STACK EMISSIONS MONITORING REPORT

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Operator & Address:
North East Lincolnshire Council Great Grimsby Crematorium Weelsby Avenue Grimsby Crematorium DN32 0BA

Permit Reference:
DEFRA Process Guidance Note: PG 5/2 (12)

Release Point:
Abatement System

Sampling Date(s):
19th & 20th February 2019

SOCOTEC UK Job Number:	LNO 14827
Report Date:	11th March 2019
Version:	1
Report By: MCERTS Number: MCERTS Level: Technical Endorsements:	Lawrence Mason MM 07 849 MCERTS Level 2 - Team Leader 1, 2, 3 & 4
Report Approved By: MCERTS Number: Business Title: Technical Endorsements: Signature:	Dave Armitage MM 04 516 MCERTS Level 2 - Team Leader 1, 2, 3 & 4 

UKAS TESTING
1015

mCERTS THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

CONTENTS

EXECUTIVE SUMMARY

MONITORING OBJECTIVES

North East Lincolnshire Council operates a cremator process at Great Grimsby Crematorium which is subject to DEFRA Process Guidance Note PG 5/2 (12), under the Environmental Permitting Regulations 2010.

SOCOTEC UK LTD were commissioned by North East Lincolnshire Council to carry out stack emissions monitoring to determine the release of prescribed pollutants from the following Plant under normal operating conditions.

The results of these tests shall be used to demonstrate compliance with a set of emission limit values for prescribed pollutants as specified in the Plant's DEFRA Process Guidance Note, PG 5/2 (12).

Plant

Abatement System

Operator

North East Lincolnshire Council
Great Grimsby Crematorium
Weelsby Avenue
Grimsby Crematorium
DN32 0BA

DEFRA Process Guidance Note: PG 5/2 (12)

Stack Emissions Monitoring Test House

SOCOTEC UK - Stockport Laboratory
Unit 5 Crown Industrial Estate
Kenwood Road
Stockport
SK5 6PH
UKAS and MCERTS Accreditation Number: 1015

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.
MCERTS accredited results will only be claimed where both the sampling and analytical stages are UKAS accredited.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Limit**	**MCERTS accredited result**
Total Particulate Matter	mg/m³	1.9	0.64	20	✓
Particulate Emission Rate	g/hr	4.0	1.3	-	
Mercury	mg/m³	0.01	0.002	0.05	✓
Mercury Emission Rate	g/hr	0.02	0.003	-	
Hydrogen Chloride	mg/m³	2.1	0.21	30	✓
Hydrogen Chloride Emission Rate	g/hr	5.3	0.53	-	
Volatile Organic Compounds	mg/m³	1.7	0.77	10	✓
Volatile Organic Compounds Emission Rate	g/hr	3.7	1.7	-	
Carbon Monoxide	mg/m³	16	16	100	✓
Carbon Monoxide Emission Rate	g/hr	35	36	-	
Oxygen	% v/v	12.7	1.6	-	✓
Moisture	%	6.2	0.21	-	✓
Stack Gas Temperature	°C	104	-	-	✓
Stack Gas Velocity	m/s	6.9	0.17	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	3645	205	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	2627	148	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	2465	138	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	2220	125	-	

ND = None Detected,

Results at or below the limit of detection are highlighted by bold italic text.

The above volumetric flow rate is an average of the data collected during the isokinetic tests. Mass emissions for non isokinetic tests are also calculated using these values.

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
Total Particulate Matter Run 1	19 February 2019	10:09 - 11:09	60 minutes
Total Particulate Matter Run 2	19 February 2019	11:20 - 12:20	60 minutes
Total Particulate Matter Run 3	20 February 2019	11:08 - 12:08	60 minutes
Mercury Run 1	20 February 2019	12:29 - 13:39	60 minutes
Hydrogen Chloride Run 1	19 February 2019	10:09 - 11:09	60 minutes
Volatile Organic Compounds Run 1	19 February 2019	10:09 - 11:09	60 minutes
Combustion Gases	19 February 2019	10:09 - 12:20	120 minutes
Preliminary Stack Traverse	13 February 2019	09:30	-

EXECUTIVE SUMMARY

PROCESS DETAILS

CREMATOR OPERATING INFORMATION				
Description of process		Cremator		
Continuous or batch		Batch		
Abatement		Carbon/sodium injected bag filter		
Plume Appearance		None visible		
TEST SPECIFIC DETAILS	**Run 1**	**Run 2**	**Run 3**	**Run 4**
Coffin Type	MDF	MDF, MDF	MDF, MDF	MDF, MDF
Sex	Male	Male, Female	Male, Male	Male, Male
Body Size	Medium	Medium, Small	Medium, Medium	Medium, Medium
Cremation Number	104881	104881, 104882	104888, 104889	104889, 104890

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by SOCOTEC UK is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency Technical Guidance Note (Monitoring) M2.

MONITORING METHODS						
Species	**Method** Standard Reference Method / Alternative Method	**SOCOTEC UK Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Limit of Detection (LOD)**	**Calculated MU +/- %**
TPM	SRM - BS EN 13284-1	AE 104	1015	Yes	0.23 mg/m³	33%
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	Yes	0.0008 mg/m³	19%
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	0.002 mg/m³	10%
VOCs	SRM - BS EN 12619:2013	AE 102	1015	Yes	0.32 mg/m³	46%
CO	SRM - BS EN 15058:2017	AE 102	1015	Yes	0.86 mg/m³	103%
O_2	AM - BS EN 14789:2017	AE 102	1015	Yes	0.01%	13%
H_2O	SRM - BS EN 14790	AE 105	1015	Yes	0.01%	3.4%
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	5 Pa	2.4%
Volumetric Flow Rate	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	-	5.6%

EXECUTIVE SUMMARY

Analytical Methods

The following tables list the analytical methods employed together with the custody and archiving details:

SAMPLING METHODS WITH SUBSEQUENT ANALYSIS							
Species	**Analytical Technique**	**Analytical Procedure**	**UKAS Lab Number**	**UKAS Accredited Lab Analysis**	**Analysis Lab**	**Sample Archive Location**	**Archive Period**
TPM	Gravimetric	AE 106	1015	Yes	SOCOTEC UK (Stockport)	SOCOTEC UK (Stockport)	8 Weeks
Mercury	Inductively coupled Plasma - Mass Spectrometry	ASC/SOP/117	1015	Yes	SOCOTEC UK (Bretby)	SOCOTEC UK (Bretby)	8 Weeks
Hydrogen Chloride	Ion Chromatography	ASC/SOP/110	1015	Yes	SOCOTEC (Bretby)	SOCOTEC (Bretby)	8 Weeks

ON-SITE TESTING							
Species	**Analytical Technique**	**Analytical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Analysis**	**Laboratory**	**Data Archive Location**	**Archive Period**
VOCs	Flame Ionisation Detection	AE 102	1015	Yes	SOCOTEC UK (Stockport)	SOCOTEC UK (Stockport)	5 years
CO	Non Dispersive Infra Red	AE 102	1015	Yes	SOCOTEC UK (Stockport)	SOCOTEC UK (Stockport)	5 years
O_2	Zirconia Cell	AE 102	1015	Yes	SOCOTEC UK (Stockport)	SOCOTEC UK (Stockport)	5 years
H_2O	Gravimetric	AE 105	1015	Yes	SOCOTEC UK (Stockport)	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	29	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	6.4	m/s	-	-	-
Highest Gas Velocity	6.6	m/s	-	-	-
Ratio of Gas Velocities	1.0	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	6.5	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	°	< 15°	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Rectangular	-
Depth	0.32	m
Width	0.46	m
Area	0.15	m^2
Port Depth	90	mm

SAMPLING LINES & POINTS		
	Isokinetic	**Non-Iso & Gases**
Sample port size	4 inch BSP	4 inch BSP
Number of lines used	1	1
Number of points / line	4	1
Duct orientation	Vertical	Vertical
Filtration	Out Stack	Out Stack
Filtration for TPM	Out Stack	-

SAMPLING PLATFORM	
General Platform Information	
Permanent / Temporary Platform / Ground level / Floor Level / Roof	Permanent
Inside / Outside	Inside

M1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	Yes
Platform has 2 levels of handrails (approximately 0.5 m & 1.0 m high)	N/A
Platform has vertical base boards (approximately 0.25 m high)	N/A
Platform has removable chains / self closing gates at the top of ladders	Yes
Handrail / obstructions do not hamper insertion of sampling equipment	No
Depth of Platform = >Stack depth / diameter + wall and port thickness + 1.5m	No

Sampling Platform Improvement Recommendations (if applicable)

The sampling location is very small and does not comply with EA Guidance Note M1.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Sample Lines

Only one sample line was used due to a seized port cap. The number of points were doubled along the remaining line in accordance with the MID.

APPENDICES

CONTENTS

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	**Method** Standard Reference Method / Alternative Method	**SOCOTEC UK Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Number of Samples**
TPM	SRM - BS EN 13284-1	AE 104	1015	Yes	3
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	Yes	1
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	1
VOCs	SRM - BS EN 12619:2013	AE 102	1015	Yes	1
CO	SRM - BS EN 15058:2017	AE 102	1015	Yes	1
O_2	AM - BS EN 14789:2017	AE 102	1015	Yes	1
H_2O	SRM - BS EN 14790	AE 105	1015	Yes	1
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	1

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

CALIBRATEABLE EQUIPMENT CHECKLIST

Extractive Sampling		Instrumental Analyser/s		Miscellaneous	
Equipment	**Equipment I.D.**	**Equipment**	**Equipment I.D.**	**Equipment**	**Equipment I.D.**
Control Box DGM	LNO 13-08	Horiba PG-250 Analyser	LNO 21-14	Laboratory Balance	LNO 00-13, 00-12
Box Thermocouples	LNO 03-08	FT-IR Gasmet	-	Tape Measure	LNO 24-LM
Meter In Thermocouple	LNO 03-08	FT-IR Oven Box	-	Stopwatch	-
Meter Out Thermocouple	LNO 03-08	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17-08	Signal 3030 FID	-	Barometer	LNO 08-LM
Oven Box	LNO 09-12	Servomex	-	Digital Micromanometer	-
Probe	LNO 11-05	JCT Heated Head Filter	-	Digital Temperature Meter	-
Probe Thermocouple	LNO 10-05	Thermo FID	LNO 21-04	Stack Thermocouple	-
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LNO 06-LM	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LNO 14-05	Chiller (JCT/MAK 10)	LNO 21-102	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	LNO 03-132	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	LNO 31-LM	Site temperature Logger	LNO 12-LM	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	LNO 18-132
Inclinometer (Swirl Device)	LNO 23-LM		-	20m Heated Line (2)	-

NOTE: If the equipment I.D is represented by a dash (-), then this piece of equipment has not been used for this test.

CALIBRATION GASES

Gas (traceable to ISO 17025)	Cylinder I.D Number	Supplier	ppm	%	Analytical Tolerance +/- %
Oxygen	132545	BOC	-	9.99	2.0
Propane	HPC 2037	BOC	9.9	-	2.0
Carbon Monoxide	HPC 2018	BOC	164	-	2.0

STACK EMISSIONS MONITORING TEAM

MONITORING TEAM								
Personnel	**MCERTS Number**	**MCERTS**		**TE / H&S Qualifications and Expiry Date**				
		Level	**Expiry**	**TE1**	**TE2**	**TE3**	**TE4**	**H&S**
Lawrence Mason	MM 07 849	MCERTS Level 2	Sep-20	Jun-23	Dec-20	Sep-21	Sep-20	Jun-22
Joe Saxton	MM 18 1501	MCERTS Trainee	Sep-23	-	-	-	-	Sep-23

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY					
Parameter	Sampling Times	Concentration mg/m³	Uncertainty mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	10:09 - 11:09 19 February 2019	1.0	0.46	20	2.5
Run 2	11:20 - 12:20 19 February 2019	3.1	0.73	20	5.4
Run 3	11:08 - 12:08 20 February 2019	1.7	0.50	20	4.1
Blank	-	0.59	-	-	-
Blank 2	-	0.86	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

Acetone Blank Value mg/l	Acceptable Value mg/l
2.0	10

FILTER INFORMATION

SAMPLES								
Test	Filter & Probe Rinse Number	Filter Start Weight g	Filter End Weight g	Mass Gained on Filter g	Probe Rinse Start Weight g	Probe Rinse End Weight g	Mass Gained on Probe g	Combined Total Mass Gained g
Run 1	Q0628	0.13927	0.13993	0.00066	199.67110	199.67130	0.00020	0.00086
Run 2	Q0591	0.15030	0.15085	0.00055	186.26680	186.26800	0.00120	0.00175
Run 3	Q0645	0.14428	0.14472	0.00044	196.96510	196.96600	0.00090	0.00134

If total mass gained is less than the LOD then the LOD is reported

BLANKS								
Test	Filter & Probe Number	Filter Start Weight g	Filter End Weight g	Mass Gained Filter g	Probe Start Weight g	Probe End Weight g	Mass Gained Probe g	Combined Total Mass Gained g
Run 1	Q0592	0.14804	0.14824	0.00020	161.83810	161.83840	0.00030	0.00050
Run 2	Q0644	0.14110	0.14142	0.00032	190.84740	190.84780	0.00040	0.00072

If total mass gained is less than the LOD then the LOD is reported

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 1 — TPM

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	756.76
Stack static pressure, P_{static}	mm H_2O	2.04
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	756.91
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	46.0
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.057316
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.966
Gas meter correction factor, Y_d		0.966
Mean dry gas meter temperature, T_m	°	19.875
Mean pressure drop across orifice, DH	mmH_2O	21.754
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$	m^3	0.868
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9250
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		11.0
% oxygen reference condition		11
O_2 Reference Factor $\frac{O_2 \text{ Ref} = 21.0 - act\%O_2}{21.0 - ref\%O_2}$		1.00
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$	m^3	0.8677
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0620
	%	6.20
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.85
Mean of velocity heads, DP_{avg}	mm H_2O	3.05
Mean square root of velocity heads, ÖDP		1.75
Mean stack gas temperature, T_s	°C	91
$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	6.76

Molecular weight of dry gas, M_d		
CO_2	%	4.61
O_2	%	11.00
Total	%	15.61
N_2 (100 -Total)	%	84.39
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.18
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.48
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.15
$Q_a = (60)(A_s)(V_s)$	m³/min	59.7
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	41.8
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	41.82
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	44.59
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	7.88
Nozzle area, A_n	mm^2	48.73
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	104.4
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00066
Mass collected in probe, M_p	g	0.00020
Total mass collected, M_n	g	0.00086
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.930
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.991
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.991
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		2.49

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 2 — TPM

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	756.76
Stack static pressure, P_{static}	mm H_2O	0.00
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	756.76
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.898
Gas meter correction factor, Y_d		0.966
Mean dry gas meter temperature, T_m		23.958
Mean pressure drop across orifice, DH	mmH_2O	20.874
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$	m^3	0.795
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.8480
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		14
% oxygen reference condition		11
O_2 Reference Factor O_2 Ref $= \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		0.70
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	0.5568
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0620
	%	6.20
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.85
Mean of velocity heads, DP_{avg}	mm H_2O	3.05
Mean square root of velocity heads, ÖDP		1.75
Mean stack gas temperature, T_s	°C	111
$V_s = \frac{(K_p)(C_p)(ÖDP)(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	6.93

Molecular weight of dry gas, M_d		
CO_2	%	4.61
O_2	%	14.00
Total	%	18.61
N_2 (100 -Total)	%	81.39
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.30
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.60
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.15
$Q_a = (60)(A_s)(V_s)$	m³/min	61.2
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	40.6
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	28.44
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	43.32
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	7.88
Nozzle area, A_n	mm^2	48.73
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	98.5
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00055
Mass collected in probe, M_p	g	0.00120
Total mass collected, M_n	g	0.00175
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	2.06
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	2.20
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	3.14
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		5.36

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 3 — TPM

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	756.76
Stack static pressure, P_{static}	mm H_2O	2.04
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	756.91
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.895
Gas meter correction factor, Y_d		0.966
Mean dry gas meter temperature, T_m		18.042
Mean pressure drop across orifice, DH	mmH_2O	20.524
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		0.809
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.8623
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		11
% oxygen reference condition		11
O_2 Reference Factor $O_2\ Ref = \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		1.00
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	0.8089
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0620
	%	6.20
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.85
Mean of velocity heads, DP_{avg}	mm H_2O	3.05
Mean square root of velocity heads, ÖDP		1.75
Mean stack gas temperature, T_s	°C	110
$V_s = \frac{(K_p)(C_p)(\text{ÖDP})(\text{Ö}(T_s + 273))}{(M_s)(P_s)}$	m/s	6.94

Molecular weight of dry gas, M_d		
CO_2	%	4.61
O_2	%	11.00
Total	%	15.61
N_2 (100 -Total)	%	84.39
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.18
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.48
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.15
$Q_a = (60)(A_s)(V_s)$	m³/min	61.3
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	40.8
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	40.76
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	43.46
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	7.88
Nozzle area, A_n	mm^2	48.73
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	99.9
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00044
Mass collected in probe, M_p	g	0.00090
Total mass collected, M_n	g	0.0013
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	1.55
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	1.66
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	1.66
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		4.05

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER QUALITY ASSURANCE CHECKLIST

LEAK RATE						
Run	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable?
Run 1	15.55	0.14	0.14	-381	0.31	Yes
Run 2	14.45	0.14	0.13	-381	0.29	Yes
Run 3	14.41	0.13	0.13	-381	0.29	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	104.42	Yes
Run 2	98.54	Yes
Run 3	99.89	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m³	5% ELV mg/m³	LOD < 5% ELV
Run 1	0.23	1.0	Yes
Run 2	0.36	1.0	Yes
Run 3	0.25	1.0	Yes

The above is based on both the Filter and rinse uncertainty

BLANK VALUE				
Run	Overall Blank Value mg/m^3	Daily Emission Limit Value mg/m^3	Acceptable Blank Value mg/m^3	Overall Blank Acceptable mg/m^3
Blank 1	0.59	20	2.0	Yes
Blank 2	0.86	20	2.0	Yes

FILTERS					
Run	Filter Material	Filter Size mm	Max Filtration Temperature °C	Pre-use Filter Conditioning Temperature °C	Post-use Filter Conditioning Temperature °C
Run 1	Quartz Fibre	47	150	180	160
Run 2	Quartz Fibre	47	150	180	160
Run 3	Quartz Fibre	47	150	180	160

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MERCURY SUMMARY - PARTICULATE & VAPOUR PHASES COMBINED

Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	12:29 - 13:39 20 February 2019	0.01	0.001	0.05	0.02
Field Blank	-	0.001	-	-	-

Mercury	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mean mg/m³	Lab Result ug	Concentration mg/m³	Stack LOD mean mg/m³	Lab Result ug	Concentration mg/m³
Run 1	0.00075	0.50	0.00075	0.0000	5.82	0.009
Volume Sampled m^3		0.6631			0.6631	

Field Blank	-	0.50	0.00075	-	0.02	0.00002
Volume Sampled m^3		0.6631			0.6631	

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1 — Mercury

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	756.8
Stack static pressure, P_{static}	mm H_2O	2.0
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	756.9
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.924
Gas meter correction factor, Y_d		0.9657
Mean dry gas meter temperature, T_m		20.17
Mean pressure drop across orifice, DH	mr	19.38
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		0.83
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.8837
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		13.0
% oxygen reference condition		11
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		0.80
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	0.663
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0620
	%	6.20
Moisture by FTIR	%	-

Molecular weight of dry gas, M_d		
CO_2	%	4.61
O_2	%	13.00
Total	%	17.61
N_2 (100 -Total)	%	82.39
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.26
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.56
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.85
Mean of velocity heads, DP_{avg}	mm H_2O	3.00
Mean square root of velocity heads, ÖDP		1.73
Mean stack gas temperature, T_s	°C	129
$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	7.04
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.15
$Q_a = (60)(A_s)(V_s)$	m^3/min	62.2
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	39.4
$Q_{std02} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O2ref	31.5
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	42.0
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	7.88
Nozzle area, A_n	mm^2	48.73
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	105.8
Acceptable isokinetic range 95% to 115%		Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS QA CHECKLIST

Leak Test Results	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable litre/min
Run 1	14.9	0.12	0.13	-355.6	0.30	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	105.8	Yes

Filtration / Temp	Filter Material	Filter Size mm	Maximum Filtration Temperature °C	Maximum storage / transit Temperature °C
Run 1	Quartz Fibre	47	180	16

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS ABSORBTION EFFICIENCY

Parameter		Total ug	5th Absorber ug	Absorption Efficiency	Required	Pass / Fail
Mercury	Run 1	6.32	0.15	98	95	N/A <30% ELV

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HYDROGEN CHLORIDE SUMMARY					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	10:09 - 11:09 19 February 2019	2.1	0.002	30	5.3
Field Blank	-	0.002	-	-	-

Please note figures in bold italic font are at the limit of detection
Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

HYDROGEN CHLORIDE QUALITY ASSURANCE CHECKLIST

Leak Test Results	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	15.5	0.14	0.14	0.31	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Max. Storage / Transit Temp. °C	Type of Absorbers	Absorption Solutions
Run 1	Quartz Fibre	47	150	16	Glass	HPLC Water

HYDROGEN CHLORIDE ABSORPTION EFFICIENCY

Parameter	**Total ug**	**IMP C ug**	**Absorption Efficiency %**	**Acceptable Absorption Efficiency %**	**Absorption Efficiency Acceptable ?**
Run 1	1836.66	32.66	98	95	Yes

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS 1 — Hydrogen Chloride

Absolute pressure of stack gas, P_s			**Velocity of stack gas, V_s**		
Barometric pressure, P_b	mm Hg	757	Pitot tube velocity constant, K_p		34.97
Stack static pressure, P_{static}	mm H_2O	2	Velocity pressure coefficient, C_p		0.85
$P_s = P_b + (P_{static})$ / 13.6	mm Hg	757	Mean of velocity heads, DP_{avg}	mm H_2O	3.05
			Mean square root of velocity heads, ÖDP		1.75
Vol. of water vapour collected, V_{wstd}			Mean stack gas temperature, T_s	°C	91
Moisture trap weight increase,Vlc	g	-			
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$V_s = \frac{(K_p)(C_p)(\text{ÖDP})(\text{Ö}(T_s + 273))}{(M_s)(P_s)}$	m/s	6.8
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		0.9660	Area of stack, A_s	m^2	0.15
Gas meter correction factor, Y_d		0.9657	$Q_a = (60)(A_s)(V_s)$	m^3/min	60
Mean dry gas meter temperature, T_m		19.88	**Dry total flow of stack gas, Q_{std}**		
Mean pressure drop across orifice, DH	mmH_2O	21.75	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		0.87	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	m^3/min	42
Volume of gas metered wet, V_{mstw}			**Wet total flow of stack gas, Q_{stw}**		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9250	$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	m^3/min	45
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Dry total flow of stack gas at X% O_2, Q_{stdO2}**		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	m^3/min	42
% oxygen measured in gas stream, act%O_2		11.00	**Percent isokinetic, %I**		
% oxygen reference condition		11	Nozzle diameter, D_n	mm	7.88
O_2 Reference Factor: $O2\ Ref = \frac{21.0 - act\%O2}{21.0 - ref\%O2}$		1.00	Nozzle area, A_n	mm^2	48.73
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	0.8677	Total sampling time, q	min	60
Moisture content, B_{wo}			$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	104
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0620 / 6.20	Acceptable isokinetic range 95% to 115%		Yes
Moisture by FTIR	%	-	**Hydrogen Chloride Concentration, C**		
Molecular weight of dry gas, M_d			Mass collected , M	ug	1837
CO_2		4.61	$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	1.986
O_2		11.00			
Total		15.61	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	2.117
N_2 (100 -Total)		84.39			
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.18	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	2.117
Molecular weight of wet gas, M_s			**Hydrogen Chloride Emission Rates, E**		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.5	$E = [(C_{wet})(Q_{stw})(60)] / 1000$	g/hr	5.31

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

VOLATILE ORGANIC COMPOUNDS SUMMARY

Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	10:09 - 11:09 19 February 2019	1.7	0.40	10	3.7

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

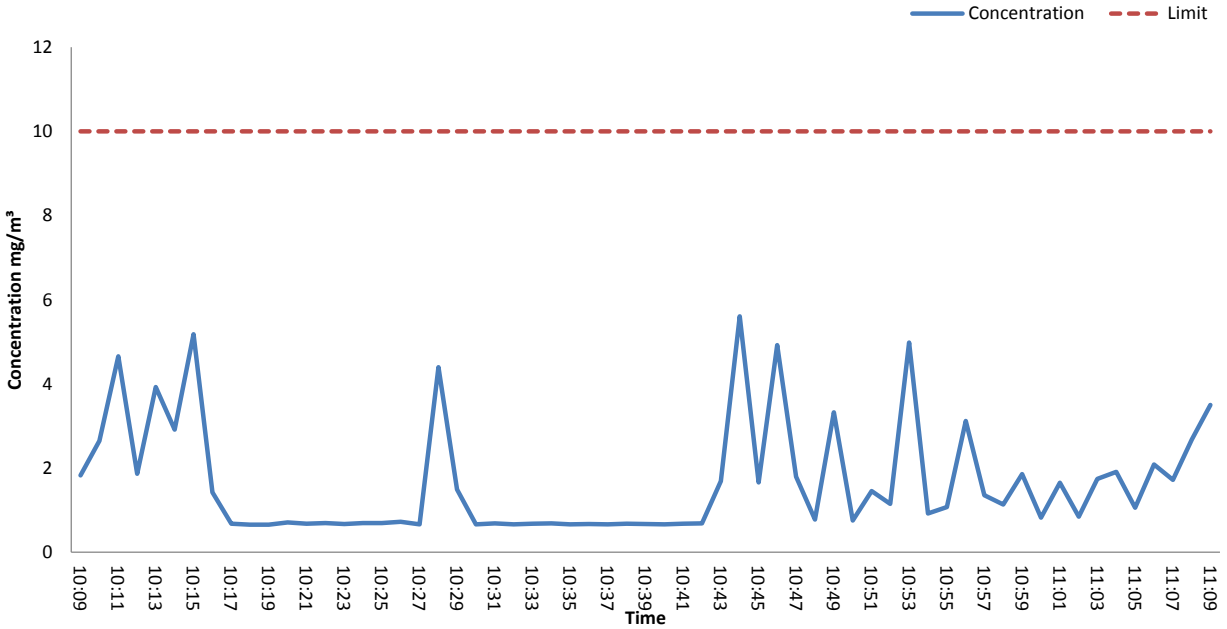
INSTRUMENTAL SPAN & ZERO CHECKS

PRE-SAMPLING CALIBRATION CHECKS								
Date	19 February 2019							
Start Time	09:15							
End Time	09:25							
Gas	Gas Conc (ppm)	Range	Instrument Zero Reading	Instrument Span Reading	Instrument Zero Reading	Zero Down line reading	Span down line reading	Leak Rate (%)
Propane	9.9	50	0.40	9.9	0.40	0.20	10.0	-1.01

Zero and Span gas contained 10% Oxygen

POST-SAMPLING CALIBRATION CHECKS				
Date	19 February 2019			
Start Time	12:22			
End Time	12:26			
Gas	Zero down line reading	Span down line reading	Zero Drift (%)	Span Drift (%)
Propane	0.20	9.8	0.00	-2.02

VOLATILE ORGANIC COMPOUNDS EMISSIONS CHART



Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GASES SUMMARY

Test	Sampling Time and Date	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
CO	10:09 - 12:20 19 February 2019	16	0.9	100	35

Test	Sampling Time and Date	Concentration %	LOD %
O_2	10:09 - 12:20 19 February 2019	13	0.01

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

PRE-SAMPLING CALIBRATION DATA

Date	19 February 2019
Start Time	09:27
End Time	09:36

Chiller Temperature (°C)	2.7
Requirement	< 4°C
Compliant	Yes

Gas	Range (ppm / %)	Zero Reading at analyser	Span Reading at analyser	Zero Check at analyser	Zero Check down line	Span Check down line	Response Time (Secs)	Leak Rate %
CO	500	0.00	164.0	0.10	0.10	163.7	75	0.18
O_2	25	0.00	9.99	0.01	0.02	10.00	70	-0.10

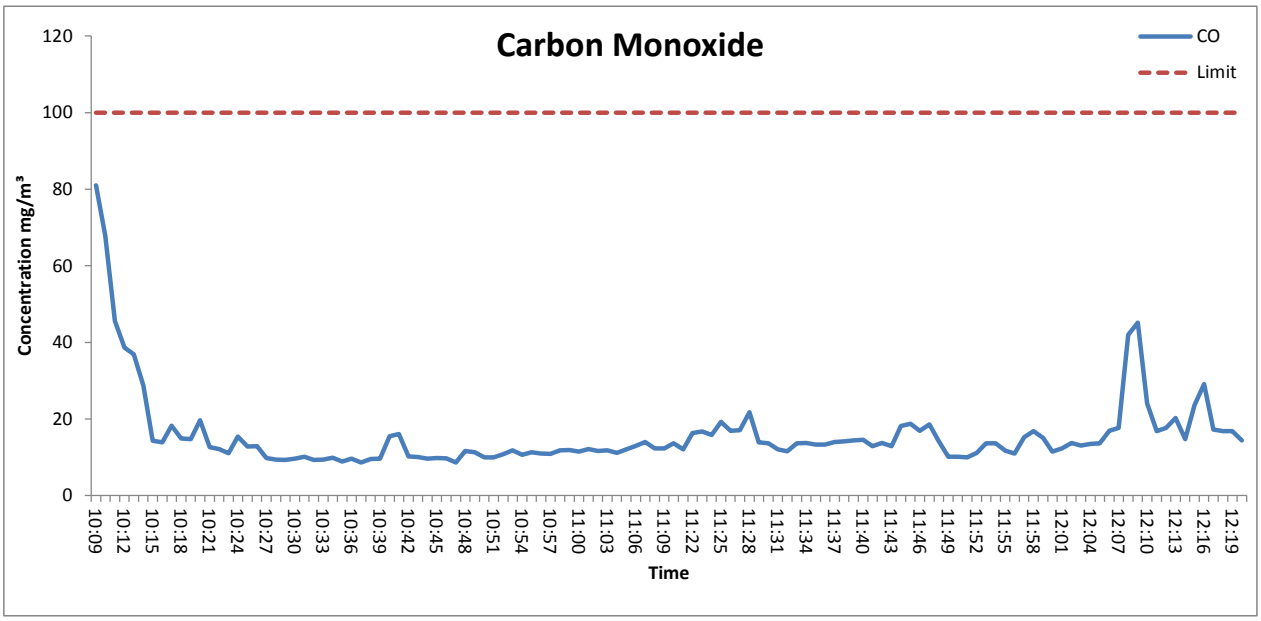
POST-SAMPLING CALIBRATION DATA

Date	19 February 2019
Start Time	12:27
End Time	12:31

Chiller Temperature (°C)	2.2
Requirement	< 4°C
Compliant	Yes

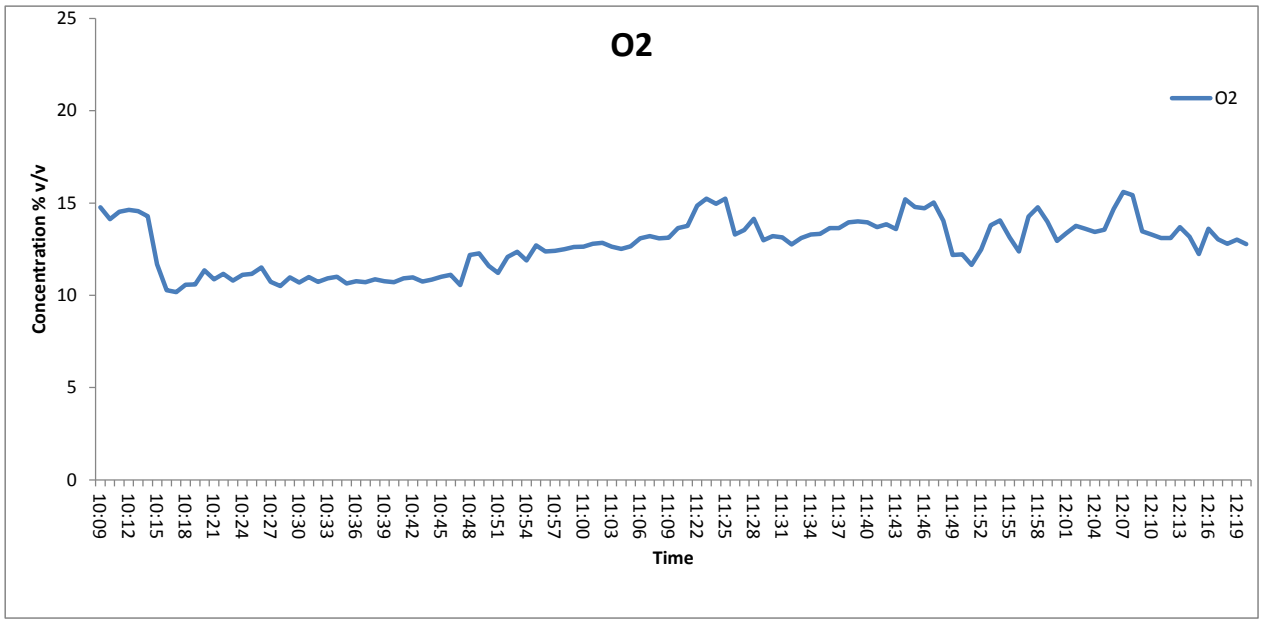
Gas	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
CO	0.20	163.6	0.02	-0.04
O_2	0.02	10.01	0.00	0.04

CARBON MONOXIDE EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

OXYGEN EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Isokinetic							
Test Number	Sampling Time and Date	Start Weight kg	End Weight kg	Total gain kg	Concentration %	LOD %	Uncertainty %
Run 1	10:09 - 11:09 19 February 2019	3.3210	3.3670	0.0460	6.2	0.01	3.4

Moisture Quality Assurance							
Test Number	Sampling Duration mins	Total Volume Sampled l	Sampling Rate l/min	Start Leak Rate l/min	End Leak Rate l/min	Acceptable Leak Rate l/min	Leak Tests Acceptable?
Run 1	60	925	15.5	0.14	0.14	0.31	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.32	m
Stack Width, W	0.46	m
Stack Area, A	0.15	m^2
Average stack gas temperature	68	^oC
Stack static pressure	0.02	kPa
Barometric Pressure	100.9	kPa

Stack Gas Composition & Molecular Weights								
Component	Molar Mass M	Density kg/m^3 p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m^3 pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m^3 pi
CO_2	44	1.963059	4.609524	0.046095	0.090488	4.323894	0.043239	0.084881
O_2	32	1.427679	12.732835	0.127328	0.181784	11.943842	0.119438	0.170520
N_2	28	1.249219	82.657641	0.826576	1.032575	77.535746	0.775357	0.968591
H_2O	18	0.803070	-	-	-	6.196518	0.061965	0.049762

Where: p = M / 22.41 p*i* = r x p

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3048	kg/m^3
Wet Density (STP), P_{STW}	1.2738	kg/m^3
Dry Density (Actual), P_{Actual}	1.0407	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	1.016	kg/m^3

Where:

P_{STD} = sum of component concentrations, kg/m^3 (not including water vapour)

$P_{STW} = (P_{STD} + pi \text{ of } H_2O) / (1 + (pi \text{ of } H_2O / 0.8036))$

$P_{Actual} = P_{STD} \times (Ts / Ps) \times (Pa / Ta)$

$P_{ActualW} = P_{STW} \times (Ts / Ps) \times (Pa / Ta)$

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	13 February 2019
Time of Survey	09:30
Velocity Measurement Device:	S-Type Pitot

Sampling Line A								
Traverse Point	Distance into duct (m)	DP pt mmH_2O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
1	0.05	3.0	29	68	6.4	0.9	-	<15
2	0.12	3.2	31	68	6.6	1.0	-	<15
3	0.20	3.0	29	68	6.4	0.9	-	<15
4	0.27	3.0	29	68	6.4	0.9	-	<15
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	3.1	30	68	6.5	1.0	-	-

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt mmH_2O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	-	-

PRELIMINARY STACK SURVEY QUALITY ASSURANCE CHECKLIST

PITOT LEAK CHECK								
Run	Pre Traverse Leak Rate				Post Traverse Leak Rate			
	Start Value Pa	End Value Pa	Difference %	Outcome	Start Value Pa	End Value Pa	Difference %	Outcome
Run 1	1427	1389	2.7	Pass	1389	1365	1.7	Pass

To complete a compliant pitot leak check a pressure of over 80 mmH_2O (or 800 Pa) is applied and the pressure drop monitored over 5 mins. A drop of less than 5% must be observed.

S-Type Pitot Stagnation Check				
Run	Stagnation (Pa)	Reference (Pa)	Difference (Pa)	Outcome (Permitted +/- 10 Pa)
Run 1	20	20	0.0	Pass

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

Sampling Plane Validation Criteria				
EA Technical Guidance Note (Monitoring) M1	Result	Units	Requirement	Compliant
Lowest Differential Pressure	29	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	6.4	m/s	-	-
Highest Gas Velocity	6.6	m/s	-	-
Ratio of Gas Velocities	1.0	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	°	< 15°	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V

Velocity at Traverse Point, V = K_{pt} x (1-e) * Ö(2 * DP_{pt} / $P_{ActualW}$)

Where:

K_{pt} = Pitot tube calibration coefficient

(1-e) = Compressibility correction factor, assumed at a constant 0.998

Average Stack Gas Velocity, Va	6.5	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	68	0	°C
Total Pressure	100.92	101.3	kPa
Oxygen	12.7	11	%
Moisture	6.20	0.00	%
Pitot tube calibration coefficient, K_{pt}	0.85		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	6.46	m/s
Stack Area (A)	0.15	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	3422	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	2730	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	2560	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	2117	m^3/hr

Where:

Q_{Actual} = Va x A x 3600

Q_{STP} = Q (Actual) x (Ts / Ta) x (Pa / Ps) x 3600

$Q_{STP,Dry}$ = Q (STP) / (100 - (100 / Ma)) x 3600

Q_{Ref} = Q (STP) x ((100 - Ma) / (100 - Ms)) x ((20.9 - O_2a) / (20.9 - O_2s))

Nomenclature:

Ts = Absolute Temperature, Standard Conditions, 273 K

Ps = Absolute Pressure, Standard Conditions, 101.3 kPa

Ta = Absolute Temperature, Actual Conditions, K

Pa = Absolute Pressure, Actual Conditions, kPa

Ma = Water vapour, Actual Conditions, % Vol

Ms = Water vapour, Reference Conditions, % Vol

O_2a = Oxygen, Actual Conditions, % Vol

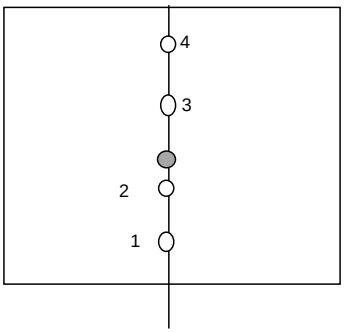
O_2s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK DIAGRAM

	Value	Units
Stack Depth	0.32	m
Stack Width	0.46	m
Area	0.15	m^2

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	50	0.16	m



Sampling Line

Isokinetic Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	15.6	0.05	< 15
2	37.5	0.12	< 15
3	62.5	0.20	< 15
4	84.4	0.27	< 15
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

○ Isokinetic sampling point
● Isokinetic sampling points not used
◉ Non Isokinetic/Gases sampling point

SAMPLING LOCATION

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - TOTAL PARTICULATE MATTER

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Limit of Detection	Leak	Uncollected Mass
	m³	K	kPa	% by volume	% by volume	% by mass	%	mg
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**	**≤ 10% of ELV**
Run 1	0.001	2.0	0.50	1.0	0.1	0.2000	-	-
as a %	0.12	0.55	0.50	1.0	0.91	1.15253	0.90	0.003
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 2	0.001	2.0	0.50	1.0	0.1	0.200	-	-
as a %	0.20	0.67	0.50	1.0	0.71	1.796	0.90	0.003
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 3	0.002	2.0	0.50	1.0	0.1	0.2000	-	-
as a %	0.20	0.69	0.50	1.0	0.91	1.23632	0.90	0.003
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP)	Mass of particulate	O_2 Correction	Leak	Uncollected Mass	Combined uncertainty
	m³	mg	-	mg/m³	mg	
Run 1	0.65	0.8600	1.0	0.005	0.0004	-
MU as mg/m³	0.01	0.2305	0.01	0.005	0.0004	**0.23**
MU as %	1.25	23.2558	-	0.520	0.0410	-
Run 2	0.51	1.7500	1.4	0.016	0.0004	-
MU as mg/m³	0.04	0.3592	0.04	0.016	0.0006	**0.36**
MU as %	1.3	11.4286	-	0.519	0.0201	-
Run 3	0.76	1.3400	1.0	0.009	0.0004	-
MU as mg/m³	0.02	0.2473	0.02	0.009	0.0004	**0.25**
MU as %	1.33	14.9254	-	0.521	0.0263	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.46**	**mg/m³**	**47**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.73**	**mg/m³**	**23**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.50**	**mg/m³**	**30**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MERCURY

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Concentration in impinger	Leak
	m^3	K	kPa	% by volume	% by volume	mg	%
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**<=2%**
Run 1	0.001	2.0	0.50	1.0	0.10	0.0006	-
as a %	0.15	0.7	0.49	1.0	0.77	3.00	0.87
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP)	O2 Correction	Mass of Mercury	Leak	Lab Uncertainty	Combined
	m^3	-	mg	mg/m^3	mg	
Run 1	0.6163	1.2500	6.3222	0.00005	-	-
MU as mg/m^3	0.0001	0.0001	0.0008	0.00005	0.00048	**0.0009**
MU as %	1.3177	1.2500	7.9103	0.5047	5.00000	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.002**	**mg/m^3**	**19**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - ISOKINETIC HYDROGEN CHLORIDE

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Limit of Detection	Leak
	m^3	K	kPa	% by volume	% by volume	% by mass	%
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**≤ 5% of ELV**	**<=2%**
Run 1	0.87	292.88	101.1	1.0	11	2.6931	-
as a %	0.12	0.68	0.49	1.0	0.91	0.02	0.90
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP)	Mass of Hydrogen Chloride	O2 Correction	Leak	Lab Uncertainty	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	0.8072	2.6931	1.0000	0.0110	-	-
MU as mg/m^3	0.0278	0.0058	0.0212	0.0110	0.1016	**0.1082**
MU as %	1.3139	0.2752	1.0000	0.5199	4.8	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.22**	**mg/m^3**	**10**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE

Run	Sampled Volume m^3	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 2%**
Run 1	0.001	2.0	0.50	1.0	0.1	-
as a %	0.12	0.55	0.50	1.0	0.91	0.90
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP) m^3	Mass Gained mg	O_2 Correction -	Leak mg/m^3	Uncollected Mass mg	Combined uncertainty
Run 1	0.65	46000	1.0	275.62	58	-
MU as % v/v	0.08	0.01	0.07	0.03	0.008	**0.11**
MU as %	1.25	0.22	1.00	0.52	0.13	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.23**	**% v/v**	**3.4**	**%**

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 1

Measured Concentration	1.7	mg/m^3
Limit	10	mg/m^3
Calibration Gas Concentration	15.84	mg/m^3
Range	80	mg/m^3

Performance characteristics	Value	Units	specification	MU Met?
Response time	60	seconds	<180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	60	minutes	-	-
Number of readings in measurement	60	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	Yes
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.70	% of value	<2 % range	Yes
Zero drift	0.00	% full scale	<2% range / 24hr	Yes
Span drift	-2.02	% full scale	<2% range / 24hr	Yes
volume or pressure flow dependence	0.02	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.80	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	0.01	% full scale/10K	<3% range / 10 K	Yes
dependence on voltage	0.10	% full scale/10V	< 0.1%vol /10 volt	Yes
losses in the line (leak)	-1.01	% of value	< 2% of span gas value	Yes
Uncertainty of calibration gas	1.0	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	0.02
Standard deviation of repeatability at span level	urs	0.02
Lack of fit	ufit	0.32
Drift	u0dr	-0.12
volume or pressure flow dependence	uspres	0.0003
atmopsheric pressure dependence	uapres	0.02
ambient temperature dependence	utemp	0.00001
Dependence on voltage	uvolt	0.07
losses in the line (leak)	uleak	-0.01
Uncertainty of calibration gas	ucalib	0.01
Uncertainty in factor	uf	0.15

Measurement uncertainty Measured Concentration	1.68	mg/m^3
Combined uncertainty	0.38	mg/m^3
Expanded uncertainty	0.77	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**7.7**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**0.77**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**46**	**% value**

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON MONOXIDE

Limit value	100	mg/m^3
Concentration @ Ref conditions	15.8	mg/m^3
Cal gas conc	205.0	mg/m^3
Analyser Full Scale	625	mg/m^3

Performance characteristics	Value	Units	specification	MU Met?
Response time	75	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	131	minutes	-	-
Number of readings in measurement	131	-	-	-
Repeatability at zero	0.1	% full scale	<1 % range	Yes
Repeatability at span level	0.2	% full scale	<2 % range	Yes
Deviation from linearity	0.61	% of value	<2 % range	Yes
Zero drift	0.02	% full scale	<2% range / 24hr	Yes
Span drift	-0.04	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	0.5	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	1.1	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence zero / span	2.5	% of full scale/10k	<3% range / 10 K	Yes
Combined interference	0.03	% of Range	<4% of Range	Yes
dependence on voltage	-0.16	% full scale/10V	< 0.1%vol /10 volt	Yes
Influence of Vibration	N/A	% of upper limit of Cal range	<2%	N/A
losses in the line (leak)	0.002	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.00	% of value	< 2% of value	Yes

N/A - Horiba's are not effected by Vibration

Performance characteristic	Uncertainty	Value of uncertainty quantity
repeatability	$U_r = S_r$	0.003
lack of fit	U_{lof}	0.12
short term zero drift	$U_{d,z}$	0.35
short term span drift	$U_{d,s}$	0.01
influence of Ambient Temp zero	$U_{t,z}$	0.0000000
influence of Ambient Temp span	$U_{t,s}$	0.0000000
influence of sample gas pressure	U_p	0.0000000
influence of sample gas flow	U_{fit}	0.35
influence of supply voltage	U_v	-0.57
Combined Interfence	U_i	6.28
Uncertainty of Cal gas	U_{adj}	0.82

Measurement uncertainty (Concentration Measured)	12.4	mg/m^3
Combined uncertainty	6.4	mg/m^3
Expanded uncertainty	12.8	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**13**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**13**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**103**	**% value**

Developed for the STA by R Robinson, NPL

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

Reference	11	%vol
Reported Concentration	12.73	%vol
Calibration gas	9.99	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	70	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	131	minutes	-	-
Number of readings in measurement	131	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	Yes
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.13	% of value	<2 % range	Yes
Zero drift	0.00	% full scale	<2% range / 24hr	Yes
Span drift	0.04	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	0.03	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.05	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	-0.08	% of full scale/10k	<3% range / 10 K	Yes
Combined interference	0.14	% range	<4% of Range	Yes
dependence on voltage	0.0005	% full scale/10V	< 0.1%vol /10 volt	Yes
losses in the line (leak)	0.14	% of value	< 2% of value	Yes
Uncertainty of calibration gas	0.1	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
repeatability	$U_r = S_r$	0.0083
lack of fit	U_{lof}	0.0751
short term zero drift	$U_{d,z}$	0.000000
short term span drift	$U_{d,s}$	0.0231
influence of Ambient Temp at Zero	$U_{t,z}$	0.000000
influence of Ambient Temp at Span	$U_{t,s}$	0.000000
influence of sample gas pressure	U_p	0.000000
influence of sample gas flow	U_{fit}	0.0173
influence of supply voltage	U_v	0.0001
Combined Interfence	U_i	0.0485
Uncertainty of Cal gas	U_{adj}	0.0500

Measurement uncertainty (Concentration Measured)	12.73	%
Combined uncertainty	0.11	%
Expanded uncertainty	0.21	%

Expanded uncertainty expressed with a level of confidence of 95%	**0.2**	**%**

Expanded uncertainty expressed with a level of confidence of 95%	**0.03**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	6.5	m/s
Measured Volumetric Flow rate at Actual Conditions	3422	m³/hr

Performance Characteristics & Source of Value	Units	Values	Requirement	Compliant
Uncertainty of Local Gas Velocity Determination				
Uncertainty of pitot tube coefficient	-	0.010		
Uncertainty of mean local dynamic pressures	-	0.34		
Factor loading, function of the number of measurements.	3 readings	0.591	minimum 3	Yes
Range of measurment device	pa	1000		
Resolution	pa	1.00		
Calibration uncertainty	pa	2.40	<1% of Value or 20 Pa whichever is greater	Yes
Drift	% range	0.10		
Linearity	% range	0.06	<2% of value	Yes
Uncertainty of gas density determination				
Uncertainty of molar mass determination	kg/mol	0.00002		
Uncertainty of temperature measurement	K	1.74	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	515		
Uncertainty associated with the estimate of density	-	0.007		
Uncertainty associated with the measurement of local velocity	-	0.0001		
Uncertainty associated with the measurement of mean velocity	-	0.0002		

Measurement Uncertainty - Velocity	m/s
Combined uncertainty	0.08
Expanded uncertainty at a 95% Confidence Interval	0.16

Note - The expanded uncertainty uses a coverage factor of k = 2.

Expanded Measurement Uncertainty of Velocity at a 95% Confidence Interval	%
Expressed as a % of the Measured Velocity	1.2
Expanded uncertainty at a 95% Confidence Interval	2.4

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	98
Expanded uncertainty at a 95% Confidence Interval	192

Note - The expanded uncertainty uses a coverage factor of k = 2.

Expanded Measurement Uncertainty of Volumetric Flow Rate at a 95% Confidence Interval	%
Expressed as a % of the Measured Volumetric Flow Rate	2.9
Expanded uncertainty at a 95% Confidence Interval	5.6

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

END OF REPORT

Thank you for choosing SOCOTEC UK for your environmental monitoring needs. We hope our services have met your requirements and that you are fully satisfied with your experience of working with us, we really do value your custom and would welcome your feedback. We would appreciate it if you could take a moment to complete a short online questionnaire so that we can improve our operations and address any areas that have not met with your expectations, by clicking on the following

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