

STACK EMISSIONS MONITORING REPORT



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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 Exhaust

Sampling Date(s):

19th February 2018

SOCOTEC UK Job Number:	LNO 14114
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Report By:	Gary Orley
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MCERTS Level:	MCERTS Level 2 - Team Leader
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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

North East Lincolnshire Council operates a cremation 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 Exhaust

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.
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EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	Units	Result	Calculated Uncertainty +/-	Limit	MCERTS accredited result
Total Particulate Matter	mg/m ³	0.49	0.74	20	✓
Particulate Emission Rate	g/hr	1.1	1.7	-	
Mercury	mg/m ³	0.003	0.001	0.05	✓
Mercury Emission Rate	g/hr	0.006	0.002	-	
Hydrogen Chloride	mg/m ³	2.8	0.28	30	✓
Hydrogen Chloride Emission Rate	g/hr	6.3	0.63	-	
Volatile Organic Compounds	mg/m ³	2.1	1.4	10	✓
Volatile Organic Compounds Emission Rate	g/hr	3.9	2.7	-	
Carbon Monoxide	mg/m ³	8.3	2.8	100	✓
Carbon Monoxide Emission Rate	g/hr	16	5.3	-	
Oxygen	% v/v	13.6	1.8	-	✓
Moisture	%	7.0	0.24	-	✓
Stack Gas Temperature	°C	128	-	-	
Stack Gas Velocity	m/s	7.7	0.19	-	
Gas Volumetric Flow Rate (Actual)	m ³ /hr	4074	230	-	✓
Gas Volumetric Flow Rate (STP, Wet)	m ³ /hr	2733	154	-	
Gas Volumetric Flow Rate (STP, Dry)	m ³ /hr	2542	144	-	
Gas Volumetric Flow Rate at Reference Conditions	m ³ /hr	1883	106	-	

ND = None Detected,

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

The above volumetric flow rate is calculated using data from the preliminary survey. Mass emissions for non isokinetic tests are calculated using these values. For all isokinetic testing the mass emission is calculated using test specific flow data and not the above 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 2018	12:25 - 13:25	60 minutes
Total Particulate Matter Run 2	19 February 2018	14:15 - 15:15	60 minutes
Total Particulate Matter Run 3	19 February 2018	15:30 - 16:30	60 minutes
Mercury Run 1	20 February 2018	10:09 - 11:09	60 minutes
Hydrogen Chloride Run 1	19 February 2018	12:25 - 13:25	60 minutes
Volatile Organic Compounds Run 1	19 February 2018	12:25 - 13:25	60 minutes
Combustion Gases	19 February 2018	12:25 - 13:25	60 minutes
Preliminary Stack Traverse	19 February 2018	12:00	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Cremation
Continuous or batch	Batch
Product Details	Human remains
Part of batch to be monitored (if applicable)	When cremating
Normal load, throughput or continuous rating	Normal Load
Fuel used during monitoring	Natural Gas
Abatement	Mercury abatement system
Plume Appearance	None Visible

	Cremation Number	Sex	Body Type	Coffin Type
Run 1	103191	Female	M	MDF
	103192	Male	M	MDF
Run 2	103194	Female	M	MDF
	103195	Female	M	MDF
Run 3	103196	Female	M	MDF
	103197	Female	M	MDF
Run 4	103199	Female	M	MDF
	103200	Male	M	MDF

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	0.25 mg/m ³	150%
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	Yes	0.0005 mg/m ³	40%
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	0.001 mg/m ³	10%
VOCs	SRM - BS EN 12619:2013	AE 102	1015	Yes	0.33 mg/m ³	69%
CO	SRM - BS EN 15058:2017	AE 102	1015	Yes	0.39 mg/m ³	34%
O ₂	AM - BS EN 14789:2017	AE 102	1015	Yes	0.01%	14%
H ₂ O	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	2.5%
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 UK (Bretby)	SOCOTEC UK (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 ₂ O	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	6.9	m/s	-	-	-
Highest Gas Velocity	8.2	m/s	-	-	-
Ratio of Gas Velocities	1.2	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	7.7	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	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 standard.

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APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

APPENDIX 3 - Measurement Uncertainty Budget Calculations

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 ₂ O	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 13-10	Horiba PG-250 Analyser	LNO 21-45	Laboratory Balance	LNO 00-12/00-13
Box Thermocouples	LNO 03-10	FT-IR Gasmet	-	Tape Measure	LNO 24-GO
Meter In Thermocouple	LNO 03-10	FT-IR Oven Box	-	Stopwatch	LNO 17-GO
Meter Out Thermocouple	LNO 03-10	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17-10	Signal 3030 FID	-	Barometer	LNO 08-GO
Oven Box	LNO 09-06	Servomex	-	Digital Micromanometer	LNO 01-GO
Probe	LNO 11-24	JCT Heated Head Filter	-	Digital Temperature Meter	LNO 03-GO
Probe Thermocouple	LNO 10-24	Thermo FID	LNO 21-04	Stack Thermocouple	LNO 10-GO
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LNO 06-GO	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LNO 14-GO	Chiller (JCT/MAK 10)	LNO 21-49	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	LNO 03-98	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	LNO 31-GO	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	LNO 18-89
Inclinometer (Swirl Device)	LNO 23-GO		-	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	HPC 1035	BOC	-	9.97	2.0
Propane	HPC 1069	BOC	10.1	-	2.0
Carbon Monoxide	HPC 1035	BOC	166	-	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
Gary Orley	MM 13 1223	MCERTS Level 2	Feb-19	Feb-19	May-19	Nov-19	Nov-20	Jun-21
Josh Davenport	MM 16 1380	MCERTS Level 1	Jul-22	-	-	-	-	Jun-21

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY					
Parameter	Sampling Times	Concentration mg/m ³	Uncertainty mg/m ³	Limit mg/m ³	Emission Rate g/hr
Run 1	12:25 - 13:25 19 February 2018	0.25	0.49	20	0.55
Run 2	14:15 - 15:15 19 February 2018	0.24	0.48	20	0.56
Run 3	15:30 - 16:30 19 February 2018	1.0	0.51	20	2.29
Blank	-	0.22	-	-	-

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	Q9933	0.14357	0.14393	0.00036	190.35360	190.35310	-0.00050	0.00024
Run 2	Q9936	0.15906	0.15910	0.00004	178.35370	178.35380	0.00010	0.00024
Run 3	Q9937	0.15541	0.15575	0.00034	165.15870	165.15930	0.00060	0.00094

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	Q9932	0.14449	0.14486	0.00037	184.48420	184.48370	-0.00050	0.00024

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			Molecular weight of dry gas, M_d		
Barometric pressure, P _b	mm Hg	747.76	CO ₂	%	5.76
Stack static pressure, P _{static}	mm H ₂ O	3.06	O ₂	%	12.10
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	747.98	Total	%	17.86
Vol. of water vapour collected, V_{wstd}			N ₂ (100 - Total)	%	82.14
Moisture trap weight increase, Vlc	g	66.0	$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2)$		29.41
$V_{wstd} = (0.001246)(V_{lc})$	m ³	0.082236	Molecular weight of wet gas, M_s		
Volume of gas metered dry, V_{mstd}			$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.61
Volume of gas sample through gas meter, V _m		1.230	Actual flow of stack gas, Q_a		
Gas meter correction factor, Y _d		0.966	Area of stack, A _s	m ²	0.15
Mean dry gas meter temperature, T _m		19.500	$Q_a = (60)(A_s)(V_s)$	m ³ /min	65.8
Mean pressure drop across orifice, DH mmH ₂ O		41.418	Total flow of stack gas, Q		
$V_{mstd} = \frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m + 273}$		1.095	Conversion factor (K/mm.Hg)		0.3592
Volume of gas metered wet, V_{mstw}			$Q_{std} = \frac{(Q_a)P_s(0.3592)(1 - B_{wo})}{(T_s) + 273}$	Dry	41.8
$V_{mstw} = V_{mstd} + V_{wstd}$	m ³	1.1773	$Q_{stdO_2} = \frac{(Q_a)P_s(0.3592)(1 - B_{wo})(O_2REF)}{(T_s) + 273}$	@O ₂ ref	37.21
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O₂}			$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet	44.97
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)		No	Percent isokinetic, %I		
% oxygen measured in gas stream, act%O ₂		12.1	Nozzle diameter, D _n	mm	8.83
% oxygen reference condition		11	Nozzle area, A _n	mm ²	61.29
O ₂ Reference	$O_2 Ref = 21.0 - act\%O_2$	0.89	Total sampling time, q	min	60
Factor	$\frac{21.0 - ref\%O_2}{21.0 - act\%O_2}$		$\%I = \frac{(4.6398E6)(T_s + 273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1 - B_{wo})}$	%	104.8
$V_{mstd@X\%oxygen} = (V_{mstd})(O_2 Ref)$	m ³	0.9746	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			Particulate Concentration, C		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	6.99	Mass collected on filter, M _f	g	0.00036
Moisture by FTIR			Mass collected in probe, M _p	g	-0.00050
	%	-	Total mass collected, M _n	g	0.00024
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m ³	0.204
Pitot tube velocity constant, K _p		34.97	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m ³	0.219
Velocity pressure coefficient, C _p		0.84	$C_{dry@X\%O_2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m ³	0.246
Mean of velocity heads, DP _{avg}	mm H ₂ O	3.50	Particulate Emission Rates, E		
Mean square root of velocity heads, ÖDP		1.87	$E = \frac{[(C_{wet})(Q_{stw})(60)]}{1000}$		0.55
Mean stack gas temperature, T _s	°C	120			
$V_s = \frac{(K_p)(C_p)(\sqrt{DP})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	7.45			

As the total mass gained was less than the LOD, the LOD has been reported

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 2			TPM		
Absolute pressure of stack gas, P_s			Molecular weight of dry gas, M_d		
Barometric pressure, P _b	mm Hg	747.76	CO ₂	%	5.76
Stack static pressure, P _{static}	mm H ₂ O	3.06	O ₂	%	12.20
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	747.98	Total	%	17.96
Vol. of water vapour collected, V_{wstd}			N ₂ (100 -Total)	%	82.04
Moisture trap weight increase, V _{lc}	g	-	$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2)$		29.41
$V_{wstd} = (0.001246)(V_{lc})$	m ³	-	Molecular weight of wet gas, M_s		
Volume of gas metered dry, V_{mstd}			$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.61
Volume of gas sample through gas meter, V _m		1.279	Actual flow of stack gas, Q_a		
Gas meter correction factor, Y _d		0.966	Area of stack, A _s	m ²	0.15
Mean dry gas meter temperature, T _m		22.250	$Q_a = (60)(A_s)(V_s)$	m ³ /min	69.2
Mean pressure drop across orifice, DH mmH ₂ O		46.287	Total flow of stack gas, Q		
$V_{mstd} = \frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m + 273}$		1.129	Conversion factor (K/mm.Hg)		0.3592
Volume of gas metered wet, V_{mstw}			$Q_{std} = \frac{(Q_a)P_s(0.3592)(1 - B_{wo})}{(T_s) + 273}$	Dry	44.0
$V_{mstw} = V_{mstd} + V_{wstd}$	m ³	1.2137	$Q_{stdO_2} = \frac{(Q_a)P_s(0.3592)(1 - B_{wo})(O_2REF)}{(T_s) + 273}$	@O ₂ ref	38.71
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O₂}			$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet	47.31
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)		No	Percent isokinetic, %I		
% oxygen measured in gas stream, act%O ₂		12.2	Nozzle diameter, D _n	mm	8.83
% oxygen reference condition		11	Nozzle area, A _n	mm ²	61.29
O ₂ Reference $O_2 Ref = 21.0 - act\%O_2$		0.88	Total sampling time, q	min	60
Factor $\frac{21.0 - ref\%O_2}{21.0 - act\%O_2}$		0.9934	$\%I = \frac{(4.6398E6)(T_s + 273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1 - B_{wo})}$	%	102.7
$V_{mstd@X\%oxygen} = (V_{mstd})(O_2 Ref)$	m ³	0.9934	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			Particulate Concentration, C		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	6.99	Mass collected on filter, M _f	g	0.00004
Moisture by FTIR			Mass collected in probe, M _p	g	0.00010
	%	-	Total mass collected, M _n	g	0.00024
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m ³	0.20
Pitot tube velocity constant, K _p		34.97	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m ³	0.21
Velocity pressure coefficient, C _p		0.84	$C_{dry@X\%O_2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m ³	0.24
Mean of velocity heads, DP _{avg}	mm H ₂ O	3.88	Particulate Emission Rates, E		
Mean square root of velocity heads, ÖDP		1.97	$E = \frac{[(C_{wet})(Q_{stw})(60)]}{1000}$		0.56
Mean stack gas temperature, T _s	°C	120			
$V_s = \frac{(K_p)(C_p)(\ddot{O}DP)(\ddot{O}(T_s + 273))}{(M_s)(P_s)}$	m/s	7.84			

As the total mass gained was less than the LOD, the LOD has been reported

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 3			TPM		
Absolute pressure of stack gas, P_s			Molecular weight of dry gas, M_d		
Barometric pressure, P _b	mm Hg	747.76	CO ₂	%	5.76
Stack static pressure, P _{static}	mm H ₂ O	3.06	O ₂	%	12.10
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	747.98	Total	%	17.86
Vol. of water vapour collected, V_{wstd}			N ₂ (100 - Total)	%	82.14
Moisture trap weight increase, Vlc	g	-	$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2)$		29.41
$V_{wstd} = (0.001246)(V_{lc})$	m ³	-	Molecular weight of wet gas, M_s		
Volume of gas metered dry, V_{mstd}			$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.61
Volume of gas sample through gas meter, V _m		1.213	Actual flow of stack gas, Q_a		
Gas meter correction factor, Y _d		0.966	Area of stack, A _s	m ²	0.15
Mean dry gas meter temperature, T _m		25.083	$Q_a = (60)(A_s)(V_s)$	m ³ /min	67.6
Mean pressure drop across orifice, DH mmH ₂ O		44.612	Total flow of stack gas, Q		
$V_{mstd} = \frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m + 273}$		1.061	Conversion factor (K/mm.Hg)		0.3592
Volume of gas metered wet, V_{mstw}			$Q_{std} = \frac{(Q_a)P_s(0.3592)(1 - B_{wo})}{(T_s) + 273}$	Dry	43.0
$V_{mstw} = V_{mstd} + V_{wstd}$	m ³	1.1402	$Q_{stdO_2} = \frac{(Q_a)P_s(0.3592)(1 - B_{wo})(O_2REF)}{(T_s) + 273}$	@O ₂ ref	38.26
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O₂}			$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet	46.23
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)		No	Percent isokinetic, %I		
% oxygen measured in gas stream, act%O ₂		12.1	Nozzle diameter, D _n	mm	8.83
% oxygen reference condition		11	Nozzle area, A _n	mm ²	61.29
O ₂ Reference	O ₂ Ref = 21.0 - act%O ₂	0.89	Total sampling time, q	min	60
Factor	$\frac{21.0 - ref\%O_2}{21.0 - act\%O_2}$		$\%I = \frac{(4.6398E6)(T_s + 273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1 - B_{wo})}$	%	98.7
$V_{mstd@X\%oxygen} = (V_{mstd})(O_2 Ref)$	m ³	0.9439	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			Particulate Concentration, C		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	6.99	Mass collected on filter, M _f	g	0.00034
Moisture by FTIR			Mass collected in probe, M _p	g	0.00060
	%	-	Total mass collected, M _n	g	0.0009
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m ³	0.82
Pitot tube velocity constant, K _p		34.97	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m ³	0.89
Velocity pressure coefficient, C _p		0.84	$C_{dry@X\%O_2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m ³	1.00
Mean of velocity heads, DP _{avg}	mm H ₂ O	3.70	Particulate Emission Rates, E		
Mean square root of velocity heads, ÖDP		1.92	$E = \frac{[(C_{wet})(Q_{stw})(60)]}{1000}$		2.29
Mean stack gas temperature, T _s	°C	120			
$V_s = \frac{(K_p)(C_p)(\ddot{O}DP)(\ddot{O}(T_s + 273))}{(M_s)(P_s)}$	m/s	7.66			

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	19.79	0.09	0.08	-406.4	0.40	Yes
Run 2	20.59	0.09	0.09	-431.8	0.41	Yes
Run 3	19.53	0.10	0.10	-431.8	0.39	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	104.79	Yes
Run 2	102.68	Yes
Run 3	98.71	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m ³	5% ELV mg/m ³	LOD < 5% ELV
Run 1	0.25	1.0	Yes
Run 2	0.24	1	Yes
Run 3	0.25	1	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	0.22	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	160	180	160
Run 2	Quartz Fibre	47	160	180	160
Run 3	Quartz Fibre	47	160	180	160

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MERCURY SUMMARY - PARTICULATE & VAPOUR PHASES COMBINED

Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	Limit mg/m ³	Emission Rate g/hr
Run 1	10:09 - 11:09 20 February 2018	0.003	0.001	0.05	0.006
Field Blank	-	0.001	-	-	-

Mercury	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mean mg/m ³	Lab Result ug	Concentration mg/m ³	Stack LOD mean mg/m ³	Lab Result ug	Concentration mg/m ³
Run 1	0.00051	0.50	0.00051	0.0000	2.09	0.002
Volume Sampled m ³		0.9813			0.9813	
Field Blank	-	0.50	0.00051	-	0.02	0.0000
Volume Sampled m ³		0.9813			0.9813	

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			Molecular weight of dry gas, M_d	
Barometric pressure, P _b	mm Hg	747.8	CO ₂	% 5.76
Stack static pressure, P _{static}	mm H ₂ O	3.1	O ₂	% 11.94
$P_s = P_b + (P_{static})$	mm Hg	748.0	Total	% 17.70
$\frac{13.6}{13.6}$			N ₂ (100 -Total)	% 82.30
			$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2)$	29.40
Vol. of water vapour collected, V_{wstd}			Molecular weight of wet gas, M_s	
Moisture trap weight increase, V _{lc}	g	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol 28.60
$V_{wstd} = (0.001246)(V_{lc})$	m ³	-	Velocity of stack gas, V_s	
Volume of gas metered dry, V_{mstd}			Pitot tube velocity constant, K _p 34.97	
Volume of gas sample through gas meter, V _m		1.2204	Velocity pressure coefficient, C _p 0.84	
Gas meter correction factor, Y _d		0.96592	Mean of velocity heads, DP _{avg}	mm H ₂ O 3.27
Mean dry gas meter temperature, T _m		20.42	Mean square root of velocity heads, ÖDP 1.81	
Mean pressure drop across orifice, DH	mm	38.01	Mean stack gas temperature, T _s	°C 131
$V_{mstd} = \frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m + 273}$		1.08	$V_s = \frac{(K_p)(C_p)(\ddot{O}DP)(\ddot{O}(T_s + 273))}{(M_s)(P_s)}$	m/s 7.30
Volume of gas metered wet, V_{mstw}			Actual flow of stack gas, Q_a	
$V_{mstw} = V_{mstd} + V_{wstd}$	m ³	1.1645	Area of stack, A _s	m ² 0.15
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O2}			$Q_a = (60)(A_s)(V_s)$	
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)	No		Total flow of stack gas, Q	
% oxygen measured in gas stream, act%O ₂	11.9		Conversion factor (K/mm.Hg)	0.3592
% oxygen reference condition	11		$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) + 273}$	Dry 39.9
O ₂ Reference O ₂ Ref = 21.0 - act%O ₂	0.91		$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) + 273}$	@O2ref 36.1
Factor 21.0 - ref%O ₂			$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet 42.9
$V_{mstd@X\%oxygen} = (V_{mstd})(O_2 Ref)$	m ³	0.981	Percent isokinetic, %I	
Moisture content, B_{wo}			Nozzle diameter, D _n mm 8.83	
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	6.99	Nozzle area, A _n mm ² 61.29	
Moisture by FTIR			Total sampling time, q min 60	
	%	-	$\%I = \frac{(4.6398E6)(T_s + 273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1 - B_{wo})}$	
			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	19.6	0.10	0.10	-431.8	0.39	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	108.7	Yes

Filtration / Temp	Filter Material	Filter Size mm	Maximum Filtration Temperature °C	Maximum storage / transit Temperature °C
Run 1	Quartz Fibre	47	180	18

HEAVY METALS ABSORPTION EFFICIENCY

Parameter		Total ug	5th Absorber ug	Absorption Efficiency	Required	Pass / Fail
Mercury	Run 1	2.59	0.03	99	95	N/A <30% ELV

HYDROGEN CHLORIDE SUMMARY					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	Limit mg/m ³	Emission Rate g/hr
Run 1	12:25 - 13:25 19 February 2018	2.8	0.001	30	6.3
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	19.8	0.09	0.08	0.40	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Max. Storage / Transit Temp. °C	Type of Absorbers	Absorption Solutions
Run 1	Quartz Fibre	GF	160	16	Glass	HPLC Water

HYDROGEN CHLORIDE ABSORPTION EFFICIENCY

Parameter	Total ug	IMP C ug	Absorption Efficiency %	Acceptable Absorption Efficiency %	Absorption Efficiency Acceptable ?
Run 1	2760	4.3	100	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	748	Pitot tube velocity constant, K _p	34.97
Stack static pressure, P _{static}	mm H ₂ O	3	Velocity pressure coefficient, C _p	0.84
P _s = P _b + (P _{static})	mm Hg	748	Mean of velocity heads, DP _{avg}	mm H ₂ O 3.50
13.6			Mean square root of velocity heads, ÖDP	1.87
Vol. of water vapour collected, V_{wstd}			Mean stack gas temperature, T _s	
Moisture trap weight increase, Vlc	g	-	°C	120
V _{wstd} = (0.001246)(V _{lc})	m ³	-	V _s = $\frac{(K_p)(C_p)(\ddot{O}DP)(\ddot{O}(T_s + 273))}{(M_s)(P_s)}$	
Volume of gas metered dry, V_{mstd}			Actual flow of stack gas, Q_a	
Volume of gas sample through gas meter, V _m		1.2296	Area of stack, A _s	m ² 0.15
Gas meter correction factor, Y _d		0.96592	Q _a = (60)(A _s)(V _s)	m ³ /min 66
Mean dry gas meter temperature, T _m		19.50	Dry total flow of stack gas, Q_{std}	
Mean pressure drop across orifice, DH	mmH ₂ O	41.42	Conversion factor (K/mm.Hg)	0.3592
V _{mstd} = $\frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m + 273}$		1.10	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	1.1773	Q _{stw} = $\frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	m ³ /min 45
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O2}			Dry total flow of stack gas at X% O₂, 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 37
% oxygen measured in gas stream, act%O ₂	12.10		Percent isokinetic, %I	
% oxygen reference condition	11		Nozzle diameter, D _n	mm 8.83
O ₂ Reference $\frac{O_2 Ref = 21.0 - act\%O_2}{21.0 - ref\%O_2}$	0.89		Nozzle area, A _n	mm ² 61.29
V _{mstd@X%oxygen} = (V _{mstd})(O ₂ Ref)	m ³	0.9746	Total sampling time, q	min 60
Moisture content, B_{wo}			%I = $\frac{(4.6398E6)(T_s + 273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1 - B_{wo})}$	
B _{wo} = $\frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	6.99	Acceptable isokinetic range 95% to 115%	Yes
Moisture by FTIR			Hydrogen Chloride Concentration, C	
			Mass collected, M	
Molecular weight of dry gas, M_d			C _{wet} = $\frac{M_n}{V_{mstw}}$	
CO ₂		5.76	C _{dry} = $\frac{M_n}{V_{mstd}}$	mg/m ³ 2.345
O ₂		12.10	C _{dry@X%O2} = $\frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m ³ 2.521
Total		17.86		2.832
N ₂ (100 - Total)		82.14	Hydrogen Chloride Emission Rates, E	
M _d = 0.44(%CO ₂) + 0.32(%O ₂) + 0.28(%N ₂)		29.41	E = $\frac{[(C_{wet})(Q_{stw})(60)]}{1000}$	
Molecular weight of wet gas, M_s			g/hr 6.33	
M _s = M _d (1 - B _{wo}) + 18(B _{wo})	g/gmol	28.6		

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

VOLATILE ORGANIC COMPOUNDS SUMMARY

Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	Limit mg/m ³	Emission Rate g/hr
Run 1	12:25 - 13:25 19 February 2018	2.1	0.40	10	3.9

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

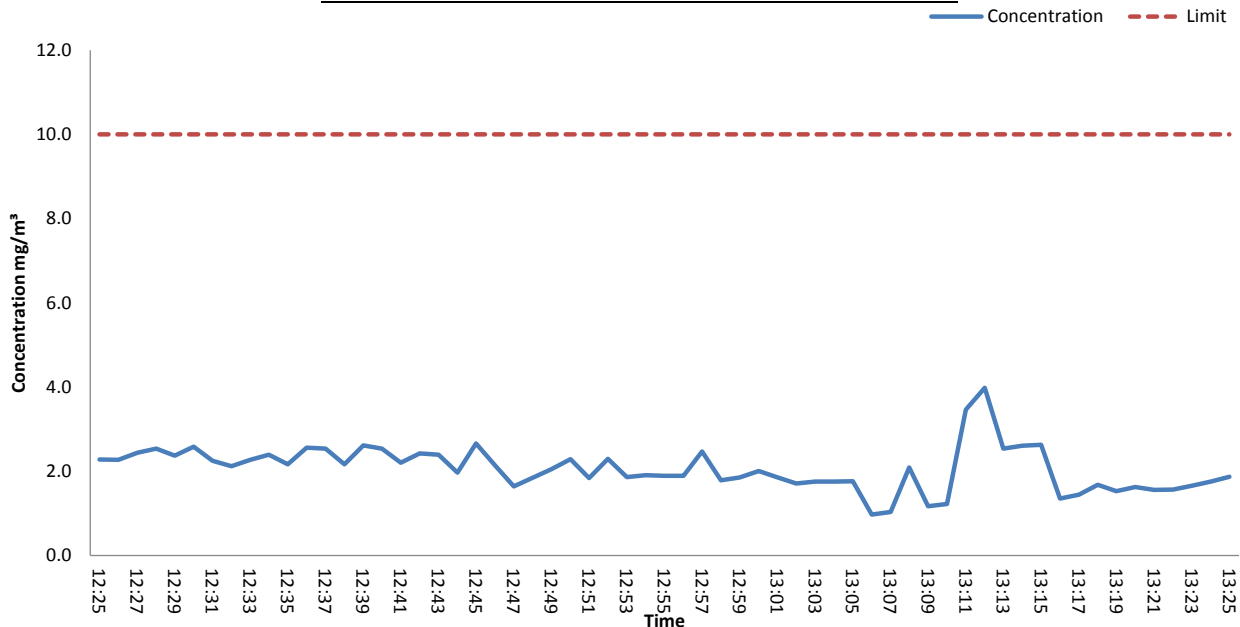
INSTRUMENTAL SPAN & ZERO CHECKS

PRE-SAMPLING CALIBRATION CHECKS								
Date	19 February 2018							
Start Time	11:50							
End Time	12:10							
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	10.1	100	0.40	10.1	0.40	0.40	10.1	0.50

Zero and Span gas contained 10% Oxygen

POST-SAMPLING CALIBRATION CHECKS				
Date	19 February 2018			
Start Time	13:30			
End Time	13:40			
Gas	Zero down line reading	Span down line reading	Zero Drift (%)	Span Drift (%)
Propane	0.40	10.0	0.00	-0.99

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/m ³	LOD mg/m ³	Limit mg/m ³	Emission Rate g/hr
CO	12:25 - 13:25 19 February 2018	8.3	0.39	100	16

Test	Sampling Time and Date	Concentration %	LOD %
O ₂	12:25 - 13:25 19 February 2018	13.6	0.01

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

PRE-SAMPLING CALIBRATION DATA

Date	19 February 2018
Start Time	11:50
End Time	12:10

Chiller Temperature (°C)	2.6
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	200	0.00	166.0	0.00	0.00	166.0	25	0.00
O ₂	25	0.00	9.97	0.02	0.08	9.91	25	0.60

POST-SAMPLING CALIBRATION DATA

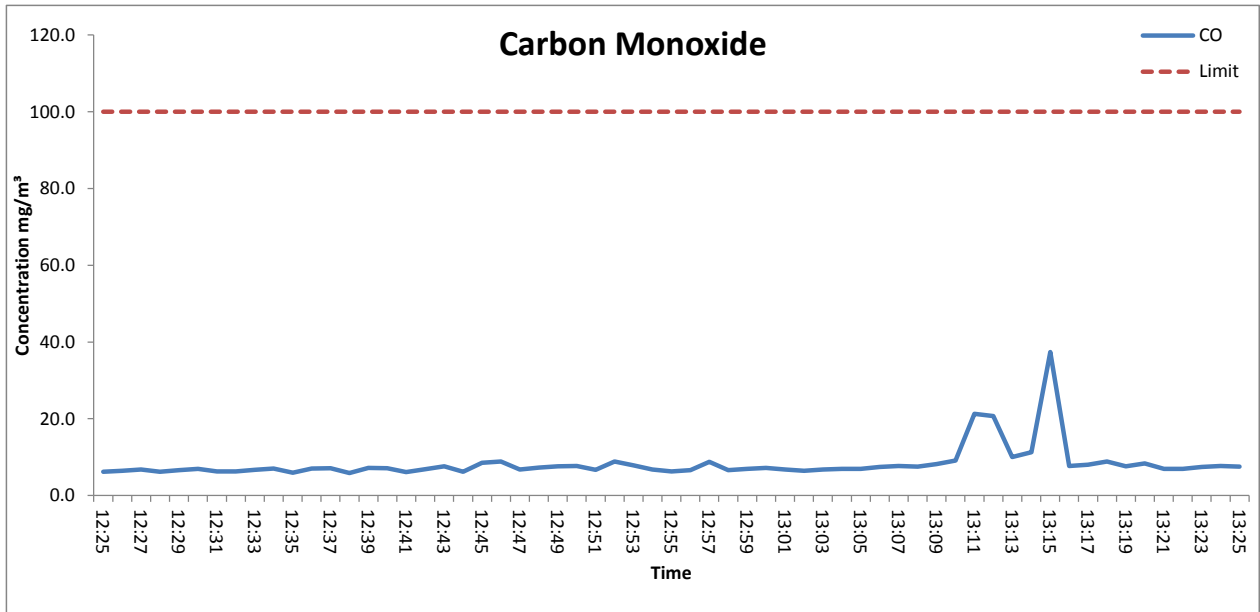
Date	19 February 2018
Start Time	16:35
End Time	16:45

Chiller Temperature (°C)	2.6
Requirement	< 4°C
Compliant	Yes

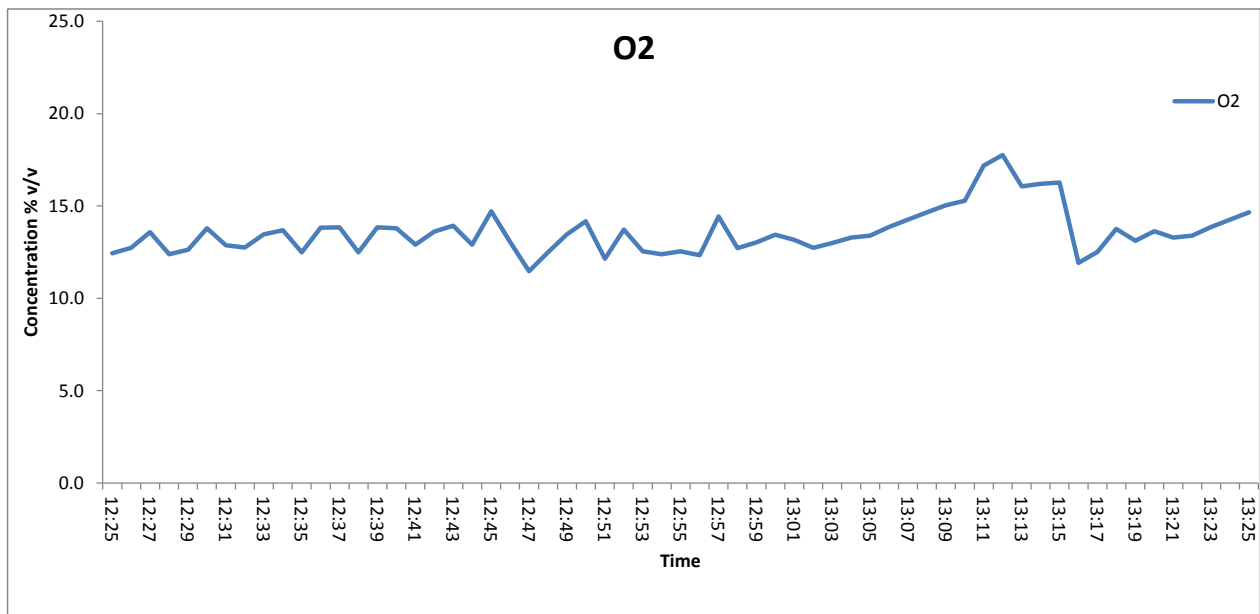
Gas	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
CO	0.00	165.0	0.00	-0.50
O ₂	0.00	10.30	-0.32	1.88

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

CARBON MONOXIDE EMISSIONS CHART



OXYGEN EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DAILY OXYGEN SUMMARY

Sampling Times	Concentration %	LOD %
12:25 - 13:25 19 February 2018	13.6	0.01
10:09 - 11:09 20 February 2018	11.9	0.01

PRE SAMPLING CALIBRATION DATA								
Date	Time of Analyser Checks	Range (%)	Zero Reading at analyser	Span Reading at analyser	Zero Check at analyser	Zero Check down line	Span Check down line	Leak Rate %
19 February 2018	11:50 - 12:10	25	0.00	9.97	0.02	0.08	9.91	-0.61
20 February 2018	09:55 - 10:00	25	0.00	9.97	0.01	0.03	9.99	0.20

POST SAMPLING CALIBRATION DATA					
Date	Time of Analyser Checks	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
19 February 2018	16:35 - 16:45	0.00	10.30	-0.80	-1.65
20 February 2018	11:16 - 11:20	0.03	9.95	0.00	-0.40

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Isokinetic							
Test Number	Sampling Time and Date	Start Weight	End Weight	Total gain	Concentration	LOD	Uncertainty
		kg	kg	kg	%	%	%
Run 1	12:25 - 13:25 19 February 2018	3.2310	3.2970	0.0660	7.0	0.0	3.4

Moisture Quality Assurance							
Test Number	Sampling Duration	Total Volume Sampled	Sampling Rate	Start Leak Rate	End Leak Rate	Acceptable Leak Rate	Leak Tests Acceptable?
	mins	l	l/min	l/min	l/min	l/min	
Run 1	60	1177	19.8	0.09	0.08	0.40	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	128	°C
Stack static pressure	0.03	kPa
Barometric Pressure	99.8	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	5.761905	0.057619	0.113110	5.359430	0.053594	0.105209
O ₂	32	1.427679	13.595444	0.135954	0.194099	12.645788	0.126458	0.180541
N ₂	28	1.249219	80.642651	0.806427	1.007404	75.009676	0.750097	0.937035
H ₂ O	18	0.803070	-	-	-	6.985107	0.069851	0.056095

Where: $p = M / 22.41$ $pi = r \times p$

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3146	kg/m ³
Wet Density (STP), P_{STW}	1.2789	kg/m ³
Dry Density (Actual), P_{Actual}	0.8820	kg/m ³
Average Wet Density (Actual), $P_{ActualW}$	0.858	kg/m ³

Where:

P_{STD} = sum of component concentrations, kg/m³ (not including water vapour)

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

$P_{STW} = (P_{STD} + pi \text{ of H}_2\text{O}) / (1 + (pi \text{ of H}_2\text{O} / 0.8036))$

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	19 February 2018
Time of Survey	12:00
Velocity Measurement Device:	S-Type Pitot

Sampling Line A								
Traverse Point	Distance into duct (m)	DP pt mmH ₂ O (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	128	6.9	1.0	-	<15
2	0.12	4.3	42	128	8.2	1.2	-	<15
3	0.20	3.9	38	128	7.8	1.1	-	<15
4	0.27	4.0	39	128	7.9	1.2	-	<15
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	3.8	37	128	7.7	1.1	-	-

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt mmH ₂ O (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	123	122	0.8	Pass	98	97	1.0	Pass

To complete a compliant pitot leak check a pressure of over 80 mmH₂O (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	30	30	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	6.9	m/s	-	-
Highest Gas Velocity	8.2	m/s	-	-
Ratio of Gas Velocities	1.2	-	< 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, $V = K_{pt} \times (1-e) \times \sqrt{2 * DP_{pt} / P_{ActualW}}$		
Where:		
K_{pt} = Pitot tube calibration coefficient		
(1-e) = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, V_a	7.7	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	128	0	°C
Total Pressure	99.83	101.3	kPa
Oxygen	13.6	11	%
Moisture	6.99	0.00	%
Pitot tube calibration coefficient, K_{pt}	0.84		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (V_a)	7.69	m/s
Stack Area (A)	0.15	m ²
Gas Volumetric Flowrate (Actual), Q_{Actual}	4074	m ³ /hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	2733	m ³ /hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	2542	m ³ /hr
Gas Volumetric Flowrate (REF), Q_{Ref}	1883	m ³ /hr

Where:

$$Q_{Actual} = V_a \times A \times 3600$$

$$Q_{STP} = Q_{Actual} \times (T_s / T_a) \times (P_a / P_s) \times 3600$$

$$Q_{STP,Dry} = Q_{STP} / (100 - (100 / Ma)) \times 3600$$

$$Q_{Ref} = Q_{STP} \times ((100 - Ma) / (100 - Ms)) \times ((20.9 - O_{2a}) / (20.9 - O_{2s}))$$

Nomenclature:

T_s = Absolute Temperature, Standard Conditions, 273 K

P_s = Absolute Pressure, Standard Conditions, 101.3 kPa

T_a = Absolute Temperature, Actual Conditions, K

P_a = Absolute Pressure, Actual Conditions, kPa

Ma = Water vapour, Actual Conditions, % Vol

Ms = Water vapour, Reference Conditions, % Vol

O_{2a} = Oxygen, Actual Conditions, % Vol

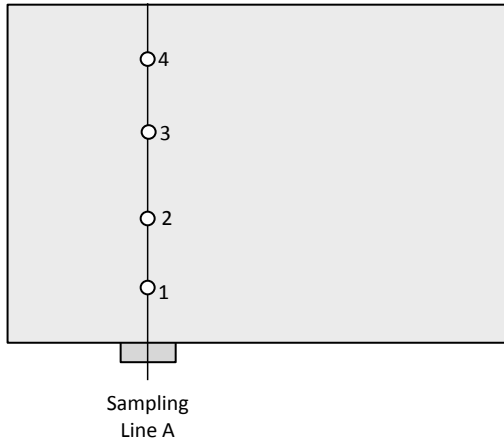
O_{2s} = Oxygen, Reference Conditions, % Vol

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



- Isokinetic sampling point
- Isokinetic sampling points not used
- Non Isokinetic/Gases sampling point

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
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

SAMPLING LOCATION



APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - TOTAL PARTICULATE MATTER

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %	Uncollected 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	0.2400	-	-
as a %	0.09	0.51	0.50	1.0	0.83	1.23126	0.40	0.001
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Run 2	0.001986872	2.0	0.50	1.0	0.1	0.240	-	-
as a %	0.20	0.68	0.50	1.0	0.82	1.208	0.44	0.001
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Run 3	0.001887791	2.0	0.50	1.0	0.1	0.2400	-	-
as a %	0.20	0.67	0.50	1.0	0.83	1.27133	0.51	0.001
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Run	Volume (STP) m ³	Mass of particulate mg	O ₂ Correction -	Leak mg/m ³	Uncollected Mass mg	Combined uncertainty
Run 1	0.75	0.2400	1.1	0.001	0.0001	-
MU as mg/m ³	0.00	0.2463	0.00	0.001	0.0001	0.25
MU as %	1.24	100.0000	-	0.233	0.0577	-
Run 2	0.90	0.2400	1.1	0.001	0.0001	-
MU as mg/m ³	0.00	0.2416	0.00	0.001	0.0001	0.24
MU as %	1.3	100.0000	-	0.252	0.0577	-
Run 3	0.85	0.9400	1.1	0.003	0.0001	-
MU as mg/m ³	0.01	0.2543	0.01	0.003	0.0001	0.25
MU as %	1.32	25.5319	-	0.296	0.0147	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.49	mg/m³	200	%
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.48	mg/m³	200	%
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.51	mg/m³	51	%

(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 m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Leak %
MU required	<=2%	<2.5 k	<=1%	<=1%	<=5%	<5%	<=2%
Run 1	0.001	2.0	0.50	1.0	0.10	0.0002	-
as a %	0.10	0.7	0.50	1.0	0.84	3.00	0.51
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Run	Volume (STP) m ³	O2 Correction -	Mass of Mercury mg	Leak mg/m ³	Lab Uncertainty mg	Combined
Run 1	0.9013	1.1038	2.5937	0.000008	-	-
MU as mg/m ³	0.0000	0.0000	0.0005	0.000008	0.00013	0.0005
MU as %	1.3141	1.1038	19.2810	0.2939	5.00000	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.0011	mg/m³	40	%
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(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 m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %
MU required	<=2%	<2.5 k	<=1%	<=1%	<=5%	≤ 5% of ELV	<=2%
Run 1	0.97461124	292.50	100	1.0	12.1	3.88	-
as a %	0.10	0.68	0.50	1.0	0.83	0.03	0.40
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Run	Volume (STP) m ³	Mass of Hydrogen Chloride mg	O2 Correction -	Leak mg/m ³	Lab Uncertainty mg	Combined uncertainty
Run 1	0.8980	3.8798	1.1236	0.0066	-	-
MU as mg/m ³	0.0373	0.0098	0.0318	0.0066	0.1359	0.1450
MU as %	1.3153	0.3450	1.1236	0.2333	4.8	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.29	mg/m³	10	%
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(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 %	0.09	0.51	0.50	1.0	0.83	0.40
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	0.75	66000	1.1	140.63	58	-
MU as % v/v	0.09	0.01	0.09	0.02	0.007	0.13
MU as %	1.24	0.15	1.12	0.23	0.09	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.26	% v/v	3.4	%
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 1

Measured Concentration	2.1	mg/m ³
Limit	10	mg/m ³
Calibration Gas Concentration	16.16	mg/m ³
Range	160	mg/m ³

Performance characteristics	Value	Units	specification	MU Met?
Response time	25	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	-0.99	% 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)	0.50	% 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	0.65
Drift	u0dr	-0.07
volume or pressure flow dependence	uspres	0.00
atmospheric pressure dependence	uapres	0.04
ambient temperature dependence	utemp	0.00
Dependence on voltage	uvolt	0.14
losses in the line (leak)	uleak	0.01
Uncertainty of calibration gas	ucalib	0.01
Uncertainty in factor	uf	0.26

Measurement uncertainty Measured Concentration	2.06	mg/m ³
Combined uncertainty	0.71	mg/m ³
Expanded uncertainty	1.43	mg/m ³

Expanded uncertainty expressed with a level of confidence of 95%	14	% ELV
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Expanded uncertainty expressed with a level of confidence of 95%	1.4	mg/m ³
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Expanded uncertainty expressed with a level of confidence of 95%	69	% value
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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	8.3	mg/m ³
Cal gas conc	207.5	mg/m ³
Analyser Full Scale	250	mg/m ³

Performance characteristics	Value	Units	specification	MU Met?
Response time	25	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	60	minutes	-	-
Number of readings in measurement	60	-	-	-
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	0.00	% full scale	<3% range / 24hr	Yes
Span drift	-0.50	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	0.2	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.44	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence zero / span	-0.8	0.36	<3% range / 10 K	Yes
Combined interference	-0.01	% of Range	<4% of Range	Yes
dependence on voltage	-0.06	% 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)	0.00	% 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_{dz}	0.35
short term span drift	U_{ds}	0.00
influence of Ambient Temp zero	U_{tz}	0.00
influence of Ambient Temp span	U_{ts}	0.14
influence of sample gas pressure	U_p	0.00
influence of sample gas flow	U_{fit}	0.14
influence of supply voltage	U_v	-0.09
Combined Interference	U_i	-0.25
Uncertainty of Cal gas	U_{adj}	0.83

Measurement uncertainty (Concentration Measured)	5.7	mg/m ³
Combined uncertainty	1.0	mg/m ³
Expanded uncertainty	1.9	mg/m ³

Expanded uncertainty expressed with a level of confidence of 95%	1.9	% ELV
Expanded uncertainty expressed with a level of confidence of 95%	1.9	mg/m³
Expanded uncertainty expressed with a level of confidence of 95%	34	% 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	13.60	%vol
Calibration gas	9.97	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	25	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	0.13	% of value	<2 % range	Yes
Zero drift	-0.32	% full scale	<2% range / 24hr	Yes
Span drift	1.88	% 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	-0.05	% full scale/10K	<3% range / 10 K	Yes
Combined interference	0.01	% range	<4% of Range	Yes
dependence on voltage	0.00	% full scale/10V	< 0.1%vol /10 volt	Yes
losses in the line (leak)	0.01	% of value	< 2% of value	Yes
Uncertainty of calibration gas	0.0	% 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	$U_{d,z}$	-0.1848
short term span drift	$U_{d,s}$	1.0854
influence of Ambient Temp at Zero	$U_{t,z}$	-0.0017
influence of Ambient Temp at Span	$U_{t,s}$	-0.0702
influence of sample gas pressure	U_p	0.0000
influence of sample gas flow	U_{fit}	0.0173
influence of supply voltage	U_v	0.0001
Combined Interference	U_i	0.0017
Uncertainty of Cal gas	U_{adj}	0.0499

Measurement uncertainty (Concentration Measured)	13.60	%
Combined uncertainty	1.11	%
Expanded uncertainty	2.17	%

Expanded uncertainty expressed with a level of confidence of 95%	2.2	%
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Expanded uncertainty expressed with a level of confidence of 95%	0.30	% vol
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Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 1 - 19 February 2018

Reference	11	%vol
Measured concentration	13.60	%vol
Calibration gas	9.97	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	30	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	0.1	% of value	<2 % range	Yes
Zero drift	-0.80	% full scale	<2% range / 24hr	Yes
Span drift	-1.65	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	-0.0425	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.0475	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	0.0025	% full scale/10K	<3% range / 10 K	Yes
Combined interference	0.00	% range	<4% of Range	Yes
dependence on voltage	0.18	% full scale/10V	< 0.1%vol /10 volt	Yes
losses in the line (leak)	-0.61	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.00	% of value	< 2% of value	Yes

losses in the line (leak)	Uncertainty	< 2% of value
repeatability	$U_r = S_r$	0.00833
lack of fit	U_{lof}	0.05774
short term zero drift	$U_{d,z}$	-0.46327
short term span drift	$U_{d,s}$	-0.95241
influence of Ambient Temp at Zero	$U_{t,z}$	0.00012
influence of Ambient Temp at Span	$U_{t,s}$	0.00234
influence of sample gas pressure	U_p	0.00000
influence of sample gas flow	U_{fit}	-0.02944
influence of supply voltage	U_v	0.01007
Combined Interference	U_i	0.00000
Uncertainty of Cal gas	U_{adj}	0.04985

Measurement uncertainty (Concentration Measured)	13.60	%
Combined Interference	1.06	%
Uncertainty of Cal gas	7.81	%

Expanded uncertainty expressed with a level of confidence of 95%	7.8	%
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Expanded uncertainty as percentage of the result	1.1	% vol
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Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

day 2 - 20 February 2018

Reference	11	%vol
Measured concentration	11.94	%vol
Calibration gas	9.97	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	30	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	0.1	% of value	<2 % range	Yes
Zero drift	0.00	% full scale	<2% range / 24hr	Yes
Span drift	-0.40	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	-0.0425	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.0475	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	0.0025	% full scale/10K	<3% range / 10 K	Yes
Combined interference	0.00	% range	<4% of Range	Yes
dependence on voltage	0.18	% full scale/10V	< 0.1%vol /10 volt	Yes
losses in the line (leak)	0.20	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.00	% of value	< 2% of value	Yes

losses in the line (leak)	Uncertainty	< 2% of value
repeatability	$U_r = S_r$	0.008333
lack of fit	U_{lof}	0.057735
short term zero drift	$U_{d,z}$	0.000000
short term span drift	$U_{d,s}$	-0.231635
influence of Ambient Temp at Zero	$U_{t,z}$	0.000000
influence of Ambient Temp at Span	$U_{t,s}$	-0.000180
influence of sample gas pressure	U_p	0.000000
influence of sample gas flow	U_{fit}	-0.029445
influence of supply voltage	U_v	0.010073
Combined Interference	U_i	0.000000
Uncertainty of Cal gas	U_{adj}	0.049850

Measurement uncertainty (Concentration Measured)	11.94	%
Combined Interference	0.25	%
Uncertainty of Cal gas	2.06	%

Expanded uncertainty expressed with a level of confidence of 95%	2.1	%
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Expanded uncertainty as percentage of the result	0.25	% vol
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Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	7.7	m/s
Measured Volumetric Flow rate at Actual Conditions	4074	m ³ /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 measurement device	pa	1000		
Resolution	pa	1.00		
Calibration uncertainty	pa	2.51	<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	0.00003		
Uncertainty of temperature measurement	K	2.05	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	509		
Uncertainty associated with the estimate of density	-	0.008		
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	0.10
Expanded uncertainty at a 95% Confidence Interval	0.19

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	1.3
Expanded uncertainty at a 95% Confidence Interval	2.5

Measurement Uncertainty Volumetric Flow Rate	m ³ /hr
Combined uncertainty	117
Expanded uncertainty at a 95% Confidence Interval	230

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

https://www.surveymonkey.co.uk/r/CAE_customer_feedback_weblink