STACK EMISSIONS MONITORING REPORT

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

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

Release Point:
Abatement System Exh

Sampling Date(s):
2nd & 3rd February 2015

ESG Job Number:	LNO 12257
Report Date:	27th February 2015
Version:	1
Report By:	Johnathon Orley
MCERTS Number:	MM 08 983
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Report Approved By:	Mark Woodruff
MCERTS Number:	MM 03 164
Business Title:	MCERTS Level 2 - Business Manager
Technical Endorsements:	1, 2, 3 & 4
Signature:	

UKAS TESTING 1015

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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

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

Environmental Scientifics Group Limited 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 Exh

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

Environmental Scientifics Group Limited - Stockport Laboratory
Unit 5 Crown Industrial Estate
Kenwood Road
Stockport
SK5 6PH
UKAS and MCERTS Accreditation Number: 1015

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

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Limit**	**MCERTS accredited result**
Total Particulate Matter	mg/m³	0.84	0.97	20	✓
Particulate Emission Rate	g/hr	2.0	2.3	-	
Mercury	mg/m³	0.004	0.0008	0.05	✓
Mercury Emission Rate	g/hr	0.009	0.002	-	
Hydrogen Chloride	mg/m³	12	1.5	30	✓
Hydrogen Chloride Emission Rate	g/hr	26	3.2	-	
Volatile Organic Compounds	mg/m³	3.3	1.6	20	✓
Volatile Organic Compounds Emission Rate	g/hr	7.7	3.7	-	
Carbon Monoxide	mg/m³	4.3	2.2	100	✓
Carbon Monoxide Emission Rate	g/hr	10	5.2	-	
Oxygen	% v/v	11.6	0.31	-	✓
Moisture	%	3.1	0.13	-	✓
Stack Gas Temperature	°C	86	-	-	✓
Stack Gas Velocity	m/s	7.1	0.18	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	3737	191	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	2816	144	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	2728	139	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	2352	120	-	

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	02 February 2015	12:28 - 13:28	60 minutes
Total Particulate Matter Run 2	03 February 2015	10:29 - 11:29	60 minutes
Total Particulate Matter Run 3	03 February 2015	11:48 - 12:48	60 minutes
Mercury Run 1	02 February 2015	10:57 - 11:57	60 minutes
Hydrogen Chloride Run 1	02 February 2015	12:28 - 13:28	60 minutes
Volatile Organic Compounds Run 1	03 February 2015	10:29 - 11:29	60 minutes
Combustion Gases	03 February 2015	10:29 - 11:29	60 minutes
Stack Gas Flow Rate & Temperature Run 1	02 February 2015	10:40	-

EXECUTIVE SUMMARY

PROCESS DETAILS

CREMATOR OPERATING INFORMATION			
Description of process	Cremation of human remains		
Continuous or batch	Batch		
Abatement	Mercury abatment system		
Plume Appearance	None Visible		
TEST SPECIFIC DETAILS	**Run 1**	**Run 2**	**Run 3**
Coffin Type	Chipboard	Chipboard	Chipboard
Sex	Male	Male	Male
Body Size	Medium	Medium	Medium
Cremation Number	97835	97836	97802

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by Environmental Scientifics Group Limited is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency Technical Guidance Note (Monitoring) M2. i.e. CEN, ISO, BS, US EPA etc.

MONITORING METHODS						
Species	**Method** Standard Reference Method / Alternative Method	**ESG Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Limit of Detection (LOD)**	**Calculated MU +/- %**
TPM	SRM - BS EN 13284-1	AE 104	1015	Yes	0.41 mg/m³	116.3 %
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	Yes	0.00002 mg/m³	20.3 %
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	0.0017 mg/m³	12.3 %
VOCs	SRM - BS EN 12619:2013	AE 102	1015	Yes	0.4 mg/m³	47.8 %
CO	SRM - BS EN 15058	AE 102	1015	Yes	0.35 mg/m³	51.41%
O_2	AM - BS EN 14789	AE 102	1015	Yes	0.01%	2.70%
H_2O	SRM - BS EN 14790	AE 105	1015	Yes	0.01%	4.00%
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	-	5.1 %

BS EN 14790 has been validated over a range of 4 - 40%. It is however the prefered method of the Environment Agency for concentrations below 4%

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 (ESG or Subcontract)**	**Sample Archive Location**	**Archive Period**
TPM	Gravimetric	AE 106	1015	Yes	ESG Stockport	ESG Stockport	3 months
Mercury	Inductively coupled Plasma - Mass Spectrometry	ANU/SOP/117, 101,102	1015	Yes	ESG Bretby	ESG Bretby	3 months
Hydrogen Chloride	Ion Chromatography	ASC/SOP/110/107	1015	Yes	ESG Bretby	ESG Bretby	3 months

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	ESG Stockport	ESG Stockport	5 years
CO	Non Dispersive Infra Red	AE 102	1015	Yes	ESG Stockport	ESG Stockport	5 years
O_2	Zirconia Cell	AE 102	1015	Yes	ESG Stockport	ESG Stockport	5 years
H_2O	Gravimetric	AE 105	1015	Yes	ESG Stockport	-	-

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	5.53	m/s	-	-	-
Highest Gas Velocity	5.69	m/s	-	-	-
Ratio of Gas Velocities	1.03	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	5.61	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^{o}	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259
Highly homogeneous flow stream / gas velocity	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 (CEN Methods)	**Isokinetic** (ISO Methods)	**Non-Iso & Gases**
Sample port size	4 Inch BSP	-	4 Inch BSP
Number of lines used	1	-	1
Number of points / line	1	-	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	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	Yes
Handrail / obstructions do not hamper insertion of sampling equipment	Yes
Depth of Platform = >Stack depth / diameter + wall and port thickness + 1.5m	Yes

Sampling Platform Improvement Recommendations (if applicable)

The sampling location needs to be increased in size if it is to comply with the guidance stipulated in EA document M1,however it was sufficient for compliant testing to be carried out.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Sample Lines

Only one sample line was used due to a siezed port cap. The number of points were doubled along the remaing line in accordance with the standard.

APPENDICES

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APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	**Method** Standard Reference Method / Alternative Method	**ESG 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	AE 102	1015	Yes	1
O_2	AM - BS EN 14789	AE 102	1015	Yes	1
H_2O	SRM - BS EN 14790	AE 105	1015	Yes	1
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	1

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

CALIBRATEABLE EQUIPMENT CHECKLIST

Extractive Sampling		Instrumental Analyser/s		Miscellaneous	
Equipment	**Equipment I.D.**	**Equipment**	**Equipment I.D.**	**Equipment**	**Equipment I.D.**
Control Box DGM	LNO 13-05	Horiba PG-250 Analyser	LNO 21-11	Laboratory Balance	LNO 00-12/00-13
Box Thermocouples	LNO 03-05	FT-IR	-	Tape Measure	LNO 24-JO
Meter In Thermocouple	LNO 03-05	FT-IR Oven Box	-	Stopwatch	LNO 17-JO
Meter Out Thermocouple	LNO 03-05	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17-05	Signal 3030 FID	-	Barometer	LNO 08-JO
Oven Box	LNO 09-25	Servomex	-	Digital Micromanometer	LNO 01-JO
Probe	LNO 11-24	JCT Heated Head Filter	-	Digital Temperature Meter	LNO 03-JO
Probe Thermocouple	LNO 10-24	Thermo FID	LNO 21-09	Stack Thermocouple	LNO 10-JO
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LNO 06-JO	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LNO 14-JO	Chiller (JCT/MAK 10)	LNO 21-41	1m Heated Line (3)	-
Last Impinger Arm	-		-	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	0	-	10m Heated Line (1)	-
Callipers	LNO 31-JO	0	-	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	LNO 18-95
Inclinometer (Swirl Device)	LNO 23-JO		-	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 +/- %
Propane	70306	BOC	10	-	2
Carbon Monoxide	HPC 804	BOC	162	-	2

STACK EMISSIONS MONITORING TEAM

MONITORING TEAM							
Personnel	**MCERTS Number**	**MCERTS Qualification**	**TE / H&S Qualifications and Expiry Date**				
			TE1	**TE2**	**TE3**	**TE4**	**H&S**
Johnathon Orley	MM 08 983	MCERTS Level 2 - Team Leader	Mar-20	Dec-15	Dec-16	Mar-16	Nov-18
Vic Johnson	MM 10 1085	MCERTS Level 1 - Technician	-	-	-	-	Sep-15

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	12:28 - 13:28 02 February 2015	1.1	0.82	20	2.4
Run 2	10:29 - 11:29 03 February 2015	1.0	0.77	20	2.6
Run 3	11:48 - 12:48 03 February 2015	0.38	0.76	20	0.90
Blank	-	0.39	-	-	-
Blank 2	-	0.39	-	-	-

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	G2792	0.11051	0.11113	0.00062	187.22380	187.22380	0.00000	0.00062
Run 2	G2794	0.10942	0.11001	0.00059	193.99520	193.99500	-0.00020	0.00039
Run 3	G2795	0.11009	0.11005	-0.00004	182.36490	182.36460	-0.00030	0.00031

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	G2791	0.10953	0.10932	-0.00021	178.35610	178.35620	0.00010	0.00031
Run 2	G2793	0.10891	0.10872	-0.00019	193.99520	193.99500	-0.00020	0.00031

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			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	750.01	CO_2	%	7.54
Stack static pressure, P_{static}	mm H_2O	2.04	O_2	%	12.77
$P_s = P_b + (P_{static}) / 13.6$	mm Hg	750.16	Total	%	20.30
			N_2 (100 -Total)	%	79.70
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.72
Moisture trap weight increase,Vlc	g	24.0	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.029904	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	29.35
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		1.215	Area of stack, A_s	m^2	0.15
Gas meter correction factor, Y_d		0.83543	$Q_a = (60)(A_s)(V_s)$	m^3/min	64.8
Mean dry gas meter temperature, T_m		23.500	**Total flow of stack gas, Q**		
Mean pressure drop across orifice, ΔH	mmH_2O	22.874	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = (0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d) / (T_m + 273)$		0.924	$Q_{std} = (Q_a)P_s(0.3592)(1-B_{wo}) / (T_s) +273$	Dry	43.1
Volume of gas metered wet, V_{mstw}			$Q_{stdO2} = (Q_a)P_s(0.3592)(1-B_{wo})(O_2REF) / (T_s) +273$	@O_2ref	35.45
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9543	$Q_{stw} = (Q_a)P_s(0.3592) / (T_s) +273$	Wet	44.47
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Percent isokinetic, %I**		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Nozzle diameter, D_n	mm	7.90
% oxygen measured in gas stream, act%O_2		12.8	Nozzle area, A_n	mm^2	49.02
% oxygen reference condition		11	Total sampling time, θ	min	60
O_2 Reference Factor O_2 Ref = 21.0 - act%O_2 / 21.0 - ref%O_2		0.82	$\%I = (4.6398E6)(T_s+273)(V_{mstd}) / (P_s)(V_s)(A_n)(\theta)(1-B_{wo})$	%	107.4
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	0.7610	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			**Particulate Concentration, C**		
$B_{wo} = V_{wstd} / (V_{mstd} + V_{wstd})$	%	0.0313 3.13	Mass collected on filter, M_f	g	0.00062
			Mass collected in probe, M_p	g	0.00023
Moisture by FTIR	%	-	Total mass collected, M_n	g	0.00085
Velocity of stack gas, V_s			$C_{wet} = M_n / V_{mstw}$	mg/m^3	0.891
Pitot tube velocity constant, K_p		34.97	$C_{dry} = M_n / V_{mstd}$	mg/m^3	0.920
Velocity pressure coefficient, C_p		.84	$C_{dry@X\%O2} = M_n / V_{mstd@X\%oxygen}$	mg/m^3	1.117
Mean of velocity heads, ΔP_{avg}	mm H_2O	3.50	**Particulate Emission Rates, E**		
Mean square root of velocity heads, $\sqrt{\Delta P}$		1.87	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		2.38
Mean stack gas temperature, T_s	°C	120			
$V_s = (K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)}) / (M_s)(P_s)$	m/s	7.34			

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	750.01	CO_2	%	7.54
Stack static pressure, P_{static}	mm H_2O	2.04	O_2	%	12.06
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	750.16	Total	%	19.59
			N_2 (100 -Total)	%	80.41
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.69
Moisture trap weight increase,Vlc	g	-	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	29.32
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		1.189	Area of stack, A_s	m^2	0.15
Gas meter correction factor, Y_d		0.83543	$Q_a = (60)(A_s)(V_s)$	m^3/min	62.7
Mean dry gas meter temperature, T_m		23.333	**Total flow of stack gas, Q**		
Mean pressure drop across orifice, ΔH	mmH_2O	27.949	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		0.906	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	47.6
Volume of gas metered wet, V_{mstw}			$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	42.60
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9348	$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	49.17
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Percent isokinetic, %I**		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Nozzle diameter, D_n	mm	7.90
% oxygen measured in gas stream, act%O_2		12.055	Nozzle area, A_n	mm^2	49.02
% oxygen reference condition		11	Total sampling time, θ	min	60
O_2 Reference Factor O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		0.89	$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	95.1
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$	m^3	0.8100	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			**Particulate Concentration, C**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0313	Mass collected on filter, M_f	g	0.00059
	%	3.13	Mass collected in probe, M_p	g	0.00023
Moisture by FTIR	%	-	Total mass collected, M_n	g	0.00082
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.88
Pitot tube velocity constant, K_p		34.97	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.91
Velocity pressure coefficient, C_p		.84	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	1.01
Mean of velocity heads, ΔP_{avg}	mm H_2O	3.74	**Particulate Emission Rates, E**		
Mean square root of velocity heads, $\sqrt{\Delta P}$		1.93	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		2.59
Mean stack gas temperature, T_s	°C	71			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	7.10			

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	750.01	CO_2	%	7.54
Stack static pressure, P_{static}	mm H_2O	2.04	O_2	%	12.33
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	750.16	Total	%	19.87
			N_2 (100 -Total)	%	80.13
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.70
Moisture trap weight increase,Vlc	g	-	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	29.33
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		1.246	Area of stack, A_s	m^2	0.15
Gas meter correction factor, Y_d		0.83543	$Q_a = (60)(A_s)(V_s)$	m^3/min	59.3
Mean dry gas meter temperature, T_m		24.125	**Total flow of stack gas, Q**		
Mean pressure drop across orifice, ΔH	mmH_2O	25.746	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		0.946	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	45.7
Volume of gas metered wet, V_{mstw}			$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	39.58
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9768	$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	47.15
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	**Percent isokinetic, %I**		
			Nozzle diameter, D_n	mm	7.90
% oxygen measured in gas stream, act%O_2		12.33333333	Nozzle area, A_n	mm^2	49.02
% oxygen reference condition		11	Total sampling time, θ	min	60
O_2 Reference Factor O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		0.87	$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	103.7
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$	m^3	0.8200	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			**Particulate Concentration, C**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0313	Mass collected on filter, M_f	g	0.00008
	%	3.13	Mass collected in probe, M_p	g	0.00023
Moisture by FTIR	%	-	Total mass collected, M_n	g	0.0003
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.32
Pitot tube velocity constant, K_p		34.97	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.33
Velocity pressure coefficient, C_p		.84	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.38
Mean of velocity heads, ΔP_{avg}	mm H_2O	3.39			
Mean square root of velocity heads, $\sqrt{\Delta P}$		1.84			
Mean stack gas temperature, T_s	°C	66			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	6.71	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.90

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	16.92	0.22	0.22	-355.6	0.34	Yes
Run 2	16.56	0.20	0.20	-304.8	0.33	Yes
Run 3	17.35	0.22	0.24	-304.8	0.35	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	107.39	Yes
Run 2	95.14	Yes
Run 3	103.67	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m³	5% ELV mg/m³	LOD < 5% ELV
Run 1	0.41	1	Yes
Run 2	0.38	1	Yes
Run 3	0.38	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	0.39	20	2.0	Yes
Blank 2	0.39	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	GF	47	160	180	160
Run 2	GF	47	160	180	160
Run 3	GF	47	160	180	160

GF = Glass Fibre

QF = Quartz Fibre

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MERCURY SUMMARY - PARTICULATE & VAPOUR PHASES COMBINED

Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	10:57 - 11:57 02 February 2015	0.004	0.00002	0.05	0.009
Field Blank	-	0.00002	-	-	-

Mercury	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mean mg/m³	Lab Result ug	Concentration mg/m³	Stack LOD mean mg/m³	Lab Result ug	Concentration mg/m³
Run 1	0.00001	0.01	0.00001	0.00002	3.28	0.004
Volume Sampled m^3		0.8821			0.8821	
Field Blank	-	0.01	0.00001	-	0.01	0.00001
Volume Sampled m^3		0.8821			0.8821	

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	750.0	CO_2	%	7.54
Stack static pressure, P_{static}	mm H_2O	-2.0	O_2	%	11.16
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	749.9	Total	%	18.69
			N_2 (100 -Total)	%	81.31
			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.65
Vol. of water vapour collected, V_{wstd}			**Molecular weight of wet gas, M_s**		
Moisture trap weight increase,Vlc	g	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	29.29
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	**Velocity of stack gas, V_s**		
Volume of gas metered dry, V_{mstd}			Pitot tube velocity constant, K_p		34.97
			Velocity pressure coefficient, C_p		.84
Volume of gas sample through gas meter, V_m		1.172	Mean of velocity heads, ΔP_{avg}	mm H_2O	3.06
Gas meter correction factor, Y_d		0.83543	Mean square root of velocity heads, $\sqrt{\Delta P}$		1.75
Mean dry gas meter temperature, T_m		22.00	Mean stack gas temperature, T_s	°C	101
Mean pressure drop across orifice, ΔH	m	20.93	$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	6.70
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		0.90	**Actual flow of stack gas, Q_a**		
			Area of stack, A_s	m^2	0.15
Volume of gas metered wet, V_{mstw}			$Q_a = (60)(A_s)(V_s)$	m^3/min	59.2
			Total flow of stack gas, Q		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9250	Conversion factor (K/mm.Hg)		0.3592
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	41.3
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O2ref	40.7
% oxygen measured in gas stream, act%O_2		11.2	$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	42.7
% oxygen reference condition		11			
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		0.98	**Percent isokinetic, %I**		
			Nozzle diameter, D_n	mm	7.90
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	0.882	Nozzle area, A_n	mm^2	49.02
Moisture content, B_{wo}			Total sampling time, θ	min	60
			$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	108.5
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0313			
	%	3.13			
Moisture by FTIR	%	-	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	16.3	0.24	0.24	-304.8	0.33	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	108.5	Yes

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

GF = Glass Fibre

QF = Quartz Fibre

HEAVY METALS ABSORBTION EFFICIENCY

Parameter		Total ug	5th Absorber ug	Absorption Efficiency	Required	Pass / Fail
Mercury	Run 1	3.29	0.01	100	95	N/A <30% ELV

HYDROGEN CHLORIDE SUMMARY					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	12:28 - 13:28 02 February 2015	12	0.002	30	26
Field Blank	-	0.014	-	-	-

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	16.9	0.22	0.22	0.34	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Max. Storage / Transit Temp. °C	Type of Absorbers	Absorption Solutions
Run 1	QF	90	160	18	Glass	HPLC Water

GF = Glass Fibre

QF = Quartz Fibre

HYDROGEN CHLORIDE ABSORPTION EFFICIENCY

Parameter	**Total ug**	**IMP C ug**	**Absorption Efficiency %**	**Acceptable Absorption Efficiency %**	**Absorption Efficiency Acceptable ?**
Run 1	9246.5	6.5	100	95	Yes

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	750	Pitot tube velocity constant, K_p		34.97
Stack static pressure, P_{static}	mm H_2O	2	Velocity pressure coefficient, C_p		.84
$P_s = P_b + (P_{static})$ / 13.6	mm Hg	750	Mean of velocity heads, ΔP_{avg}	mm H_2O	3.50
			Mean square root of velocity heads, $\sqrt{\Delta P}$		1.87
Vol. of water vapour collected, V_{wstd}			Mean stack gas temperature, T_s	°C	120
Moisture trap weight increase,Vlc	g	-			
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	7.3
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		1.2150	Area of stack, A_s	m^2	0.15
Gas meter correction factor, Y_d		0.83543	$Q_a = (60)(A_s)(V_s)$	m^3/min	65
Mean dry gas meter temperature, T_m		23.50	**Dry total flow of stack gas, Q_{std}**		
Mean pressure drop across orifice, ΔH	mmH_2O	22.87	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		0.92	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	m^3/min	43
Volume of gas metered wet, V_{mstw}			**Wet total flow of stack gas, Q_{stw}**		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9543	$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	m^3/min	44
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Dry total flow of stack gas at X% O_2, Q_{stdO2}**		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No			
			$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	m^3/min	35
% oxygen measured in gas stream, act%O_2		12.77			
% oxygen reference condition		11	**Percent isokinetic, %I**		
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		0.82	Nozzle diameter, D_n	mm	7.90
			Nozzle area, A_n	mm^2	49.02
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	0.7610	Total sampling time, θ	min	60
Moisture content, B_{wo}			$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	107
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0313			
	%	3.13	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	9247
CO_2		7.54	$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	9.690
O_2		12.77			
Total		20.30	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	10.003
N_2 (100 -Total)		79.70			
			$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	12.151
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.72			
Molecular weight of wet gas, M_s			**Hydrogen Chloride Emission Rates, E**		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	29.3	$E = [(C_{wet})(Q_{stw})(60)] / 1000$	g/hr	25.85

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

VOLATILE ORGANIC COMPOUNDS SUMMARY

Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	10:29 - 11:29 03 February 2015	3.3	0.40	20	7.7

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

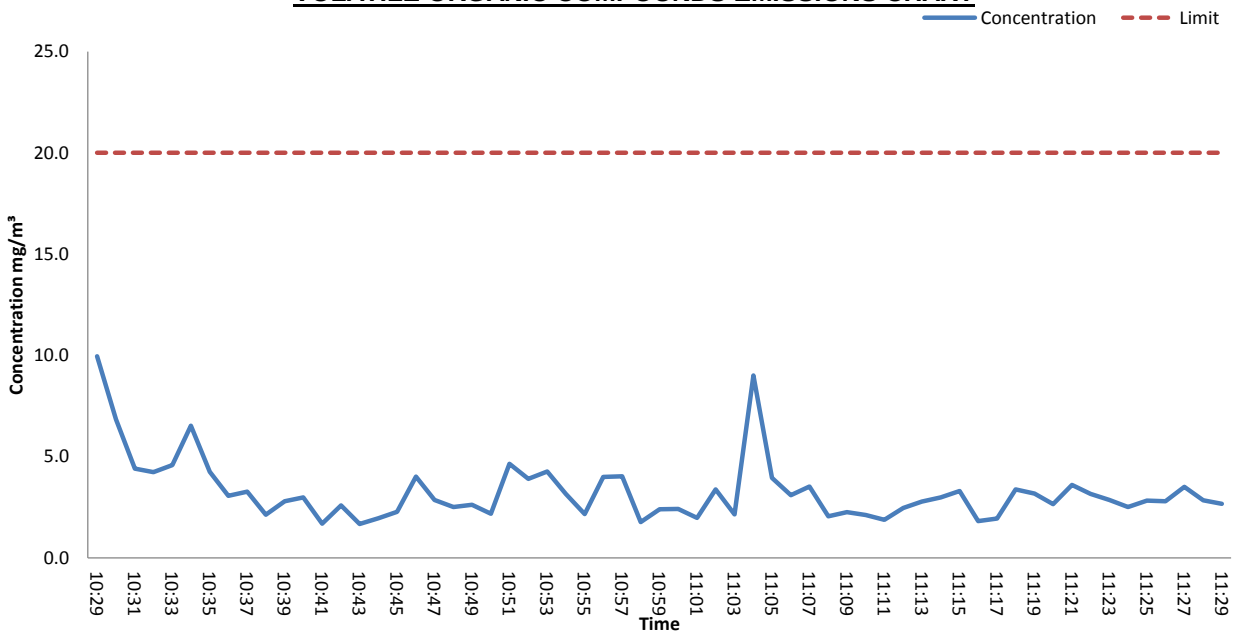
INSTRUMENTAL SPAN & ZERO CHECKS

PRE-SAMPLING CALIBRATION CHECKS RUN 1								
Date	03 February 2015							
Start Time	09:40							
End Time	09:50							
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	100	0.4	80	0.422	0.463	79.8	0.25

Zero and Span gas contained 20% Oxygen

POST-SAMPLING CALIBRATION CHECKS RUN 1				
Date	03 February 2015			
Start Time	12:50			
End Time	13:10			
Gas	Zero down line reading	Span down line reading	Zero Drift (%)	Span Drift (%)
Propane	0.401	79.7	-0.62	-0.38

VOLATILE ORGANIC COMPOUNDS EMISSIONS CHART



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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GASES SUMMARY

Test	Sampling Time and Date	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
CO	10:29 - 11:29 03 February 2015	4.3	0.35	100	10

Test	Sampling Time and Date	Concentration %	LOD %
O_2	10:29 - 11:29 03 February 2015	11.6	0.01

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

PRE-SAMPLING CALIBRATION DATA

Date	03 February 2015
Start Time	09:50
End Time	10:10

Chiller Temperature (°C)	2
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	162	0.04	0.08	159.7	25	1.42
O_2	25	0.0	20.95	0.02	0.04	20.9	25	0.24

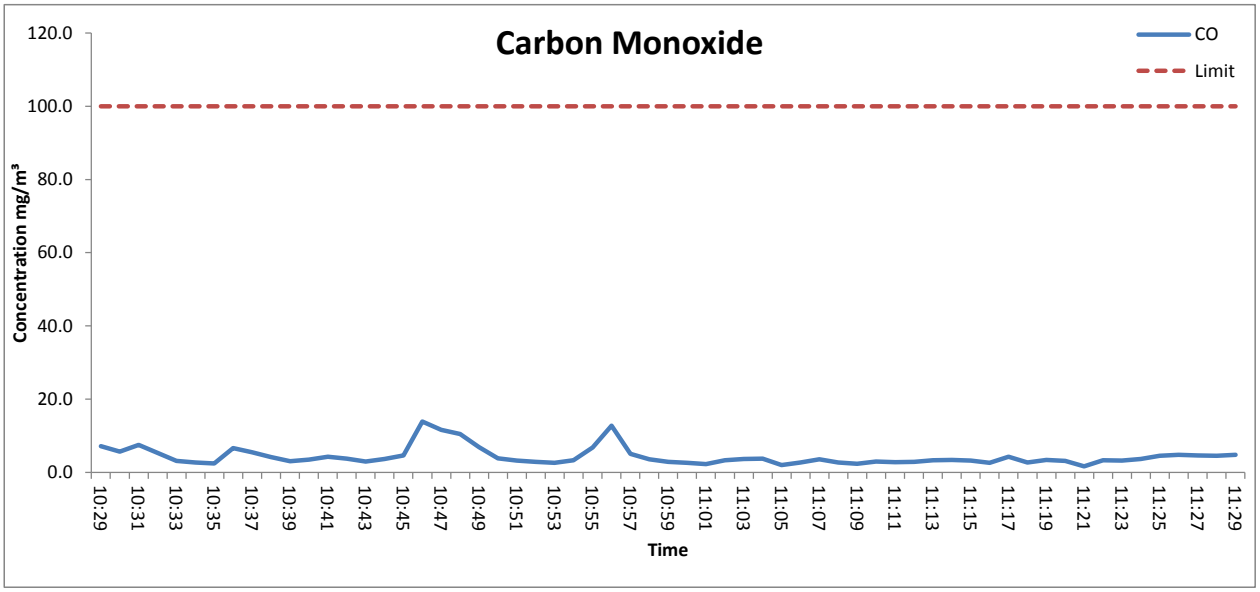
POST-SAMPLING CALIBRATION DATA

Date	03 February 2015
Start Time	12:50
End Time	13:10

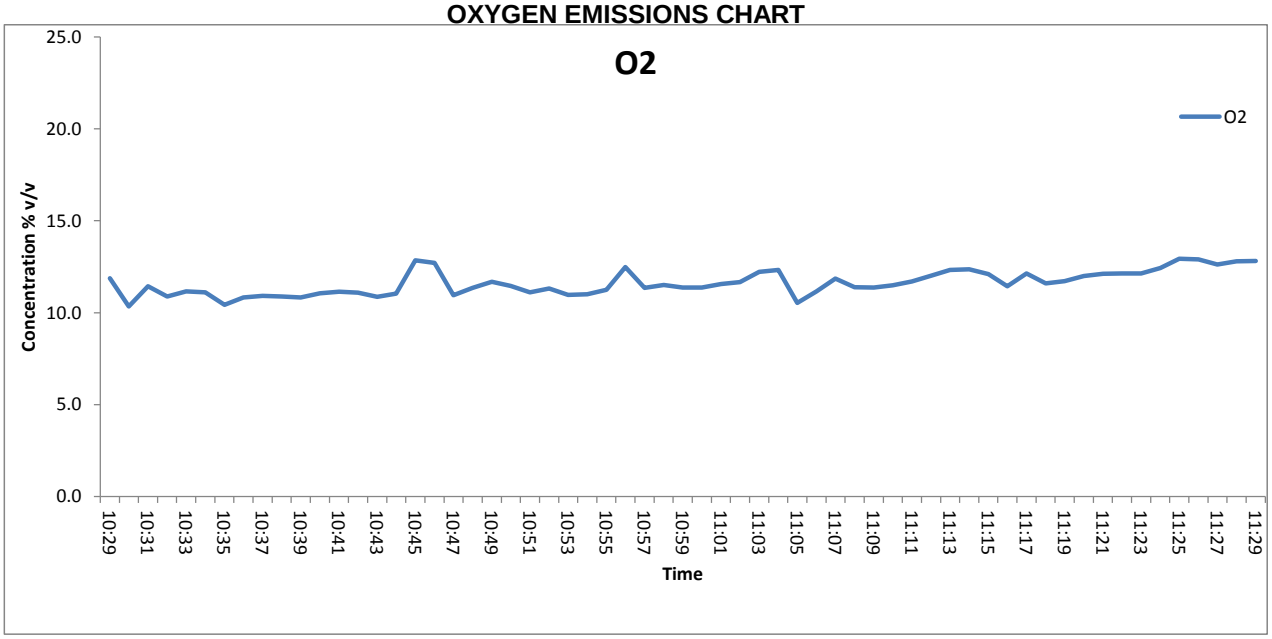
Chiller Temperature (°C)	2
Requirement	< 4°C
Compliant	Yes

Gas	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
CO	0.08	159.8	0.00	0.05
O_2	0.00	20.94	-0.16	0.32

CARBON MONOXIDE EMISSIONS CHART



OXYGEN EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Isokinetic							
Test Number	Sampling Time and Date	Start Weight kg	End Weight kg	Total gain kg	Concentration %	LOD %	Uncertainty %
Run 1	12:28 - 13:28 02 February 2015	3.7171	3.7411	0.0240	3.1	0.013	4.0

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	954	16.9	0.2200	0.2200	0.3383	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	79	^oC
Stack static pressure	0.02	kPa
Barometric Pressure	100	kPa
Pitot tube calibration coefficient, K_{pt}	0.84	-

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	7.000000	0.070000	0.137414	6.780637	0.067806	0.133108
O_2	32	1.427679	11.613948	0.116139	0.165810	11.249995	0.112500	0.160614
N_2	28	1.249219	81.386052	0.813861	1.016690	78.835611	0.788356	0.984830
H_2O	18	0.803070	-	-	-	3.133757	0.031338	0.025166

Where: p = M / 22.41 pi = r x p

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3199	kg/m^3
Wet Density (STP), P_{STW}	1.3037	kg/m^3
Dry Density (Actual), P_{Actual}	1.0107	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.998	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	02 February 2015
Time of Survey	10:40
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O (average of 3)	ΔP pt Pa (average of 3)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
1	0.02	2.3	22	79	5.57	0.82	-	<15
2	0.05	2.4	23	79	5.69	0.84	-	<15
3	0.08	2.2	22	79	5.53	0.81	-	<15
4	0.11	2.2	22	79	5.53	0.81	-	<15
5	0.14	2.3	23	79	5.61	0.83	-	<15
6	0.18	2.3	22	79	5.57	0.82	-	<15
7	0.21	2.3	22	79	5.57	0.82	-	<15
8	0.24	2.4	23	79	5.69	0.84	-	<15
9	0.27	2.4	23	79	5.69	0.84	-	<15
10	0.30	2.4	23	79	5.69	0.84	-	<15
Mean	-	2.3	23	79	5.61	0.83	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O (average of 3)	ΔP pt Pa (average of 3)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	-	

PRELIMINARY STACK SURVEY QUALITY ASSURRANCE CHECKLIST

PITOT LEAK CHECK

Run	Pre Traverse Leak Rate				Post Traverse Leak Rate			
	Start Value mmH_2O	End Value mmH_2O	Difference %	Outcome	Start Value mmH_2O	End Value mmH_2O	Difference %	Outcome
Run 1	100.0	98.0	2.0	Pass	101.00	99	2.0	Pass

To complete a compliant pitot leak check a pressure of over 80mmH_2O 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
Run 1	20	20	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	21.9	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	5.53	m/s	-	-
Highest Gas Velocity	5.69	m/s	-	-
Ratio of Gas Velocities	1.03	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	0	^{o}	< 15^{o}	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, $V = K_{pt} \times (1-\varepsilon) * \sqrt{(2 * \Delta P_{pt} / P_{ActualW})}$		
Where: K_{pt} = Pitot tube calibration coefficient $(1-\varepsilon)$ = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, Va	**5.61**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	79	0	^{o}C
Total Pressure	100.02	101.3	kPa
Oxygen	11.6	11	%
Moisture	3.13	0.00	%

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	5.61	m/s
Stack Area (A)	0.15	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	2975	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	2278	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	2207	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	2071	m^3/hr

Where:

Q_{Actual} = Va x A x 3600

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

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

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

Nomenclature:

Ts = Absolute Temperature, Standard Conditions, 273 K

Ps = Absolute Pressure, Standard Conditions, 101.3 kPa

Ta = Absolute Temperature, Actual Conditions, K

Pa = Absolute Pressure, Actual Conditions, kPa

Ma = Water vapour, Actual Conditions, % Vol

Ms = Water vapour, Reference Conditions, % Vol

O_2a = Oxygen, Actual Conditions, % Vol

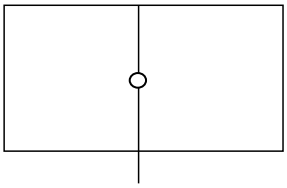
O_2s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK DIAGRAM

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

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



Isokinetic Sampling CEN Methods			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	50.0	0.16	< 15
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
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-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

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

SAMPLING LOCATION

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - TOTAL PARTICULATE MATTER

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Limit of Detection	Leak	Uncollected Mass
	m^3	K	kPa	% by volume	% by volume	% by mass	%	mg
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**	**≤ 10% of ELV**
Run 1	0.001	2	0.5	1	0.1	0.3100	-	-
as a %	0.13	0.67	0.50	1.00	0.78	2.03687	1.30	0.002
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.310	-	-
as a %	0.12	0.67	0.50	1.00	0.83	1.914	1.21	0.002
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 3	0.001	2	0.5	1	0.1	0.3100	-	-
as a %	0.12	0.67	0.50	1.00	0.81	1.89014	1.38	0.002
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP)	Mass of particulate	O_2 Correction	Leak	Uncollected Mass	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	0.69	0.8500	1.21	0.008	0.0002	-
MU as mg/m^3	0.01	0.4074	0.01	0.008	0.0002	**0.41**
MU as %	1.31	36.4706	-	0.751	0.0211	-
Run 2	0.74	0.8200	1.12	0.007	0.0002	-
MU as mg/m^3	0.01	0.3827	0.01	0.007	0.0002	**0.38**
MU as %	1.3	37.8049	-	0.697	0.0218	-
Run 3	0.74	0.3100	1.15	0.003	0.0002	-
MU as mg/m^3	0.00	0.3780	0.00	0.003	0.0002	**0.38**
MU as %	1.31	100.0000	-	0.799	0.0577	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.82**	**mg/m^3**	**73.04**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.77**	**mg/m^3**	**75.70**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.76**	**mg/m^3**	**200.04**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)

Developed for the STA by R Robinson, NPL

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	0.5	1	0.1	0.0003	-
as a %	0.11	0.68	0.50	1.00	0.90	3.00	1.47
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP) m^3	O2 Correction -	Leak mg/m^3	Lab Uncertainty mg	Combined uncertainty
Run 1	0.8042	1.0158	0.00003	-	-
MU as mg/m^3	0.0000	0.0000	0.00003	0.00037	**0.0004**
MU as %	1.3138	1.0158	0.8491	10.00000	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.0008**	**mg/m^3**	**20.34**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - ISOKINETIC HYDROGEN CHLORIDE

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Concentration in impinger	Limit of Detection	Leak
	m^3	K	kPa	% by volume	% by volume	mg	% by mass	%
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**≤ 5% of ELV**	**<=2%**
Run 1	0.761	296.50	100.2	1.0	12.7675	0.061	0.028	-
as a %	0.13	0.67	0.50	1.00	0.78	3.00	1.22	1.30
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP)	Mass of Hydrogen Chloride	O2 Correction	Leak	Lab Uncertainty	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	0.6930	0.0281	1.2147	0.0912	-	-
MU as mg/m^3	0.1596	0.3655	0.1476	0.0912	0.6075	**0.7472**
MU as %	1.3133	3.0079	1.2147	0.7508	5.0	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**1.49**	**mg/m^3**	**12.30**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Leak
	m^3	K	kPa	% by volume	% by volume	%
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	-
as a %	0.13	0.67	0.50	1.00	0.78	1.30
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run	Volume (STP)	Mass Gained	O_2 Correction	Leak	Uncollected Mass	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	0.69	24000.00	1.21	236.79	57.74	-
MU as % v/v	0.05	0.02	0.05	0.03	0.010	**0.08**
MU as %	1.31	0.42	1.21	0.75	0.24	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.16**	**% v/v**	**4.00**	**%**

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 1

Measured Concentration	3.3	mg/m^3
Limit	20	mg/m^3
Calibration Gas Concentration	16	mg/m^3
Range	160	mg/m^3

Performance characteristics	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	0.70	% of value	<2 % range	Yes
Zero drift	-0.62	% full scale	<2% range / 24hr	Yes
Span drift	-0.38	% 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)	0.25	% of value	< 2% of span gas value	Yes
Uncertainty of calibration gas	2.0	% 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	-0.40
volume or pressure flow dependence	uspres	0.00
atmopsheric pressure dependence	uapres	0.04
ambient temperature dependence	utemp	0.00
Dependence on voltage	uvolt	0.14
losses in the line (leak)	uleak	0.00
Uncertainty of calibration gas	ucalib	0.04
Uncertainty in factor	uf	0.06

Measurement uncertainty Measured Concentration	3.26	mg/m^3
Combined uncertainty	0.78	mg/m^3
Expanded uncertainty	1.56	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**7.78**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**1.56**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**47.80**	**% value**

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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON MONOXIDE

Limit value	100	mg/m^3
Concentration @ Ref conditions	4.3	mg/m^3
Cal gas conc	202.5	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	0.25	% full scale	<1 % range	Yes
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.7	% of value	<2 % range	Yes
Zero drift	0.00	% full scale	<2% range / 24hr	Yes
Span drift	0.10	% 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)	1.42	% of value	< 2% of value	No
Uncertainty of calibration gas	1	% 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	1.01
Drift	u0dr	0.00
volume or pressure flow dependence	uspres	0.00
atmopsheric pressure dependence	uapres	0.06
ambient temperature dependence	utemp	0.00
Dependence on voltage	uvolt	0.22
losses in the line (leak)	uleak	0.03
Uncertainty of calibration gas	ucalib	0.02
Uncertainty in factor	uf	0.07

Measurement uncertainty (Concentration Measured)	4.0	mg/m^3
Combined uncertainty	1.0	mg/m^3
Expanded uncertainty	2.1	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**2.08**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**2.08**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**51.41**	**% value**

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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

Reference	11	%vol
Reported Concentration	11.61	%vol
Calibration gas	20.95	%vol
Analyser Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	25	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	60	minutes	-	-
Number of readings in measurement	60	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	-0.04	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	0.08	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.80	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.10	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.24	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.00	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.0018
Lack of fit	ufit	0.0751
Drift	u0dr	0.0025
volume or pressure flow dependence	uspres	0.00003
atmospheric pressure dependence	uapres	0.0122
ambient temperature dependence	utemp	0.0005
Combined interference (from mcerts)	-	0.0808
dependence on voltage	uvolt	0.0862
losses in the line (leak)	uleak	0.0160
Uncertainty of calibration gas	ucalib	0.0671

Measurement uncertainty (Concentration Measured)	11.61	%vol
Combined uncertainty	0.16	%vol
% of value	1.35	%

Expanded uncertainty expressed with a level of confidence of 95%	**2.70**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**0.313**	**% vol**

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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	5.6	m/s
Measured Volumetric Flow rate at Actual Conditions	2975	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	0.23	<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	0.00004		
Uncertainty of temperature measurement	K	1.80	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	510		
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	0.07
Expanded uncertainty at a 95% Confidence Interval	0.14

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 Concentration	1.28
Expanded uncertainty at a 95% Confidence Interval	2.50

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	76.82
Expanded uncertainty at a 95% Confidence Interval	150.57

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 Concentration	2.58
Expanded uncertainty at a 95% Confidence Interval	5.06

END OF REPORT