0			

Water vapour content (% v/v)	1.5

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

Preliminary Velocity Traverse & Moisture Data

Probe/Pitot ID No		P48/PT113
Pitot Calibration Factor (Cp)		0.85
Gas Calibration Factor (Y)		1.002
Barometric Pressure	kPa	98.9
Duct static Pressure	kPa	-0.02
Date		14/10/2014
Start Time	hh:min	15:24
End Time	hh:min	16:04
Sampling Duration	hh:min	00:40

Nozzle Diameter (d)	mm	9.07
In-stack Filtration	Y/N	N
Leak check OK	Y/N	Y
Meter ID No		CU13
Initial Gas Meter Reading	m^3	6.402
Final Gas Meter Reading	m^3	7.144
Sampled Vol, Dry at Meter	m^3	0.742
Sampled Vol, Dry STP	Nm^3	0.686
Moisture content of stack gas	% v/v	2.1
Isokinetic	%	101.6

Impinger	1	2	3	4
Initial mass (g)	678.0	679.7	565.5	947.5
Final mass (g)	676.6	682.1	566.6	957.3

Sample Point Number	Line	Sampling Time hh:min	Pitot Reading (h) mm w.g	Temperatures: Sample Gas Temperature (Ts) °C	Temperatures: Filter Temperature °C	Temperatures: Meter Temperature (Tm) °C	Orifice Pressure (Dh) mm w.g
1	A	00:00	1.75	16	158	17	31.0
		00:05	1.75	16	160	17	31.0
		00:10	1.75	16	160	17	31.0
		00:15	2.0	16	160	17	35.0
2	A	00:20	2.0	15	160	17	35.0
		00:25	2.0	15	160	17	35.0
		00:30	2.0	16	160	17	35.0
		00:35	2.0	16	160	17	35.0
		00:40					
		Averages	1.9	15.8	159.8	17.0	33.5

Average velocity	**4.76**	**m/s**
Average flow rate	**1.44**	**m^3/s**
Average flow rate	**1.33**	**m^3/s***

Total Particulate Matter - Sampling Data

Blank Filter Weight		Date of analysis	After (g)	Before (g)	Collected (g)	% of Filter Tare Weight
Filter No	X11379	24/10/2014	0.75280	0.75249	0.00031	
Washings	10401	20/10/2014	48.78087	48.78025	0.00062	0.1

Filter Weight Test 1		Date of analysis	After (g)	Before (g)	Collected (g)	% of Filter Tare Weight
Filter No	X11380	24/10/2014	0.73985	0.74003	-0.00018	
Washings	10402	20/10/2014	47.80151	47.80101	0.00050	0.0

Sample Number	Hopper Or Filter No	Total weights (g)			Control Blank Corrected	Comments
		After	Before	Collected		
Blank	X11379	49.53367	49.53274	0.00093	0.00137	
Test 1	X11380	48.54136	48.54104	0.00032	0.00076	

Washings Control Blank Weight Variance	-0.00044	Acetone Residue Weight	<1ppm

Particulate emission results	Blank	
Detection Limit	0.71	mg/m^3*
Particulate Emission	1.96	mg/m^3*

Particulate Emission Results	Test 1	
Detection Limit	0.71	mg/m^3*
Particulate Emission	1.09	mg/m^3*

Total Particulate Matter - Emission Results

Probe/Pitot ID No		P48/PT113	Nozzle Diameter (d)	9.07	mm
Pitot Calibration Factor (Cp)		0.85	In-stack Filtration	N	Y/N
Probe liner material		Titanium	Leak check OK	Y	Y/N
Gas Calibration Factor (Y)		1.002	Meter ID No	CU13	
Barometric Pressure	kPa	98.9	Initial Gas Meter Reading	5.470	m³
Duct static Pressure	kPa	-0.02	Final Gas Meter Reading	6.188	m³
Date		14/10/2014	Sampled Vol, Dry at Meter	0.718	m³
Start Time	hh:min	14:28	Sampled Vol, Dry STP	0.668	Nm³
End Time	hh:min	15:08	Moisture content of stack gas	1.5	% v/v
Sampling Duration	hh:min	00:40	Isokinetic	99.2	%

Impinger	1	2	3	4	5
Initial mass (g)	679.9	726.3	754.6	583.3	947.5
Final mass (g)	680.0	728.6	755.5	584.0	951.5

Sample Point Number	Line	Sampling Time hh:min	Pitot Reading (h) mm w.g	Temperatures: Sample Gas Temperature (Ts) °C	Meter Temperature (Tm) °C	Probe Temperature °C	Filter Temperature °C	Orifice Pressure (Dh) mm w.g
1	A	00:00	2.0	16	14	160	159	35.0
		00:05	2.0	16	14	160	159	35.0
		00:10	2.0	16	14	160	160	35.0
		00:15	2.0	16	15	160	160	35.0
2	A	00:20	1.5	16	16	160	160	26.0
		00:25	1.5	16	16	160	160	26.0
		00:30	2.0	16	16	160	159	35.0
		00:35	2.0	16	16	160	160	35.0
		00:40						
		Averages	1.9	16.0	15.1	160.0	159.6	32.8

Average velocity	**4.72**	**m/s**
Average flow rate	**1.43**	**m³/s**
Average flow rate	**1.31**	**m³/s***

Lead - Sampling Data

Date	14/10/2014
Start time	14:28
Finish time	15:08
Sample volume Nm^3 (dry gas)	0.668

HEAVY METALS	Impinger mass	
Impinger 1,2 & wash	250.9	g
Impinger 3 & wash	158.2	g

Measured moisture concentration	1.47	% v/v
Measured oxygen concentration	N/A	%

HEAVY METALS	Filter Analysis 2p71962/07	Particulate Phase Emission	Impinger 1 & 2 Analysis 2p71962/08	Vapour phase Emission Impinger 1& 2	Impinger 3 Analysis 2p71962/09	Vapour phase Emission Impinger 3	Detection Limit	Efficiency % Trapped In impinger 3	Total Emission
Units	µg	mg/m³*	µg/l	mg/m³*	µg/l	mg/m³*	mg/m³*	%	mg/m³*
Lead (Pb)	4.90	0.00723	4.80	0.00178	1.20	0.00028	0.00092	N/A	0.009288

TOTAL HEAVY METALS Particulate Phase & Vapour Phase	Total Emission mg/m³*	Detection Limits mg/m³*	Total Emission As % ELV
Total heavy metals, Pb	0.00929	0.00092	1.9

Numbers in bold indicate detection limits

Metals excluding Mercury

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

Lead - Emission Result

Date	14/10/2014
Start time	14:28
Finish time	15:08
Sample volume Nm^3 (dry gas)	0.668

HEAVY METALS	Impinger mass	
Impinger 1,2 & wash	142.9	g
Impinger 3 & wash	146.7	g

Measured moisture concentration	1.47	% v/v
Measured oxygen concentration	N/A	%

HEAVY METALS	Filter Analysis 2p71962/04	Particulate Phase Emission	Impinger 1 & 2 Analysis 2p71962/05	Vapour phase Emission Impinger 1& 2	Impinger 3 Analysis 2p71962/06	Vapour phase Emission Impinger 3	Detection Limit	Efficiency % Trapped In impinger 3	Total Emission
Units	µg	mg/m³*	µg/l	mg/m³*	µg/l	mg/m³*	mg/m³*	%	mg/m³*
Lead (Pb)	**0.50**	0.00000	**0.30**	0.00000	**0.30**	0.00000	0.00087	N/A	0.000000

TOTAL HEAVY METALS Particulate phase & Vapour phase	Total Emission mg/m³*	Detection Limits mg/m³*	Total Emission As % ELV
Total heavy metals, Pb	0.00000	0.00087	0.0

Numbers in bold indicate detection limits

Metals excluding Mercury

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

Lead - Field Blank Emission Result

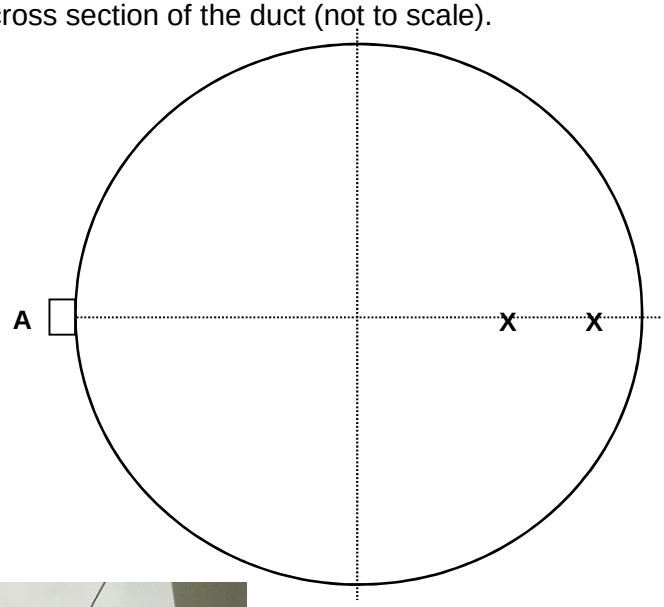
APPENDIX 3

Diagram Of The Sampling Location

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

Traverse length = 0.62 m

Point	% of D	Location cm
1	6.7	4.2
2	25.0	15.5



General Calculations

Stack area:

$$Area\,of\ a\,circle = \frac{\pi.D^2}{4}$$

D = Diameter (m)
π = 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):

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

VWC (%) = Water vapour content on wet basis, in volume % (m^3 of water vapour in m^3 of wet gas)
Vm(std) = Dry gas volume measured, corrected to standard conditions (m^3)
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 (m3/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^3)
yd = Gas meter calibration coefficient
(V2-V1) = Dry gas meter volume at actual conditions (m^3)
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):

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

Estimating Measurment 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):

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

$\bar{v}$ = Average velocity (m/s)
C = velocity calculation constant = 129
Ts = Average stack temperature (K)
Ms = Molar mass of gas; assume 29 kg/kmol unless the molar mass is < 27 kg/kmol or > 31 g/kmol
K = Pitot calibration coefficient
Pe = Absolute gas pressure (kPa)
$\Delta\bar{p}$ = Average pitot tube pressure differencial (kPa)

Volume flow rate
From reference calculations (taken from ISO 10780):

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

qva = Average flow rate (m^3/s)
$\bar{v}$ = Average velocity (m/s)
A = Stack cross-sectional area (m^2)

Volume flow rate corrected for moisture
From reference calculations (taken from BS ISO 9096):

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

qm = Corrected volume flowrate (m^3/s)
qva = Volume flow rate at actual conditions (m^3/s)
Ha = Moisture at actual conditions (%volume)
Hm = Reference moisture (%volume)

Volume flow rate corrected for temperature and pressure
From reference calculations (taken from BS ISO 9096):

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

qm = Corrected volume flowrate (m^3/s)
qva = Volume flow rate at actual conditions (m^3/s)
Ta = Temperature at actual conditions (K)
Tm = Reference Temperatue (K)
pa = Absolute gas pressure at actual conditions (kPa)
pm = Reference pressure (kPa)

Volume flow rate corrected for oxygen
From reference calculations (taken from BS ISO 9096):

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

qm = Corrected volume flowrate (m^3/s)
qva = Volume flow rate at actual conditions (m^3/s)
O2,m = Actual oxygen concentration (%)
O2,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 substane
V = Volume sampled

Mass Emission

$$Mass\ emission = c \times q_m$$

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
O2, ref = Reference oxygen (%)
O2, 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

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

cwet = Concentration wet gas
cdry = Concentration dry gas
Ha = Water vapour content (%vol)

Conversion of parts per million (ppm) to mg/m^3
From reference calculations (taken from EA TGN M2):

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

molar volume at 273K = 22.4 litres

When Converting TOC

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

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^3
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^3
T_m	=	mean temperature of gas meter	in	K
T_{std}	=	standard temperature	=	273K
p=prel+Patm	=	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^3

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 negliable
Expression for calculation of the combined uncertainty of the measured concentration

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

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

Overall expanded uncertainty (k = 2)

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

Uncertainty of the measured concentration at oxygen reference concentration

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

Where:

u(Cm,$O_{2,ref}$)	=	uncertainty associated with the mass concentration at O_2 reference concentration	in	mg/m^3
Cm,$O_{2,ref}$	=	mass concentration at O_2 reference concentration	in	mg/m^3
$O_{2,meas}$	=	O_2 measured concentration	in	% volume
u(($O_{2,meas)dry}$)	=	uncertainty associated to the measured O_2 concentration	in	% (relative to $O_{2\ meas}$)

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
Cm	1.11	mg/m^3
Cm at O2 ref	N/A	mg/m^3

Filter	-0.18	mg
Washings	0.50	mg

Symbol	Reference Oxygen	Units
O2,ref (0=No Correction)	0	%

Symbol	Daily emission limit value	Units
DELV	20.0	mg/m^3

Mass of Particulate

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	*ci*	*Ui*
u (calBal)	Calibration	0.1180	mg	Normal	2	1	0.0590
u (repBal)	Repeatability Filter	0.0110	mg	Normal	1	2	0.0220
u (repBal)	Repeatability Washings	0.0300	mg	Normal	1	2	0.0600
u (driftBal)	Drift	0.0312	mg	Rectangular	$\sqrt{3}$	1	0.0180
u (resBal)	Resolution	0.0050	mg	Rectangular	$\sqrt{3}$	1	0.0029
u (aceBal)	Residual acetone	0.0400	mg	Normal	2	1	0.0200
u(buoBal)	Air buoyancy	0.0015	mg	Normal	1	1	0.0015
u (mass)	Combined Uncertainty	-		Normal	-	-	0.0911
u (mass)/mass	Relatve	0.760	mg	-	-	-	0.0822
						u $(mass)^2/mass^2$	0.006755

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	*ci*	*Ui*
u $(calV_{T,p})$	Calibration	0.0034	m^3	Normal	2	1	0.0017
u $(repV_{T,p})$	Repeatability	0.0003	m^3	Normal	1	1	0.0003
u $(driftV_{T,p})$	Drift	0.0019	m^3	Rectangular	$\sqrt{3}$	1	0.0011
u $(resV_{T,p})$	Resolution	0.0002	m^3	Rectangular	$\sqrt{3}$	1	0.0001
u $(V_{T,p})$	Combined Uncertainty	-	-	Normal	-	-	0.0020
u $(V_{T,p})/V_{T,p}$	Relatve	0.686	m^3	-	-	-	0.0030
						u $(Vm)^2/Vm^2$	0.000009

Temperature of the DGM

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	*ci*	*Ui*
u $(calTi_m)$	Calibration	1.0	K	Normal	2	1	0.5000
u $(calTc_m)$	Calibration	1.0	K	Normal	2	1	0.5000
u $(resT_m)$	Resolution	0.1	K	Rectangular	$\sqrt{3}$	1	0.0577
u $(driftT_m)$	Drift	1.0	K	Rectangular	$\sqrt{3}$	1	0.5774
u (T_m)	Combined Uncertainty	-	-	Normal	-	-	0.9147
u (T_m)/Tm	Relatve	290.0	K	Normal	-	-	0.0032
						u $(Tm)^2/Tm^2$	0.000010

Atmospheric Pressure

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	*ci*	*Ui*
u (P_{atm})	Metrological Office	300	Pa	Normal	$\sqrt{3}$	1	173
u (P_{atm})	Combined Uncertainty	-	-	Normal	-	-	173
u $(P_{atm})/P$	Relatve	98900	-	Normal	-	-	0.0018
						u $(P_{atm})^2/P^2$	0.000003

Relative DGM Pressure

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	*ci*	*Ui*
u (P_{rel})	DGM Pressure	40	Pa	Normal	1	1	40
u (P_{rel})	Combined Uncertainty	-	-	Normal	-	-	40
u $(P_{rel})/P$	Measured pressure	99229	-	-	-	-	0.0004
						u $(Prel)^2/P^2$	0.0000002

Oxygen reference concentration

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	*ci*	*Ui*
u $((O_2,meas)dry)rel$	Measurement of oxygen	N/A	%	Normal	1	1	N/A
	Uncertainty of oxygen correction	-	-	-	-	-	N/A
	Measured Oxygen	N/A	%			*u* $(Orel)^2/O^2$	N/A

Measurement uncertainty

u(Cm)	Combined Standard Uncertainty			±	0.13	mg/m^3
u(Cm) at ref O_2	Combined Standard Uncertainty			±	N/A	mg/m^3

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

U(Cm)	Expanded Combined Uncertainty	*k = 2*		±	0.26	mg/m^3
U(Cm,rel)	Expanded Combined Uncertainty	*k = 2*		±	23.3	%
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

U(Cm) at ref O_2	Expanded Combined Uncertainty	*k = 2*		±	N/A	mg/m^3
U(Cm_{rel}) at ref O_2	Expanded Combined Uncertainty	*k = 2*		±	N/A	%
U(Cm,rel,ELV) at ref O_2	Expanded Combined Uncertainty	*k = 2*		±	N/A	%

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	0.00943	mg/m^3
Cm at O2 ref	N/A	mg/m^3

Mass of heavy metals in filter digest

	Qmf (mg)	LODmf	u(Qmf) % (k = 2)	u(Qmf)/Qmf	u(Qmf)2/Qmf2
Lead (Pb)	4.900	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)2/Qm2
Lead (Pb)	4.800	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	0.668	m3	-	-	-	0.005
						u(Vm)2/Vm2	0.000023

Temperature of the DGM

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	ci	Ui
u(calTim)	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	288	K	Normal	-	-	0.003
						u(Tm)2/Tm2	0.000007

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	98900	-	Normal	-	-	0.003
						u(Patm)2/P2	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	99221	-	Normal	-	-	0.0004
						u(Prel)2/P2	0.0000002

Volume (mass) of Absorption Solution

Symbol	Source of Uncertainty	Value	Units	Probability Distribution	Divisor	ci	Ui
u(repvs)	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(drvs)	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	251	-	Normal	-	-	0.0008
						u(vs)2/vs2	0.0000006

u(Cm)rel	Overall Combined Uncertainty	mg/m3	Total Lead		±	0.0015

U(Cm)rel	Expanded Combined Uncertainty	mg/m3	Total Lead	k = 2	±	0.0029
U(Cm,rel)	Expanded Combined Uncertainty	% of ELV	Total Lead	k = 2	±	0.1

u(Cmrel) at ref O2	Expanded Combined Uncertainty	mg/m3	Total Lead	k = 2	±	N/A
U(Cm,rel)	Expanded Combined Uncertainty	% of ELV	Total Lead	k = 2	±	N/A

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.