STACK EMISSIONS MONITORING REPORT

SOCOTEC

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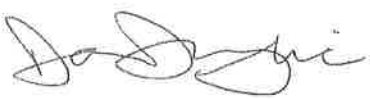
Operator & Address:
North Tyneside Council Whitley Bay Crematorium Blyth Road Whitley Bay Tyne & Wear NE26 4NH

Permit Reference:
EPR Permit: NT006 / PG 5/2(12)

Release Point:
Cremator 2

Sampling Date(s):
4th June 2018

SOCOTEC UK Job Number:	LEK 11173
Report Date:	23rd July 2018
Version:	1
Report By:	Andrew O'Neill
MCERTS Number:	MM 08 985
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Report Approved By:	David Drylie
MCERTS Number:	MM 04 493
Business Title:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Signature:	

UKAS TESTING 1015

mCERTS

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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

North Tyneside Council operates a cremation process at Whitley Bay Crematorium which is subject to EPR Permit NT006 / PG 5/2(12), under the Environmental Permitting Regulations 2010.

SOCOTEC UK LTD were commissioned by North Tyneside 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 EPR Permit, NT006 / PG 5/2(12).

Plant

Cremator 2

Operator

North Tyneside Council
Whitley Bay Crematorium
Blyth Road
Whitley Bay
Tyne & Wear
NE26 4NH

EPR Permit: NT006 / PG 5/2(12)

Stack Emissions Monitoring Test House

SOCOTEC UK - East Kilbride Laboratory
2-4 Langlands Place
Kelvin South Business Park
East Kilbride
G75 0YF
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	41.0	1.48	160	✓
Particulate Emission Rate	g/hr	146	5.3	-	
Hydrogen Chloride	mg/m³	32.65	3.331	200	✓
Hydrogen Chloride Emission Rate	g/hr	118.69	12.106	-	
Volatile Organic Compounds	mg/m³	0.84	2.25	20	✓
Volatile Organic Compounds Emission Rate	g/hr	3.02	8.11	-	
Carbon Monoxide	mg/m³	2.01	1.90	200	✓
Carbon Monoxide Emission Rate	g/hr	7.23	6.85	-	
Oxygen	% v/v	11.4	1.3	-	✓
Moisture	%	9.2	0.29	-	✓
Stack Gas Temperature	°C	787	-	-	✓
Stack Gas Velocity	m/s	10.7	0.27	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	17059	883	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	4406	228	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	4006	207	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	3602	186	-	

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	04 June 2018	12:16 - 13:16	60 minutes
Total Particulate Matter Run 2	04 June 2018	14:17 - 15:17	60 minutes
Total Particulate Matter Run 3	04 June 2018	15:38 - 16:38	60 minutes
Hydrogen Chloride Run 1	04 June 2018	12:16 - 13:16	60 minutes
Hydrogen Chloride Run 2	04 June 2018	14:17 - 15:17	60 minutes
Hydrogen Chloride Run 3	04 June 2018	15:38 - 16:38	60 minutes
Volatile Organic Compounds Run 1	04 June 2018	12:16 - 13:16	60 minutes
Volatile Organic Compounds Run 2	04 June 2018	14:17 - 15:17	60 minutes
Volatile Organic Compounds Run 3	04 June 2018	15:38 - 16:38	60 minutes
Combustion Gases Run 1	04 June 2018	12:16 - 13:16	60 minutes
Combustion Gases Run 2	04 June 2018	14:17 - 15:17	60 minutes
Combustion Gases Run 3	04 June 2018	15:38 - 16:38	60 minutes
Preliminary Stack Traverse	04 June 2018	11:00	-

EXECUTIVE SUMMARY

PROCESS DETAILS

CREMATOR OPERATING INFORMATION			
Description of process	Cremation		
Continuous or batch	Batch		
Abatement	Secondary Chamber		
Plume Appearance	None visible from sampling location		
TEST SPECIFIC DETAILS	**Run 1**	**Run 2**	**Run 3**
Coffin Type	Standard	Standard	Standard
Sex	Male	Female	Female
Body Size	Medium	Medium	Medium
Cremation Number	44285	44287	44288

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	0.21 mg/m³	3.6%
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	0 mg/m³	10.2%
VOCs	SRM - BS EN 12619:2013	AE 102	1015	Yes	0.34 mg/m³	268.7%
CO	SRM - BS EN 15058:2017	AE 102	1015	Yes	0.29 mg/m³	94.7%
O_2	AM - BS EN 14789:2017	AE 102	1015	Yes	0.01%	11.4%
H_2O	SRM - BS EN 14790	AE 105	1015	Yes	0.01%	3.22%
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	-	5.2%

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 (East Kilbride)	SOCOTEC UK (East Kilbride)	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 (East Kilbride)	SOCOTEC UK (East Kilbride)	5 years
CO	Non Dispersive Infra Red	AE 102	1015	Yes	SOCOTEC UK (East Kilbride)	SOCOTEC UK (East Kilbride)	5 years
O_2	Zirconia Cell	AE 102	1015	Yes	SOCOTEC UK (East Kilbride)	SOCOTEC UK (East Kilbride)	5 years
H_2O	Gravimetric	AE 105	1015	Yes	SOCOTEC UK (East Kilbride)	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	Value	Units	Requirement	Compliant	Method
Lowest Differential Pressure	20	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	9.0	m/s	-	-	-
Highest Gas Velocity	11.0	m/s	-	-	-
Ratio of Gas Velocities	1.2	:1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	9.8	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	Circular	-
Depth	0.75	m
Width	-	m
Area	0.44	m^2
Port Depth	180	mm

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

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

M1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	No
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	N/A
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 restricted by ductwork so does not meet the requirements as specified in EA Guidance Note M1.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Sample Plane

Due to the restrictive nature of the sampling location, it is only possible to sample on one line and at one point. This is likely to increase the uncertianty of the result.

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
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	3
VOCs	SRM - BS EN 12619:2013	AE 102	1015	Yes	3
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	3
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 Analyaer/s		Miscellaneous	
Equipment	Equipment I.D.	Equipment	Equipment I.D.	Equipment	Equipment I.D.
Control Box DGM	LEK 9.36	Horiba PG-350 Analyser	LEK 12.14	Laboratory Balance	LEK 15.21
Box Thermocouples	LEK 9.37	FT-IR Gasmet	-	Tape Measure	LEK 20.7
Meter In Thermocouple	LEK 9.37	FT-IR Oven Box	-	Stopwatch	LEK 17.16
Meter Out Thermocouple	LEK 9.37	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LEK 17.19	Signal 3030 FID	-	Barometer	LEK 16.6
Oven Box	LEK 13.14	Servomex	-	Digital Micromanometer	LEK 1.14
Probe	LEK 6.50	JCT Heated Head Filter	-	Digital Temperature Meter	LEK 2.15
Probe Thermocouple	-	Thermo FID	LEK 8.11	Stack Thermocouple	LEK 3.214
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LEK 6.21	Anemometer	-	1m Heated Line (1)	LEK 8.37
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LEK 23.16	Chiller (JCT/MAK 10)	LEK 12.13	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	LEK 8.37	6m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	LEK 8.31	10m Heated Line (1)	-
Callipers	LEK 15.1K	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	LEK 8.31
Inclinometer (Swirl Device)	LEK 24.8		-	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	LEK 140	BOC	-	10.96	2.0
Propane	LEK 159	BOC	10.7	-	2.0
Carbon Monoxide	LEK 172	BOC	167.8	-	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
David Drylie	MM 04 493	MCERTS Level 2	Jan 19	Dec 20	Mar 19	Dec 21	Jun 21	Jan 19
Callum Montgomery	MM 16 1399	MCERTS Level 1	Nov 21	-	-	-	-	Nov 21

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	12:16 - 13:16 04 June 2018	30.5	1.06	160	115.7
Run 2	14:17 - 15:17 04 June 2018	43.5	1.63	160	155.8
Run 3	15:38 - 16:38 04 June 2018	49.0	1.72	160	167.8
Blank	-	3.11	-	-	-

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	AH 1739	0.70951	0.72576	0.01625	200.55940	200.57230	0.01290	0.02915
Run 2	AH 1743	0.62904	0.65857	0.02953	183.91100	183.92080	0.00980	0.03933
Run 3	AH 1742	0.61746	0.64477	0.02731	172.43320	172.44810	0.01490	0.04221

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	AH 1737	0.72738	0.72748	0.00010	158.49540	158.49850	0.00310	0.00320

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

ISOKINETIC SAMPLING EQUATIONS - RUN 1			TPM
Absolute pressure of stack gas, P_s			
Barometric pressure, P_b	mm Hg	762.76	
Stack static pressure, P_{static}	mm H_2O	-8.16	
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	762.16	
Vol. of water vapour collected, V_{wstd}			
Moisture trap weight increase,Vlc	g	103.6	
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.1290856	
Volume of gas metered dry, V_{mstd}			
Volume of gas sample through gas meter, V_m		1.062	
Gas meter correction factor, Y_d		1.024	
Mean dry gas meter temperature, T_m	°	20.583	
Mean pressure drop across orifice, DH	mmH_2O	38.412	
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$	m^3	1.019	
Volume of gas metered wet, V_{mstw}			
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.1477	
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		11.6	
% oxygen reference condition		11	
O_2 Reference Factor $O_2\ Ref = \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		0.94	
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	0.9561	
Moisture content, B_{wo}			
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1125	
	%	11.25	
Moisture by FTIR	%	-	
Velocity of stack gas, V_s			
Pitot tube velocity constant, K_p		34.97	
Velocity pressure coefficient, C_p		0.93	
Mean of velocity heads, DP_{avg}	mm H_2O	2.38	
Mean square root of velocity heads, ÖDP		1.54	
Mean stack gas temperature, T_s	°C	801	
$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	11.23	

Molecular weight of dry gas, M_d		
CO_2	%	5.76
O_2	%	11.61
Total	%	17.38
N_2 (100 -Total)	%	82.62
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.39
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.11
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.44
$Q_a = (60)(A_s)(V_s)$	m^3/min	297.7
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	67.4
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	63.27
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	75.90
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	11.98
Nozzle area, A_n	mm^2	112.74
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	98.8
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.01625
Mass collected in probe, M_p	g	0.01290
Total mass collected, M_n	g	0.02915
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	25.398
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	28.617
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	30.489
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		115.66

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	762.76
Stack static pressure, P_{static}	mm H_2O	-8.16
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	762.16
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	58.4
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.0727664
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		1.176
Gas meter correction factor, Y_d		1.024
Mean dry gas meter temperature, T_m		26.917
Mean pressure drop across orifice, DH	mmH_2O	42.091
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$	m^3	1.104
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.1771
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		12.8175
% oxygen reference condition		11
O_2 Reference Factor $O_2\ Ref = \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		0.82
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	0.9037
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0618
	%	6.18
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.93
Mean of velocity heads, DP_{avg}	mm H_2O	2.50
Mean square root of velocity heads, ÖDP		1.58
Mean stack gas temperature, T_s	°C	778
$V_s = \frac{(K_p)(C_p)(ÖDP)(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	11.26

Molecular weight of dry gas, M_d		
CO_2	%	5.76
O_2	%	12.82
Total	%	18.58
N_2 (100 -Total)	%	81.42
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.43
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.73
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.44
$Q_a = (60)(A_s)(V_s)$	m^3/min	298.4
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	72.9
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	59.70
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	77.70
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	11.98
Nozzle area, A_n	mm^2	112.74
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	99.0
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.02953
Mass collected in probe, M_p	g	0.00980
Total mass collected, M_n	g	0.03933
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	33.41
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	35.61
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	43.52
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		155.77

ISOKINETIC SAMPLING EQUATIONS - RUN 3 — TPM

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	762.76
Stack static pressure, P_{static}	mm H_2O	-8.16
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	762.16
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	81.0
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.100926
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.962
Gas meter correction factor, Y_d		1.024
Mean dry gas meter temperature, T_m		25.833
Mean pressure drop across orifice, DH	mmH_2O	30.261
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		0.906
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.0069
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		11.49
% oxygen reference condition		11
O_2 Reference Factor $\frac{O_2 \text{ Ref} = 21.0 - act\%O_2}{21.0 - ref\%O_2}$		0.95
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\,Ref})$	m^3	0.8616
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1002
	%	10.02
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.93
Mean of velocity heads, DP_{avg}	mm H_2O	1.82
Mean square root of velocity heads, ÖDP		1.35
Mean stack gas temperature, T_s	°C	781
$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	9.69

Molecular weight of dry gas, M_d		
CO_2	%	5.76
O_2	%	11.49
Total	%	17.25
N_2 (100 -Total)	%	82.75
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.38
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.24
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.44
$Q_a = (60)(A_s)(V_s)$	m^3/min	256.9
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	60.0
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	57.14
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	66.72
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	11.98
Nozzle area, A_n	mm^2	112.74
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	98.6
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.02731
Mass collected in probe, M_p	g	0.01490
Total mass collected, M_n	g	0.0422
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	41.92
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	46.59
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	48.99
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		167.82

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	18.12	0.05	0.04	-635	0.36	Yes
Run 2	20.07	0.01	0.01	-482.6	0.40	Yes
Run 3	16.42	0.02	0.02	-558.8	0.33	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	98.78	Yes
Run 2	98.95	Yes
Run 3	98.58	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	0.21	8.0	Yes
Run 2	0.22	8.0	Yes
Run 3	0.23	8.0	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	3.11	160	16.0	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	Glass Fibre	110	162	180	160
Run 2	Glass Fibre	110	161	180	160
Run 3	Glass Fibre	110	160	180	160

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	12:16 - 13:16 04 June 2018	41.15	0.002	200	159.10
Run 2	14:17 - 15:17 04 June 2018	23.87	0.002	200	83.23
Run 3	15:38 - 16:38 04 June 2018	32.94	0.002	200	113.73
Field Blank	-	0.01	-	-	-

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	18.1	0.05	0.04	0.36	Yes
Run 2	20.1	0.01	0.01	0.40	Yes
Run 3	16.4	0.02	0.02	0.33	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Max. Storage / Transit Temp. °C	Type of Absorbers	Absorption Solutions
Run 1	Glass Fibre	110	162	23	Glass	HPLC Water
Run 2	Glass Fibre	110	161	23	Glass	HPLC Water
Run 3	Glass Fibre	110	160	23	Glass	HPLC Water

HYDROGEN CHLORIDE ABSORPTION EFFICIENCY

Parameter	Total ug	IMP C ug	Absorption Efficiency %	Acceptable Absorption Efficiency %	Absorption Efficiency Acceptable ?
Run 1	39341.1	581.1	99	95	Yes
Run 2	21573	0	100	95	Yes
Run 3	28380	0	100	95	Yes

ISOKINETIC SAMPLING EQUATIONS 1			Hydrogen Chloride
Absolute pressure of stack gas, P_s			
Barometric pressure, P_b	mm Hg	763	
Stack static pressure, P_{static}	mm H_2O	-8	
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	762	
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		1.0620	
Gas meter correction factor, Y_d		1.024	
Mean dry gas meter temperature, T_m		20.58	
Mean pressure drop across orifice, DH	mmH_2O	38.41	
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		1.02	
Volume of gas metered wet, V_{mstw}			
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.1212	
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		11.61	
% oxygen reference condition		11	
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		0.94	
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	0.9561	
Moisture content, B_{wo}			
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0915	
	%	9.15	
Moisture by FTIR	%	-	
Molecular weight of dry gas, M_d			
CO_2		5.76	
O_2		11.61	
Total		17.38	
N_2 (100 -Total)		82.62	
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.39	
Molecular weight of wet gas, M_s			
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.3	

Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.93
Mean of velocity heads, DP_{avg}	mm H_2O	2.38
Mean square root of velocity heads, ÖDP		1.54
Mean stack gas temperature, T_s	°C	801
$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	11.2
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.44
$Q_a = (60)(A_s)(V_s)$	m^3/min	296
Dry total flow of stack gas, Q_{std}		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	m^3/min	69
Wet total flow of stack gas, Q_{stw}		
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	m^3/min	76
Dry total flow of stack gas at X% O_2, Q_{stdO2}		
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	m^3/min	64
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	11.98
Nozzle area, A_n	mm^2	112.74
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{msld})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	97
Acceptable isokinetic range 95% to 115%		Yes
Hydrogen Chloride Concentration, C		
Mass collected , M	ug	39341
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	35.087
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	38.621
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	41.148
Hydrogen Chloride Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$	g/hr	159.10

ISOKINETIC SAMPLING EQUATIONS 2			Hydrogen Chloride		
Absolute pressure of stack gas, P_s			**Velocity of stack gas, V_s**		
Barometric pressure, P_b	mm Hg	763	Pitot tube velocity constant, K_p		34.97
Stack static pressure, P_{static}	mm H_2O	-8	Velocity pressure coefficient, C_p		0.93
$P_s = P_b + (P_{static})$ / 13.6	mm Hg	762	Mean of velocity heads, DP_{avg}	mm H_2O	2.50
			Mean square root of velocity heads, ÖDP		1.58
Vol. of water vapour collected, V_{wstd}			Mean stack gas temperature, T_s	°C	778
Moisture trap weight increase,Vlc	g	-			
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	11.3
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_s**		
Volume of gas sample through gas meter, V_m		1.1758	Area of stack, A_s	m^2	0.44
Gas meter correction factor, Y_d		1.024	$Q_s = (60)(A_s)(V_s)$	m^3/min	300
Mean dry gas meter temperature, T_m		26.92	**Dry total flow of stack gas, Q_{std}**		
Mean pressure drop across orifice, DH	mmH_2O	42.09	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	$Q_{std} = \frac{(Q_s)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	m^3/min	71
Volume of gas metered wet, V_{mstw}			**Wet total flow of stack gas, Q_{stw}**		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.2156	$Q_{stw} = \frac{(Q_s)P_s(0.3592)}{(T_s) +273}$	m^3/min	78
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	$Q_{stdO2} = \frac{(Q_s)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	m^3/min	58
% oxygen measured in gas stream, act%O_2		12.82			
% oxygen reference condition		11	**Percent isokinetic, %I**		
O_2 Reference Factor: O2 Ref = 21.0 - act%O2 / 21.0 - ref%O2		0.82	Nozzle diameter, D_n	mm	11.98
			Nozzle area, A_n	mm^2	112.74
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$	m^3	0.9037	Total sampling time, q	min	60
Moisture content, B_{wo}			$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	102
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0915			
	%	9.15	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	21573
CO_2		5.76	$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	17.747
O_2		12.82			
Total		18.58	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	19.534
N_2 (100 -Total)		81.42			
			$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	23.873
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.43			
Molecular weight of wet gas, M_s			**Hydrogen Chloride Emission Rates, E**		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.4	$E = [(C_{wet})(Q_{stw})(60)] / 1000$	g/hr	83.23

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS 3			Hydrogen Chloride		
Absolute pressure of stack gas, P_s			**Velocity of stack gas, V_s**		
Barometric pressure, P_b	mm Hg	763	Pitot tube velocity constant, K_p		34.97
Stack static pressure, P_{static}	mm H_2O	-8	Velocity pressure coefficient, C_p		0.93
$P_s = P_b + (P_{static})$ / 13.6	mm Hg	762	Mean of velocity heads, DP_{avg}	mm H_2O	1.82
			Mean square root of velocity heads, ÖDP		1.35
Vol. of water vapour collected, V_{wstd}			Mean stack gas temperature, T_s	°C	781
Moisture trap weight increase,Vlc	g	-			
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$V_s = (K_p)(C_p)(ÖDP)(Ö(T_s + 273)) / (M_s)(P_s)$	m/s	9.7
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		0.9622	Area of stack, A_s	m^2	0.44
Gas meter correction factor, Y_d		1.024	$Q_a = (60)(A_s)(V_s)$	m^3/min	256
Mean dry gas meter temperature, T_m		25.83	**Dry total flow of stack gas, Q_{std}**		
Mean pressure drop across orifice, DH	mmH_2O	30.26	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = (0.3592)(V_m)(P_b+(DH/13.6))(Y_d) / T_m + 273$		0.91	$Q_{std} = (Q_a)P_s(0.3592)(1-B_{wo}) / (T_s) +273$	m^3/min	61
Volume of gas metered wet, V_{mstw}			**Wet total flow of stack gas, Q_{stw}**		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9972	$Q_{stw} = (Q_a)P_s(0.3592) / (T_s) +273$	m^3/min	67
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	$Q_{stdO2} = (Q_a)P_s(0.3592)(1-B_{wo})(O_2REF) / (T_s) +273$	m^3/min	58
% oxygen measured in gas stream, act%O_2		11.49	**Percent isokinetic, %I**		
% oxygen reference condition		11	Nozzle diameter, D_n	mm	11.98
O_2 Reference O2 Ref = 21.0 - act%O2 / Factor 21.0 - ref%O2		0.95	Nozzle area, A_n	mm^2	112.74
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$	m^3	0.8616	Total sampling time, q	min	60
Moisture content, B_{wo}			$\%I = (4.6398E6)(T_s+273)(V_{mstd}) / (P_s)(V_s)(A_n)(q)(1-B_{wo})$	%	98
$B_{wo} = V_{wstd} / (V_{mstd} + V_{wstd})$	%	0.0915 / 9.15	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	28380
CO_2		5.76	$C_{wet} = M_n / V_{mstw}$	mg/m^3	28.458
O_2		11.49	$C_{dry} = M_n / V_{mstd}$	mg/m^3	31.325
Total		17.25	$C_{dry@X\%O2} = M_n / V_{mstd@X\%oxygen}$	mg/m^3	32.939
N_2 (100 -Total)		82.75			
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.38			
Molecular weight of wet gas, M_s			**Hydrogen Chloride Emission Rates, E**		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.3	$E = [(C_{wet})(Q_{stw})(60)] / 1000$	g/hr	113.73

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	12:16 - 13:16 04 June 2018	0.75	0.40	20	2.70
Run 2	14:17 - 15:17 04 June 2018	0.97	0.40	20	3.48
Run 3	15:38 - 16:38 04 June 2018	0.80	0.40	20	2.87

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

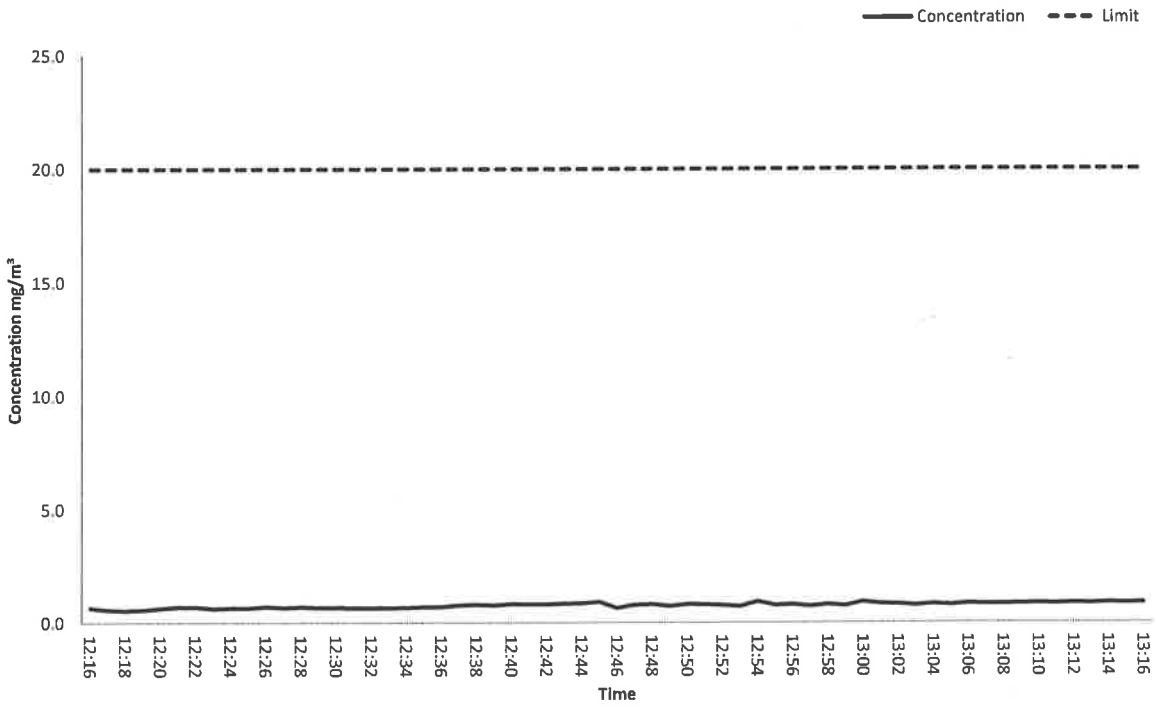
INSTRUMENTAL SPAN & ZERO CHECKS

PRE-SAMPLING CALIBRATION CHECKS RUN 1								
Date	04 June 2018							
Start Time	10:59							
End Time	11:44							
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	10.7	100	0.40	10.7	0.40	0.51	10.5	1.68

Zero and Span gas contained 9.96% Oxygen

POST-SAMPLING CALIBRATION CHECKS RUN 1				
Date	04 June 2018			
Start Time	16:44			
End Time	16:52			
Gas	Zero down line reading	Span down line reading	Zero Drift (%)	Span Drift (%)
Propane	0.34	10.5	-1.61	1.33

VOLATILE ORGANIC COMPOUNDS EMISSIONS CHART R1

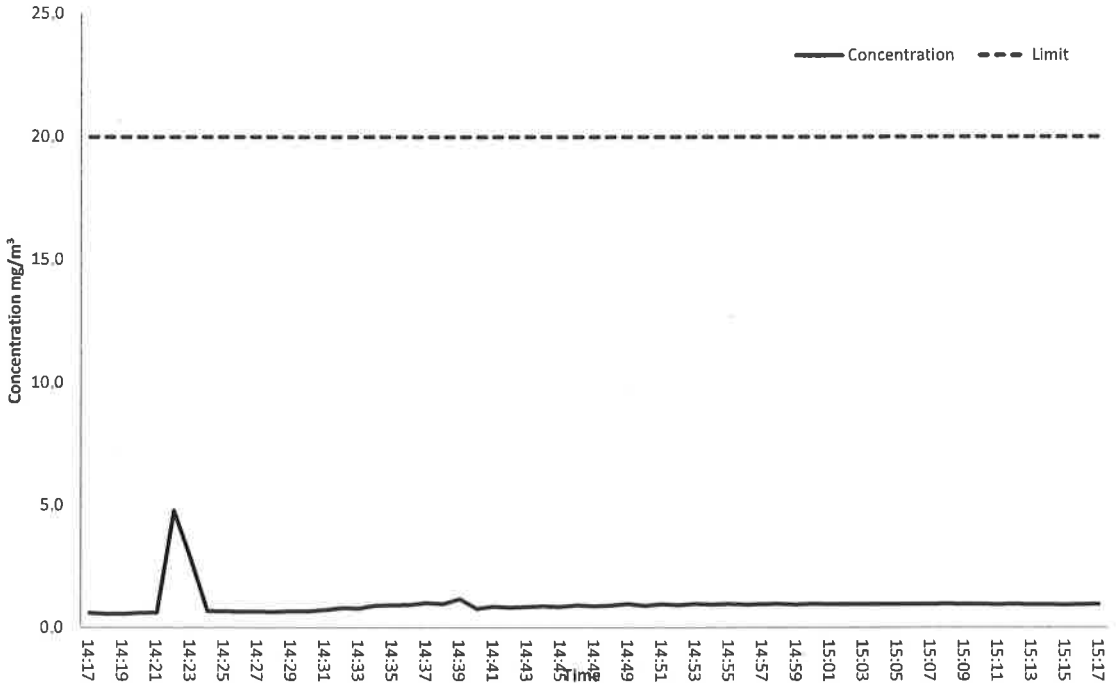


Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

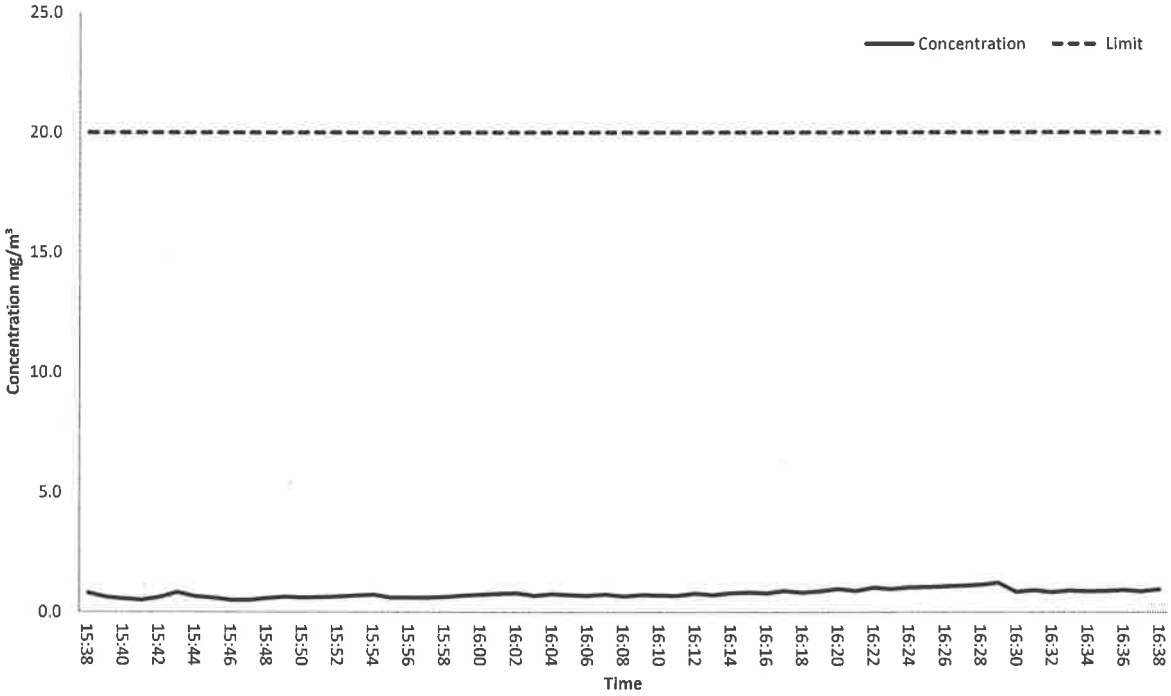
VOLATILE ORGANIC COMPOUNDS SUMMARY

VOLATILE ORGANIC COMPOUNDS EMISSIONS CHART R2



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

VOLATILE ORGANIC COMPOUNDS EMISSIONS CHART R3



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	12:16 - 13:16 04 June 2018	2.01	0.29	200	7.23

Test	Sampling Time and Date	Concentration %	LOD %
O_2	12:16 - 13:16 04 June 2018	11.41	0.01

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

PRE-SAMPLING CALIBRATION DATA

Date	04 June 2018
Start Time	11:09
End Time	11:41

Chiller Temperature (°C)	3.1
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	0.0	167.8	-0.2	-0.2	166.0	27	1.07
O_2	25	0.00	10.96	-0.01	0.02	11.01	18	-0.46

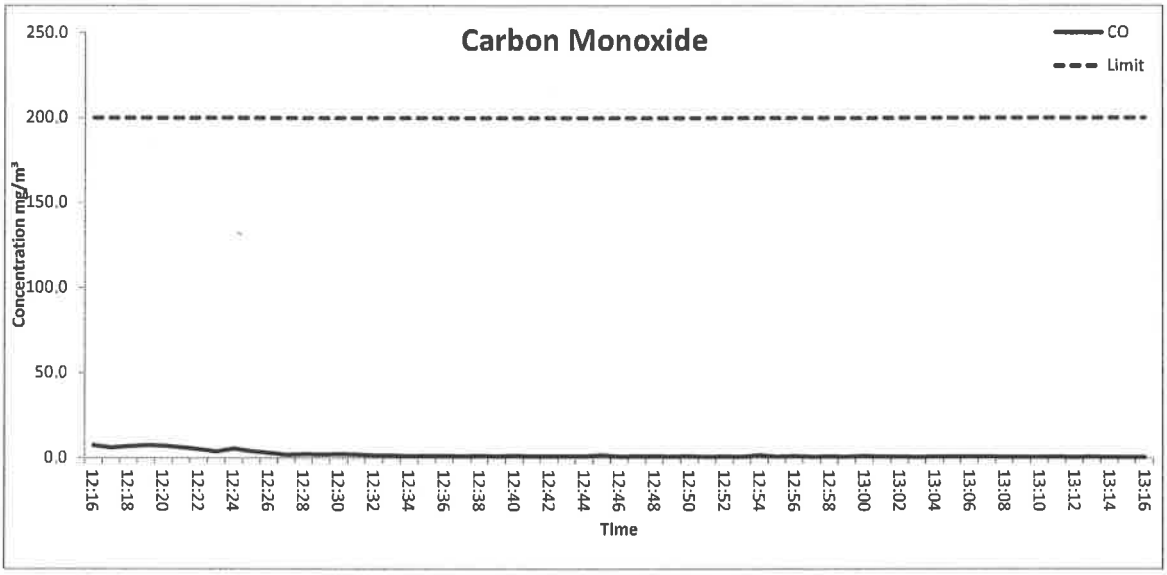
POST-SAMPLING CALIBRATION DATA

Date	04 June 2018
Start Time	16:42
End Time	16:49

Chiller Temperature (°C)	2.9
Requirement	< 4°C
Compliant	Yes

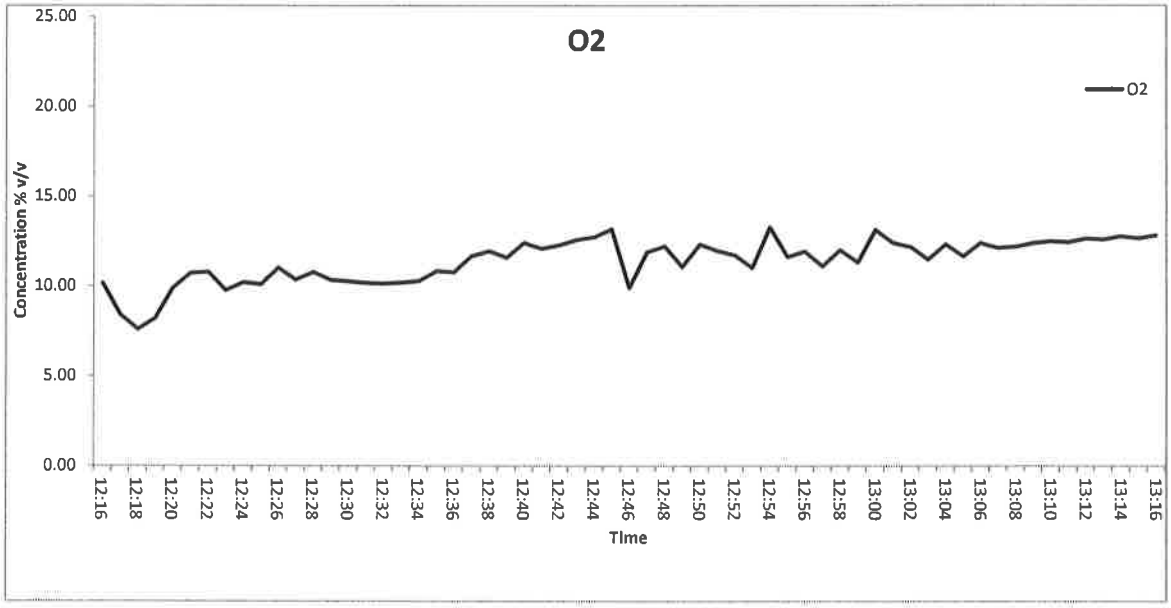
Gas	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
CO	0.2	165.2	0.20	-0.60
O_2	0.05	11.04	0.12	0.00

CARBON MONOXIDE EMISSIONS CHART R1

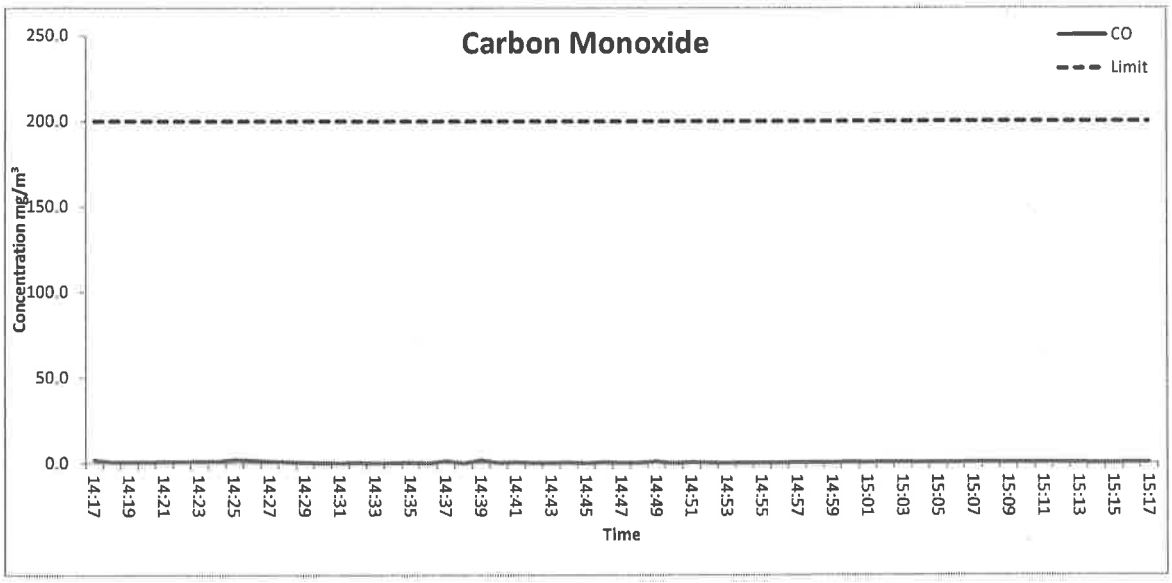


APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

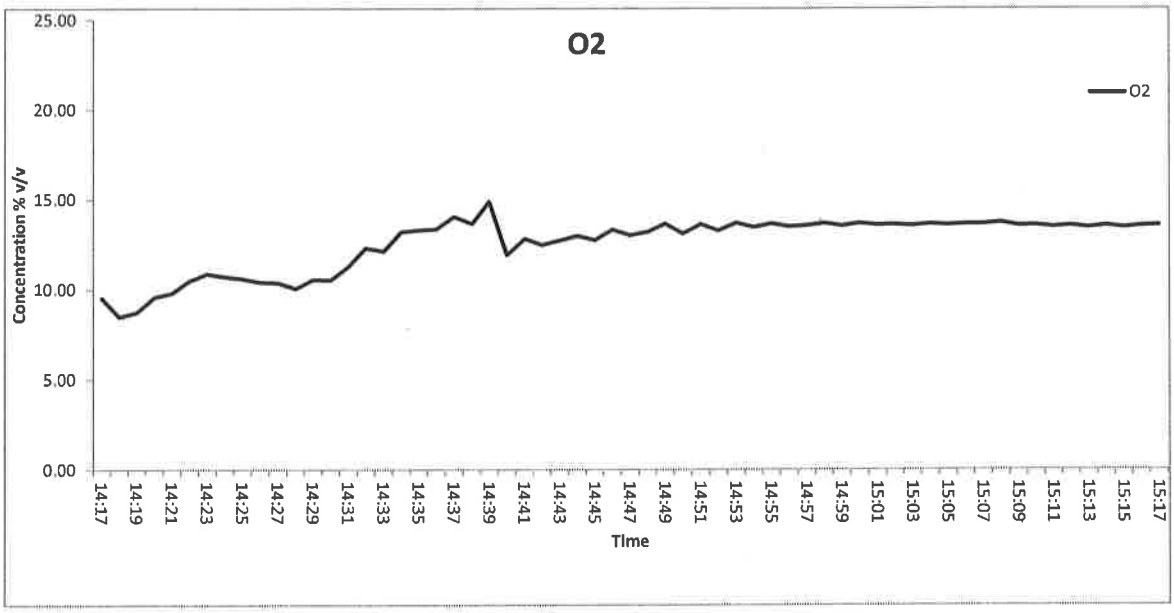
OXYGEN EMISSIONS CHART R1



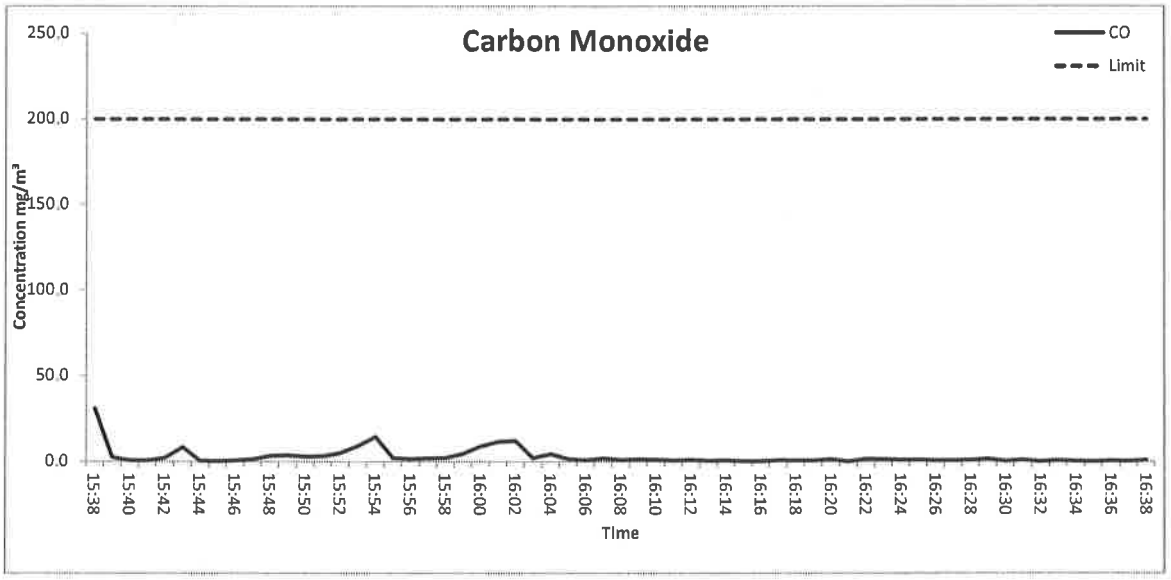
CARBON MONOXIDE EMISSIONS CHART R2



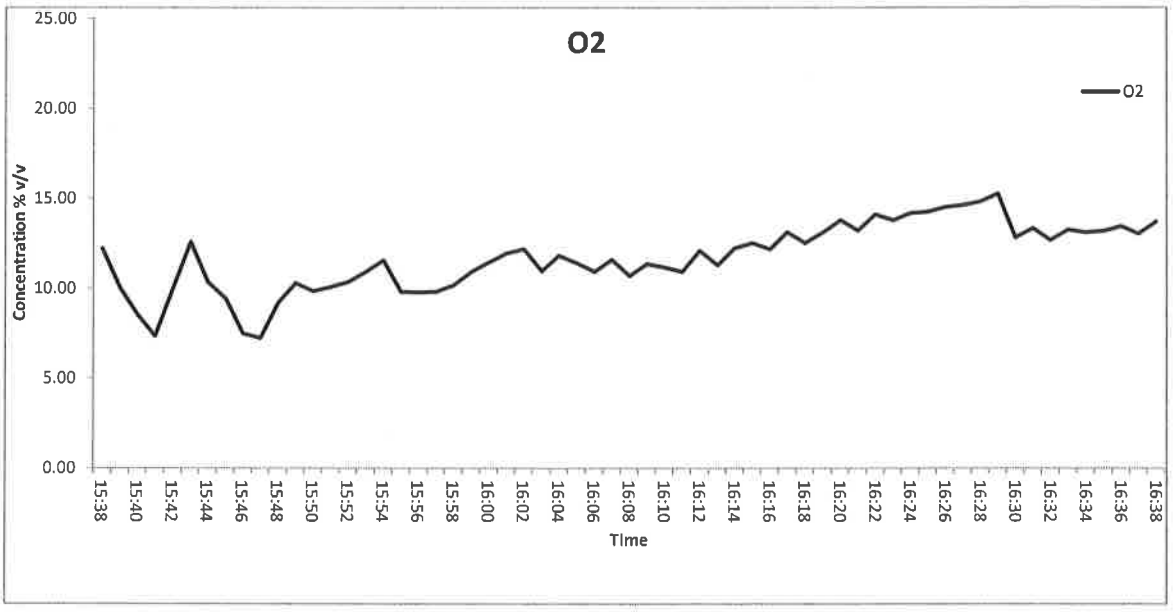
OXYGEN EMISSIONS CHART R2



CARBON MONOXIDE EMISSIONS CHART R3



OXYGEN EMISSIONS CHART R3



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	12:16 - 13:16 04 June 2018	2.6711	2.7747	0.1036	11.2	0.01	3.2
Run 2	14:17 - 15:17 04 June 2018	2.6251	2.6835	0.0584	6.2	0.01	3.6
Run 3	15:38 - 16:38 04 June 2018	2.6761	2.7571	0.0810	10.0	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	1147.7	18.1	0.05	0.04	0.36	Yes
Run 2	60	1177.1	20.1	0.01	0.01	0.40	Yes
Run 3	60	1006.9	16.4	0.02	0.02	0.33	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.75	m
Stack Width, W	-	m
Stack Area, A	0.44	m^2
Average stack gas temperature	815	°C
Stack static pressure	-0.08	kPa
Barometric Pressure	101.7	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	5.234652	0.052347	0.102759
O_2	32	1.427679	11.409167	0.114092	0.162886	10.365153	0.103652	0.147981
N_2	28	1.249219	82.828929	0.828289	1.034715	75.249535	0.752495	0.940032
H_2O	18	0.803070	-	-	-	9.150660	0.091507	0.073486

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3107	kg/m^3
Wet Density (STP), P_{STW}	1.2643	kg/m^3
Dry Density (Actual), P_{Actual}	0.3299	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.318	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	04 June 2018
Time of Survey	11:00
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	0.02	2.0	20	815	9.0	4.0	-	<15
2	0.06	2.0	20	815	9.0	4.0	-	<15
3	0.11	2.0	20	815	9.0	4.0	-	<15
4	0.17	2.0	20	815	9.0	4.0	-	<15
5	0.26	3.0	29	815	11.0	4.9	-	<15
6	0.49	3.0	29	815	11.0	4.9	-	<15
7	0.58	3.0	29	815	11.0	4.9	-	<15
8	0.64	3.0	29	815	11.0	4.9	-	<15
9	0.69	2.0	20	815	9.0	4.0	-	<15
10	0.73	2.0	20	815	9.0	4.0	-	<15
Mean	-	2.4	24	815	9.8	4.3	-	-

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	122	122	0.0	Pass	136	136	0.0	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	-80	-85	5.0	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	20	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	9.0	m/s	-	-
Highest Gas Velocity	11.0	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, $V = K_{pt} \times (1\text{-}e) * \sqrt{(2 * DP_{pt} / P_{ActualW})}$		
Where: K_{pt} = Pitot tube calibration coefficient (1-e) = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, Va	9.8	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	815	0	°C
Total Pressure	101.62	101.3	kPa
Oxygen	11.4	11	%
Moisture	9.15	0.00	%
Pitot tube calibration coefficient, K_{pt}	0.82		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	9.79	m/s
Stack Area (A)	0.44	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	15576	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	3921	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	3562	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	3416	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

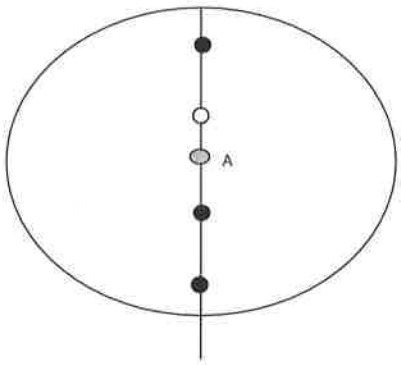
APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK DIAGRAM

	Value	Units
Stack Depth	0.75	m
Stack Width	-	m
Area	0.44	m^2

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	50	0.38	m

Circular 1 Line 1 Point

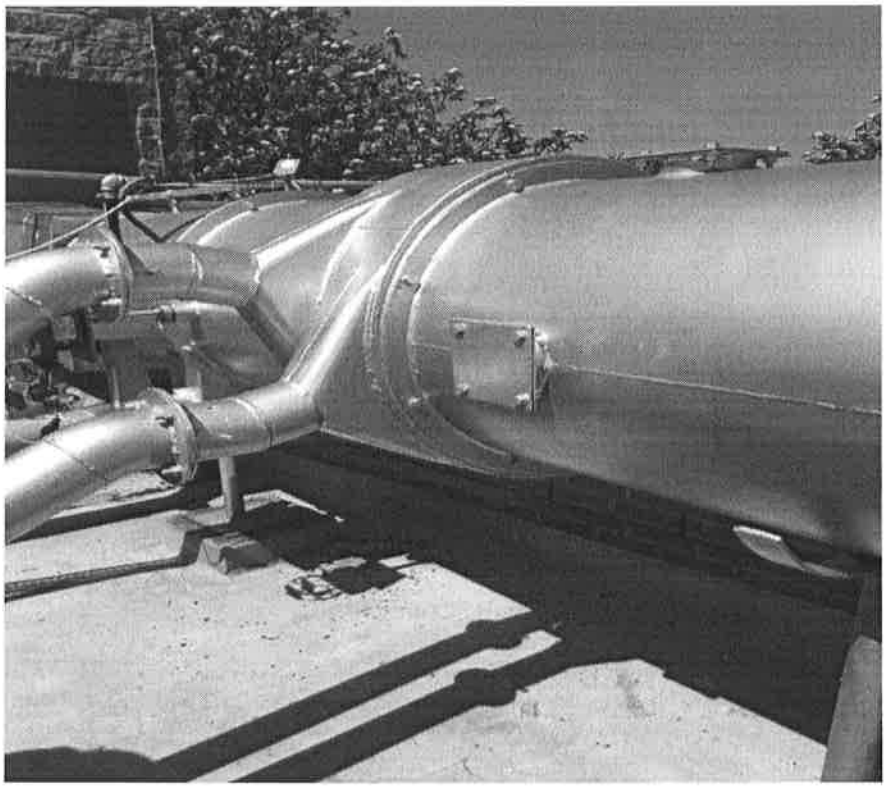


Sampling Line

Isokinetic Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	6.7	0.05	< 15
2	25.0	0.19	< 15
3	75.0	0.56	< 15
4	93.3	0.70	< 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 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	0.2000	-	-
as a %	0.10	0.19	0.49	1.0	0.86	0.13074	0.22	0.002
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 2	0.002	2.0	0.50	1.0	0.1	0.200	-	-
as a %	0.20	0.67	0.49	1.0	0.78	0.138	0.05	0.002
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	0.67	0.49	1.0	0.87	0.14508	0.12	0.002
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	0.26	29.1500	1.1	0.039	0.0018	-
MU as mg/m^3	0.36	0.2092	0.32	0.039	0.0019	**0.53**
MU as %	1.19	0.6861	-	0.127	0.0063	-
Run 2	0.83	39.3300	1.2	0.013	0.0018	-
MU as mg/m^3	0.57	0.2213	0.53	0.013	0.0020	**0.81**
MU as %	1.3	0.5085	-	0.029	0.0047	-
Run 3	0.79	42.2100	1.1	0.034	0.0018	-
MU as mg/m^3	0.65	0.2321	0.52	0.034	0.0021	**0.86**
MU as %	1.32	0.4738	-	0.070	0.0044	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**1.06**	**mg/m^3**	**3.49**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**1.63**	**mg/m^3**	**3.74**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**1.72**	**mg/m^3**	**3.51**	**%**

(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 - ISOKINETIC HYDROGEN CHLORIDE

Run	Sampled Volume m³	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	0.956	293.6	100.9	1.0	11.61	58.4808	-
as a %	0.10	0.68	0.50	1.0	0.86	0.04	0.22
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 2	0.904	299.9	100.9	1.0	12.82	21.573	-
as a %	0.11	0.67	0.50	1.0	0.78	0.03	0.05
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 3	0.862	298.8	100.9	1.0	11.49	28.38	-
as a %	0.12	0.67	0.50	1.0	0.87	0.04	0.12
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP) m³	Mass of Hydrogen Chloride mg	O2 Correction -	Leak mg/m³	Lab Uncertainty mg	Combined uncertainty
Run 1	0.8855	58.4808	1.0654	0.0524	-	-
MU as mg/m³	0.5400	0.0872	0.4384	0.0524	1.9751	**2.0965**
MU as %	1.3124	0.2120	1.0654	0.1274	4.8	-
Run 2	0.819	21.573	1.222	0.007	-	-
MU as mg/m³	0.312	0.057	0.292	0.007	1.146	**1.224**
MU as %	1.306	0.237	1.222	0.029	4.800	-
Run 3	0.784	28.380	1.052	0.023	-	-
MU as mg/m³	0.431	0.077	0.346	0.023	1.581	**1.677**
MU as %	1.308	0.233	1.052	0.070	4.800	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**4.19**	**mg/m³**	**10.19**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**2.45**	**mg/m³**	**10.26**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**3.35**	**mg/m³**	**10.18**	**%**

(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 %	0.10	0.19	0.49	1.0	0.86	0.22
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 2	0.001	2.0	0.50	1.0	0.1	-
as a %	0.11	0.67	0.49	1.0	0.78	0.05
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 3	0.001	2.0	0.50	1.0	0.1	-
as a %	0.12	0.67	0.49	1.0	0.87	0.12
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	0.26	103600	1.1	129.59	58	-
MU as % v/v	0.15	0.01	0.14	0.02	0.007	**0.21**
MU as %	1.19	0.10	1.07	0.13	0.06	-
Run 2	0.83	58400	1.2	18.59	58	-
MU as % v/v	0.11	0.01	0.10	0.002	0.01	**0.15**
MU as %	1.30	0.17	0.78	0.03	0.10	-
Run 3	0.79	81000	1.1	66.11	58	-
MU as % v/v	0.15	0.01	0.12	0.01	0.01	**0.20**
MU as %	1.31	0.12	0.97	0.07	0.07	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.41**	**% v/v**	**3.22**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.29**	**% v/v**	**3.60**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.40**	**% v/v**	**3.37**	**%**

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 1

Measured Concentration	0.7	mg/m^3
Limit	20	mg/m^3
Calibration Gas Concentration	17.12	mg/m^3
Range	160	mg/m^3

Performance characteristics	Value	Units	specification	MU Met?
Response time	11	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	-1.61	% full scale	<2% range / 24hr	Yes
Span drift	1.33	% 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)	1.68	% 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	-0.89
volume or pressure flow dependence	uspres	0.001
atmopsheric 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	0.00
Uncertainty in factor	uf	0.05

Measurement uncertainty Measured Concentration	0.75	mg/m^3
Combined uncertainty	1.11	mg/m^3
Expanded uncertainty	2.23	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**11.14**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**2.23**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**297.34**	**% value**

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

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 2

Measured Concentration	1.0	mg/m^3
Limit	20	mg/m^3
Calibration Gas Concentration	17.12	mg/m^3
Range	160	mg/m^3

Performance characteristics	Value	Units	specification	MU Met?
Response time	11	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	-1.61	% full scale	<2% range / 24hr	Yes
Span drift	1.33	% 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)	1.68	% 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	-0.88
volume or pressure flow dependence	uspres	0.001
atmopsheric 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	0.07

Measurement uncertainty Measured Concentration	0.97	mg/m^3
Combined uncertainty	1.11	mg/m^3
Expanded uncertainty	2.22	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**11.08**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**2.22**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**229.12**	**% value**

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

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 3

Measured Concentration	0.8	mg/m^3
Limit	20	mg/m^3
Calibration Gas Concentration	17.12	mg/m^3
Range	160	mg/m^3

Performance characteristics	Value	Units	specification	MU Met?
Response time	11	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	-1.61	% full scale	<2% range / 24hr	Yes
Span drift	1.33	% 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)	1.68	% 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	-0.89
volume or pressure flow dependence	uspres	0.001
atmopsheric 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	0.005
Uncertainty in factor	uf	0.06

Measurement uncertainty Measured Concentration	0.80	mg/m^3
Combined uncertainty	1.11	mg/m^3
Expanded uncertainty	2.23	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**11.13**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**2.23**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**279.77**	**% 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	200	mg/m^3
Concentration @ Ref conditions	2.0	mg/m^3
Cal gas conc	209.8	mg/m^3
Analyser Full Scale	250	mg/m^3

Performance characteristics	Value	Units	specification	MU Met?
Response time	27	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	0.20	% full scale	<2% range / 24hr	Yes
Span drift	-0.60	% 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)	0.01	% 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	$U_{d,s}$	0.12
influence of Ambient Temp zero	$U_{t,z}$	-0.07
influence of Ambient Temp span	$U_{t,s}$	0.17
influence of sample gas pressure	U_p	0.02
influence of sample gas flow	U_{fit}	0.14
influence of supply voltage	U_v	-0.09
Combined Interfence	U_i	-0.27
Uncertainty of Cal gas	U_{adj}	0.84

Measurement uncertainty (Concentration Measured)	2.1	mg/m^3
Combined uncertainty	1.0	mg/m^3
Expanded uncertainty	2.0	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**1.0**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**2.0**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**94.7**	**% 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	11.41	%vol
Calibration gas	10.96	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	18	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	0.12	% full scale	<2% range / 24hr	Yes
Span drift	0.00	% 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	0.45	<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	$U_{d,z}$	0.0693
short term span drift	$U_{d,s}$	0.0000
influence of Ambient Temp at Zero	$U_{t,z}$	0.0007
influence of Ambient Temp at Span	$U_{t,s}$	-0.0063
influence of sample gas pressure	U_p	-0.0009
influence of sample gas flow	U_{flt}	0.0173
influence of supply voltage	U_v	0.0001
Combined Interfence	U_i	0.0017
Uncertainty of Cal gas	U_{adj}	0.0548

Measurement uncertainty (Concentration Measured)	11.41	%
Combined uncertainty	0.12	%
Expanded uncertainty	0.23	%

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	9.8	m/s
Measured Volumetric Flow rate at Actual Conditions	15576	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	2.31	<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	0.00006		
Uncertainty of temperature measurement	K	5.55	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	518		
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	0.13
Expanded uncertainty at a 95% Confidence Interval	0.25

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	m³/hr
Combined uncertainty	411
Expanded uncertainty at a 95% Confidence Interval	806

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	2.6
Expanded uncertainty at a 95% Confidence Interval	5.2

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