

STACK EMISSIONS MONITORING REPORT



Unit 5 Crown Industrial Estate
Kenwood Road
Stockport
SK5 6PH
Tel: 0161 443 0980

Your contact at SOCOTEC LTD
[Redacted] [Redacted] [Redacted] 81 [Redacted]

Operator & Address:
Derby City Council Mearkeaton Lane Derby Derbyshire DE22 4NH

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

Release Point:
Abatement System 2

Sampling Date(s):
12th April 2023

SOCOTEC Job Number:	LNO 17793
Report Date:	3rd May 2023
Version:	1
Report By:	[Redacted]
MCERTS Number:	[Redacted]
MCERTS Level:	[Redacted]
Technical Endorsements:	1, 2, 3 & 4
Report Approved By:	[Redacted]
MCERTS Number:	[Redacted]
Business Title:	[Redacted]
Technical Endorsements:	1, 2, 3 & 4
Signature:	[Redacted]



1015



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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Derby City Council operates a cremation process at Markeaton Crematorium which is subject to DEFRA Process Guidance Note PG 5/2 (12), under the Environmental Permitting Regulations 2010.

SOCOTEC LTD were commissioned by Derby City 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 2

Operator

Derby City Council
Mearkeaton Lane
Derby
Derbyshire
DE22 4NH

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

Stack Emissions Monitoring Test House

SOCOTEC - 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.

The results of this testing relate only to the emission release point(s) listed in the report.

MCERTS accredited results will only be claimed where both the sampling and analytical stages are MCERTS accredited.

This test report shall not be reproduced, except in full, without written approval of SOCOTEC LTD.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	Units	Result	Calculated Uncertainty +/-	Emission Limit Value (ELV)	Accreditation
Total Particulate Matter	mg/m ³	3.3	2.6	20	MCERTS
Particulate Emission Rate	g/hr	3.6	2.8	-	
Mercury	mg/m ³	0.0022	0.0024	0.5	MCERTS
Mercury Emission Rate	g/hr	0.0021	0.0023	-	
Hydrogen Chloride	mg/m ³	0.19	0.030	30	MCERTS
Hydrogen Chloride Emission Rate	g/hr	0.195	0.0312	-	
Total Volatile Organic Compounds	mg/m ³	0.85	1.3	20	MCERTS
Total Volatile Organic Compounds Emission Rate	g/hr	0.80	1.2	-	
Carbon Monoxide	mg/m ³	25	8.5	100	MCERTS
Carbon Monoxide Emission Rate	g/hr	24	8.1	-	
Oxygen	% v/v	16.5	0.055	-	MCERTS
Moisture	%	6.2	0.32	-	MCERTS
Stack Gas Temperature	°C	82	-	-	MCERTS
Stack Gas Velocity	m/s	7.6	0.19	-	
Gas Volumetric Flow Rate (Actual)	m ³ /hr	3232	181	-	
Gas Volumetric Flow Rate (STP, Wet)	m ³ /hr	2405	135	-	
Gas Volumetric Flow Rate (STP, Dry)	m ³ /hr	2255	127	-	
Gas Volumetric Flow Rate at Reference Conditions	m ³ /hr	1056	59	-	

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	12 April 2023	10:12 - 11:12	60 minutes
Total Particulate Matter Run 2	12 April 2023	12:04 - 13:04	60 minutes
Total Particulate Matter Run 3	12 April 2023	13:54 - 14:54	60 minutes
Mercury Run 1	12 April 2023	15:24 - 16:24	60 minutes
Hydrogen Chloride Run 1	12 April 2023	10:12 - 11:12	60 minutes
Hydrogen Chloride Run 2	12 April 2023	12:04 - 13:04	60 minutes
Hydrogen Chloride Run 3	12 April 2023	13:54 - 14:54	60 minutes
Total Volatile Organic Compounds Run 1	12 April 2023	10:12 - 16:12	360 minutes
Combustion Gases	12 April 2023	10:12 - 16:12	360 minutes
Preliminary Stack Traverse	12 April 2023	10:00	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Cremation
Continuous or batch	Batch
Product Details	Cremated remains
Part of batch to be monitored (if applicable)	First 60 minutes minus 2 minute charging period
Normal load, throughput or continuous rating	Normal
Fuel used during monitoring	Natural Gas
Abatement	None
Plume Appearance	None visible

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by SOCOTEC is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency technical Guidance 'Monitoring stack emissions: techniques and standards for periodic monitoring'.

MONITORING METHODS							
Species	Method Standard Reference Method / Alternative Method	SOCOTEC Technical Procedure	UKAS Lab Number	Method Accreditation	Limit of Detection (LOD)	Calculated MU +/- % Result	Calculated MU +/- % ELV
Total Particulate Matter	SRM - BS EN 13284-1	AE 104	1015	MCERTS	0.41 mg/m ³	79%	4.4%
Mercury	SRM - BS EN 13211	AE 107	1015	MCERTS	0.0012 mg/m ³	108%	0.5%
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	MCERTS	0.003 mg/m ³	16%	0.08%
Total Volatile Organic Compounds	SRM - BS EN 12619:2013	AE 102	1015	MCERTS	0 mg/m ³	153%	6.5%
Carbon Monoxide	SRM - BS EN 15058:2017	AE 102	1015	MCERTS	0.66 mg/m ³	34%	3.6%
Oxygen	AM - BS EN 14789:2017	AE 102	1015	MCERTS	0.01%	0.33%	N/A - No ELV
Moisture	BS EN 14790	AE 105	1015	MCERTS	0.01%	5.2%	N/A - No ELV
Velocity	SRM - EN ISO 16911-1	AE 154	1015	MCERTS	5 Pa	2.4%	N/A - No ELV
Volumetric Flow Rate	SRM - EN ISO 16911-1	AE 154	1015	MCERTS	-	5.6%	N/A - No ELV

EXECUTIVE SUMMARY

Analytical Methods

The following tables list the analytical methods employed together with the custody details. Unless otherwise stated the samples are archived at the analysis lab location.

SAMPLING METHODS WITH SUBSEQUENT ANALYSIS							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	Analysis Accreditation	Analysis Lab	Analysis Report No. Date of Analysis	Archive Period
Total Particulate Matter	Gravimetric	AE 106	1015	MCERTS	SOCOTEC (Stockport)	N/A	8 Weeks
Mercury	Inductively coupled plasma - mass spectrometry / Cold vapour - atomic fluorescence spectroscopy	ASC/SOP/112	1252	MCERTS	SOCOTEC (Bretby)	ASC 57831 02 May 2023	8 Weeks
Hydrogen Chloride	Ion Chromatography	ASC/SOP/110	1252	MCERTS	SOCOTEC (Bretby)	ASC 57830	8 Weeks

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	Accreditation	Laboratory	Data Archive Location	Archive Period
Total Volatile Organic Compounds	Flame Ionisation Detection	AE 102	1015	MCERTS	SOCOTEC (Stockport)	SOCOTEC (Stockport)	5 years
Carbon Monoxide	Non Dispersive Infra Red	AE 102	1015	MCERTS	SOCOTEC (Stockport)	SOCOTEC (Stockport)	5 years
Oxygen	Zirconia Cell	AE 102	1015	MCERTS	SOCOTEC (Stockport)	SOCOTEC (Stockport)	5 years
Moisture	Gravimetric	AE 105	1015	MCERTS	SOCOTEC (Stockport)	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	Value	Units	Requirement	Compliant	Method
Lowest Differential Pressure	38	Pa	≥ 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	7.5	m/s	-	-	-
Highest Gas Velocity	7.9	m/s	-	-	-
Ratio of Gas Velocities	1.1	: 1	$< 3 : 1$	Yes	BS EN 15259
Mean Velocity	7.6	m/s	-	-	-
Maximum angle of flow with regard to duct axis	< 15	$^{\circ}$	$< 15^{\circ}$	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259

DUCT CHARACTERISTICS		
	Value	Units
Shape	Square	-
Depth	0.34	m
Width	0.34	m
Area	0.12	m ²
Port Depth	380	mm

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

SAMPLING PLATFORM	
General Platform Information	
Permanent / Temporary Platform / Ground level / Floor Level / Roof	Temporary - Scaffold
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)	Yes
Platform has vertical base boards (approximately 0.25 m high)	Yes
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	No

Sampling Platform Improvement Recommendations (if applicable)

The sampling platform needs to be increased in order to meet the requirements of technical guidance note M1.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Sampling points

The sampling point requirements of EN 13284-1 could not be met as there was not enough room due to the limited platform space. As a result, one point sampling was utilised.

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APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

APPENDIX 3 - Measurement Uncertainty Budget Calculations

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	Method Standard Reference Method / Alternative Method	SOCOTEC Technical Procedure	UKAS Lab Number	MCERTS Accredited Method	Number of Samples
Total Particulate Matter	SRM - BS EN 13284-1	AE 104	1015	MCERTS	3
Mercury	SRM - BS EN 13211	AE 107	1015	MCERTS	1
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	MCERTS	3
Total Volatile Organic Compounds	SRM - BS EN 12619:2013	AE 102	1015	MCERTS	1
Carbon Monoxide	SRM - BS EN 15058:2017	AE 102	1015	MCERTS	1
Oxygen	AM - BS EN 14789:2017	AE 102	1015	MCERTS	1
Moisture	BS EN 14790	AE 105	1015	MCERTS	1
Velocity	SRM - EN ISO 16911-1	AE 154	1015	MCERTS	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 13-19	Horiba PG - 250 Analyser	LNO 21-14	Laboratory Balance	LNO 00-33 / 00-13
Box Thermocouples	LNO 03-19	FT-IR	-	Tape Measure	LNO 24-WR
Meter In Thermocouple	LNO 03-19	FT-IR Oven Box	-	Stopwatch	-
Meter Out Thermocouple	LNO 03-19	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17-19	Signal 3030 FID	-	Barometer	LNO 08-WR
Oven Box	LNO 09-68	Servomex	-	Digital Micromanometer	LNO 01-WR
Probe	LNO 11-07	JCT Heated Head Filter	-	Digital Temperature Meter	LNO 03-WR
Probe Thermocouple	LNO 10-07	Thermo FID	LNO 21-55	Stack Thermocouple	LNO 10-WR
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LNO 06-WR	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LNO 14-WR	Chiller (JCT/MAK 10)	LNO 21-101	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	LNO 03-102	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	LNO 31-WR	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-			15m Heated Line (1)	-
Heater Controller	-			20m Heated Line (1)	LNO 18-83
Inclinometer (Swirl Device)	LNO 23-WR			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	HPC2178	BOC	80.7	-	2.0
Carbon Monoxide	HPC2144	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
██████████ ul	██████████	██████████	Mar-25	Dec-28	Jun-25	Dec-25	Mar-25	Mar-27
██████████	██████████	██████████	Feb-26	-	-	-	-	Feb-26

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY					
Parameter	Sampling Times	Concentration mg/m ³	Uncertainty mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	10:12 - 11:12 12 April 2023	4.9	0.86	20	5.1
Run 2	12:04 - 13:04 12 April 2023	0.46	0.91	20	0.46
Run 3	13:54 - 14:54 12 April 2023	4.6	0.87	20	5.2
Blank	-	0.94	-	-	-

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

Acetone Blank Value mg/l	Acceptable Value mg/l
0.3	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	Q2230	0.14554	0.14534	-0.00020	65.43270	65.43530	0.00260	0.00240
Run 2	Q2315	0.15058	0.14858	-0.00200	69.98460	69.98680	0.00220	0.00020
Run 3	Q2314	0.14880	0.14891	0.00011	65.28980	65.29190	0.00210	0.00221

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	Q2229	0.14471	0.14450	-0.00021	60.48130	60.48250	0.00120	0.00099

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 1				TPM
Absolute pressure of stack gas, P_s				
Barometric pressure, P _b	Kpa	99.1		
Stack static pressure, P _{static}	pa	7.0		
P _s = P _b + P _{static}	Kpa	99.1		
Vol. of water vapour collected, V_{wstd}				
Moisture trap weight increase, V _{lc}	g	56.1		
V _{wstd} = (0.001246)(V _{lc})	m ³	0.0699006		
Volume of gas metered dry, V_{mstd}				
Volume of gas sample through gas meter, V _m		1.127		
Gas meter correction factor, Y _d		1.011		
Mean dry gas meter temperature, T _m		291		
Mean pressure drop across orifice, DH	mmH ₂ O	32.721		
V _{mstd} = $\frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m}$	m ³	1.050		
Volume of gas metered wet, V_{mstw}				
V _{mstw} = V _{mstd} + V _{wstd}	m ³	1.1196		
Vol. of gas metered at O₂ 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		16.4		
% oxygen reference condition		11		
O ₂ Reference O ₂ Ref = 21.0 - act%O ₂		0.46		
Factor $\frac{21.0 - \text{ref}\%O_2}{21.0 - \text{act}\%O_2}$				
V _{mstd@X%oxygen} = (V _{mstd}) (O ₂ Ref)	m ³	0.4871		
Moisture content, B_{wo}				
B _{wo} = $\frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0624		
	%	6.24		
Moisture by FTIR				
	%	-		
Velocity of stack gas, V_s				
Velocity pressure coefficient, C _p		0.85		
Mean of velocity heads, DP _{avg}	Pa	38.30		
Mean stack gas temperature, T _s	K	355		
Gas density (wet, ambient), p				
p = (M _s *P _s)/(8.314*T _s)	kg/m ³	0.952		
Stack Velocity, V _s	$V_s = \frac{\sum_{i=1}^n V_i}{n}$	m/s	7.63	
Molecular weight of dry gas, M_d				
CO ₂	%	2.49		
O ₂	%	16.36		
Total	%	18.85		
N ₂ (100 - Total)	%	81.15		
M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)		29.05		
Molecular weight of wet gas, M_s				
M _s = M _d (1 - B _{wo}) + 18(B _{wo})	g/gmol	28.36		
Actual flow of stack gas, Q_a				
Area of stack, A _s	m ²	0.12		
Q _a = (60)(A _s)(V _s)	m ³ /min	52.9		
Total flow of stack gas, Q				
Conversion factor (K/mm.Hg)		0.3592		
Q _{std} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$	Dry	37.3		
Q _{stdO2} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2\text{REF})}{(T_s)}$	@O ₂ ref	17.29		
Q _{stw} = $\frac{(Q_a)P_s(0.3592)}{(T_s)}$	Wet	39.74		
Percent isokinetic, %I				
Nozzle diameter, D _n	mm	7.88		
Nozzle area, A _n	mm ²	48.82		
Total sampling time, q	min	60		
%I = $\frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	111.2		
Acceptable isokinetic range 95% to 115%		Yes		
Particulate Concentration, C				
Mass collected on filter, M _f	g	-0.00020		
Mass collected in probe, M _p	g	0.00260		
Total mass collected, M _n	g	0.00240		
C _{wet} = $\frac{M_n}{V_{mstw}}$	mg/m ³	2.144		
C _{dry} = $\frac{M_n}{V_{mstd}}$	mg/m ³	2.286		
C _{dry@X%O2} = $\frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m ³	4.928		
Particulate Emission Rates, E				
E = [(C _{wet})(Q _{stw})(60)] / 1000		5.11		

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	Kpa	99.1		
Stack static pressure, P _{static}	pa	7.0		
P _s = P _b + P _{static}	Kpa	99.1		
Vol. of water vapour collected, V_{wstd}				
Moisture trap weight increase, V _{lc}	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		1.062		
Gas meter correction factor, Y _d		1.011		
Mean dry gas meter temperature, T _m		302		
Mean pressure drop across orifice, DH	mmH ₂ O	32.574		
V _{mstd} = $\frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m}$	m ³	0.952		
Volume of gas metered wet, V_{mstw}				
V _{mstw} = V _{mstd} + V _{wstd}	m ³	1.0152		
Vol. of gas metered at O₂ 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		16.4		
% oxygen reference condition		11		
O ₂ Reference O ₂ Ref = 21.0 - act%O ₂		0.46		
Factor = $\frac{21.0 - \text{ref}\%O_2}{21.0 - \text{act}\%O_2}$				
V _{mstd@X%oxygen} = (V _{mstd}) (O ₂ Ref)	m ³	0.4378		
Moisture content, B_{wo}				
B _{wo} = $\frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0624		
		6.24		
Moisture by FTIR				
	%	-		
Velocity of stack gas, V_s				
Velocity pressure coefficient, C _p		0.85		
Mean of velocity heads, DP _{avg}	Pa	36.83		
Mean stack gas temperature, T _s	K	359		
Gas density (wet, ambient), p				
p = (M _s *P _s)/(8.314*T _s)	kg/m ³	0.942		
Stack Velocity, V _s = $\frac{\sum_{i=1}^n V_i}{n}$	m/s	7.51		
Molecular weight of dry gas, M_d				
CO ₂	%	2.49		
O ₂	%	16.40		
Total	%	18.89		
N ₂ (100 - Total)	%	81.11		
M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)		29.05		
Molecular weight of wet gas, M_s				
M _s = M _d (1 - B _{wo}) + 18(B _{wo})	g/gmol	28.36		
Actual flow of stack gas, Q_a				
Area of stack, A _s	m ²	0.12		
Q _a = (60)(A _s)(V _s)	m ³ /min	52.1		
Total flow of stack gas, Q				
Conversion factor (K/mm.Hg)		0.3592		
Q _{std} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$	Dry	36.3		
Q _{stdO2} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2\text{REF})}{(T_s)}$	@O ₂ ref	16.72		
Q _{stw} = $\frac{(Q_a)P_s(0.3592)}{(T_s)}$	Wet	38.76		
Percent isokinetic, %I				
Nozzle diameter, D _n	mm	7.88		
Nozzle area, A _n	mm ²	48.82		
Total sampling time, q	min	60		
%I = $\frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	103.4		
Acceptable isokinetic range 95% to 115%		Yes		
Particulate Concentration, C				
Mass collected on filter, M _f	g	-0.00200		
Mass collected in probe, M _p	g	0.00220		
Total mass collected, M _n	g	0.00020		
C _{wet} = $\frac{M_n}{V_{mstw}}$	mg/m ³	0.197		
C _{dry} = $\frac{M_n}{V_{mstd}}$	mg/m ³	0.210		
C _{dry@X%O2} = $\frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m ³	0.457		
Particulate Emission Rates, E				
E = [(C _{wet})(Q _{stw})(60)] / 1000		0.46		

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 3				TPM
Absolute pressure of stack gas, P_s				
Barometric pressure, P _b	Kpa	99.1		
Stack static pressure, P _{static}	pa	7.0		
P _s = P _b + P _{static}	Kpa	99.1		
Vol. of water vapour collected, V_{wstd}				
Moisture trap weight increase, V _{lc}	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		1.126		
Gas meter correction factor, Y _d		1.011		
Mean dry gas meter temperature, T _m		305		
Mean pressure drop across orifice, DH	mmH ₂ O	38.002		
V _{mstd} = $\frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m}$	m ³	1.001		
Volume of gas metered wet, V_{mstw}				
V _{mstw} = V _{mstd} + V _{wstd}	m ³	1.0672		
Vol. of gas metered at O₂ 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		16.2		
% oxygen reference condition		11		
O ₂ Reference O ₂ Ref = 21.0 - act%O ₂		0.48		
Factor 21.0 - ref%O ₂				
V _{mstd@X%oxygen} = (V _{mstd}) (O ₂ Ref)	m ³	0.4803		
Moisture content, B_{wo}				
B _{wo} = $\frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0624		
		6.24		
Moisture by FTIR				
	%	-		
Velocity of stack gas, V_s				
Velocity pressure coefficient, C _p		0.85		
Mean of velocity heads, DP _{avg}	Pa	43.12		
Mean stack gas temperature, T _s	K	362		
Gas density (wet, ambient), p				
p = (Ms*Ps)/(8.314*T _s)	kg/m ³	0.934		
Stack Velocity, V _s = $\frac{\sum_{i=1}^n V_i}{n}$	m/s	8.16		
Molecular weight of dry gas, M_d				
CO ₂	%	2.49		
O ₂	%	16.20		
Total	%	18.69		
N ₂ (100 -Total)	%	81.31		
M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)		29.05		
Molecular weight of wet gas, M_s				
M _s = M _d (1 - B _{wo}) + 18(B _{wo})	g/gmol	28.36		
Actual flow of stack gas, Q_a				
Area of stack, A _s	m ²	0.12		
Q _a = (60)(A _s)(V _s)	m ³ /min	56.6		
Total flow of stack gas, Q				
Conversion factor (K/mm.Hg)		0.3592		
Q _{std} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$	Dry	39.1		
Q _{stdO2} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2\text{REF})}{(T_s)}$	@O ₂ ref	18.78		
Q _{stw} = $\frac{(Q_a)P_s(0.3592)}{(T_s)}$	Wet	41.74		
Percent isokinetic, %I				
Nozzle diameter, D _n	mm	7.88		
Nozzle area, A _n	mm ²	48.82		
Total sampling time, q	min	60		
%I = $\frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	100.9		
Acceptable isokinetic range 95% to 115%		Yes		
Particulate Concentration, C				
Mass collected on filter, M _f	g	0.00011		
Mass collected in probe, M _p	g	0.00210		
Total mass collected, M _n	g	0.00221		
C _{wet} = $\frac{M_n}{V_{mstw}}$	mg/m ³	2.071		
C _{dry} = $\frac{M_n}{V_{mstd}}$	mg/m ³	2.209		
C _{dry@X%O2} = $\frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m ³	4.602		
Particulate Emission Rates, E				
E = [(C _{wet})(Q _{stw})(60)] / 1000		5.19		

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	18.99	0.21	-	-355.6	0.38	Yes
Run 2	17.90	0.22	-	-381	0.36	Yes
Run 3	18.97	0.20	-	-381	0.38	Yes

In BS EN 13284-1:2017 a post sampling leak check is not required.

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	111.18	Yes
Run 2	103.36	Yes
Run 3	100.92	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	0.41	1.0	Yes
Run 2	0.46	1.0	Yes
Run 3	0.42	1.0	Yes

The above is based on both the Filter and rinse uncertainty

BLANK VALUE				
Run	Overall Blank Value mg/m ³	Daily Emission Limit Value mg/m ³	Acceptable Blank Value mg/m ³	Overall Blank Acceptable mg/m ³
Blank 1	0.94	20	2.0	Yes

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MERCURY SUMMARY - PARTICULATE & VAPOUR PHASES COMBINED

MERCURY COMBINED					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	15:24 - 16:24 12 April 2023	0.0022	0.0012	0.50	0.0021
Field Blank	-	0.0012	-	-	-

Mercury	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mean mg/m ³	Lab Result ug	Concentration mg/m ³	Stack LOD mean mg/m ³	Lab Result ug	Concentration mg/m ³
Run 1	0.00118	0.50	0.0012	0.00003	0.45	0.0011
Volume Sampled m ³		0.4238			0.4238	
Field Blank	-	0.50	0.0012	-	0.00153	0.0000036
Volume Sampled m ³		0.4238			0.4238	

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	kPa	99.10		CO ₂	% 2.49
Stack static pressure, P _{static}	Pa	7.00		O ₂	% 16.67
P _s = P _b + (P _{static})	kPa	99.11		Total	% 19.17
				N ₂ (100 -Total)	% 80.83
				M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)	29.07
Vol. of water vapour collected, V_{wstd}				Molecular weight of wet gas, M_s	
Moisture trap weight increase, V _{lc}	g	-		M _s = M _d (1 - B _{wo}) + 18(B _{wo})	g/gmol 28.37
V _{wstd} = (0.001246)(V _{lc})	m ³	-		Velocity of stack gas, V_s	
Volume of gas metered dry, V_{mstd}				Velocity pressure coefficient, C _p	0.85
Volume of gas sample through gas meter, V _m	m ³	1.11		Mean of velocity heads, DP _{avg}	Pa 38.79
Gas meter correction factor, Y _d		1.01		Mean stack gas temperature, T _s	K 367.08
Mean dry gas meter temperature, T _m		307.83		Gas density (wet, ambient), ρ	
Mean pressure drop across orifice, DH	mmH ₂ O	33.95		p = (M _s *P _s)/(8.314*T _s)	kg/m ³ 0.921
V _{mstd} = (0.3592)(V _m)(P _b +(DH/13.6))(Y _d) / (T _m + 273)	m ³	0.98		Stack Velocity, V _s = $\frac{\sum_{i=1}^n V_i}{n}$	m/s 7.79
Volume of gas metered wet, V_{mstw}				Actual flow of stack gas, Q_a	
V _{mstw} = V _{mstd} + V _{wstd}	m ³	1.0445		Area of stack, A _s	m ² 0.12
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O2}				Q _a = (60)(A _s)(V _s)	m ³ /min 54.1
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)	No			Total flow of stack gas, Q	
% oxygen measured in gas stream, act%O ₂	16.67			Conversion factor (K/mm.Hg)	
% oxygen reference condition	11			Q _{std} = (Q _a)P _s (0.3592)(1-B _{wo}) / (T _s)	Dry 36.9
O ₂ Reference O ₂ Ref = 21.0 - act%O ₂	0.43			Q _{stdO2} = (Q _a)P _s (0.3592)(1-B _{wo})(O ₂ REF) / (T _s)	@O2ref 16
Factor 21.0 - ref%O ₂				Q _{stw} = (Q _a)P _s (0.3592) / (T _s)	Wet 39
V _{mstd@X%oxygen} = (V _{mstd}) (O ₂ Ref)	m ³	0.42		Percent isokinetic, %I	
Moisture content, B_{wo}				Nozzle diameter, D _n	mm 7.9
B _{wo} = $\frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0624		Nozzle area, A _n	mm ² 48.8
		6.24		Total sampling time, q	min 60.0
Moisture by FTIR				%I = $\frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	% 104.8
	%	-		Acceptable isokinetic range 95% to 115%	Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MERCURY 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	18.8	0.20	-	-381	0.38	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	104.8	Yes

Filtration / Temp	Filter Material	Filter Size mm	Maximum Filtration Temperature °C	Temperature during storage / transit <25°C
Run 1	Quartz Fibre	47	180	Yes

Mercury	Type of Absorbers - Mercury	Absorption Solutions - Mercury
Run 1	PTFE	4% Potassium Dichromate, 20% Nitric Acid

Parameter		Total ug	Final Absorber ug	Absorption Efficiency	Required	Pass / Fail
Mercury	Run 1	0.95	ND	100	95	N/A <30% ELV

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HYDROGEN CHLORIDE SUMMARY					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	10:12 - 11:12 12 April 2023	0.45	0.002	30	0.46
Run 2	12:04 - 13:04 12 April 2023	0.038	0.003	30	0.038
Run 3	13:54 - 14:54 12 April 2023	0.073	0.003	30	0.082
Field Blank	-	0.010	-	-	-

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

HYDROGEN CHLORIDE QUALITY ASSURANCE CHECKLIST

	Barometric Pressure Kpa	Average Oxygen Value for Referencing %	Total Sample Volume @ ref Conditions m ³	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	99.1	16.4	0.487	19.0	0.21	-	0.38	Yes
Run 2	99.1	16.4	0.438	17.9	0.22	-	0.36	Yes
Run 3	99.1	16.2	0.480	19.0	0.20	-	0.38	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Temperature during storage / transit <25°C	Type of Absorbers	Absorption Solutions
Run 1	Quartz Fibre	47	160	N/A	Glass	HPLC Water
Run 2	Quartz Fibre	47	160	N/A	Glass	HPLC Water
Run 3	Quartz Fibre	47	160	N/A	Glass	HPLC Water

HYDROGEN CHLORIDE ABSORPTION EFFICIENCY

Parameter	Total ug	IMP C ug	Absorption Efficiency %	Acceptable Absorption Efficiency %	Absorption Efficiency Acceptable ?
Run 1	217.92	27.12	88	95	N/A - <30% ELV
Run 2	16.69	8.89	47	95	N/A - <30% ELV
Run 3	34.82	2.48	93	95	N/A - <30% ELV

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	kPa	99	Velocity pressure coefficient, C _p	0.85
Stack static pressure, P _{static}	Pa	7	Mean of velocity heads, DP _{avg}	Pa 38.30
P _s = P _b + (P _{static})	kPa	99.11	Mean stack gas temperature, T _s	K 355.33
Vol. of water vapour collected, V_{wstd}			Gas density (wet, ambient), ρ	kg/m ³ 0.952
Moisture trap weight increase, V _{lc}	g	-	p=(M _s *P _s)/(8.314*T _s)	
V _{wstd} = (0.001246)(V _{lc})	m ³	-	Stack Velocity, V _s	m/s 7.63
Volume of gas metered dry, V_{mstd}			Actual flow of stack gas, Q_a	
Volume of gas sample through gas meter, V _m	m ³	1.1270	Area of stack, A _s	m ² 0.12
Gas meter correction factor, Y _d		1.011070729	Q _a = (60)(A _s)(V _s)	m ³ /min 53
Mean dry gas meter temperature, T _m	K	290.75	Dry total flow of stack gas, Q_{std}	
Mean pressure drop across orifice, DH	mmH ₂ O	32.72	Conversion factor (K/mm.Hg)	0.3592
V _{mstd} = (0.3592)(V _m)(P _b +(DH/13.6))(Y _d)	m ³	1.05	Q _{std} = (Q _a)P _s (0.3592)(1-B _{wo})	m ³ /min 37
			(T _s)	
Volume of gas metered wet, V_{mstw}			Wet total flow of stack gas, Q_{stw}	
V _{mstw} = V _{mstd} + V _{wstd}	m ³	1.1196	Q _{stw} = (Q _a)P _s (0.3592)	m ³ /min 40
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O2}			(T _s)	
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)	No		Dry total flow of stack gas at X% O₂, Q_{stdO2}	
% oxygen measured in gas stream, act%O ₂	16.36		Q _{stdO2} = (Q _a)P _s (0.3592)(1-B _{wo})(O ₂ REF)	m ³ /min 17
% oxygen reference condition	11		(T _s)	
O ₂ Reference O ₂ Ref = 21.0 - act%O ₂	0.46		Percent isokinetic, %I	
Factor 21.0 - ref%O ₂			Nozzle diameter, D _n	mm 7.88
V _{mstd@X%oxygen} = (V _{mstd}) (O ₂ Ref)	m ³	0.4871	Nozzle area, A _n	mm ² 48.82
Moisture content, B_{wo}			Total sampling time, q	min 60
B _{wo} = V _{wstd}		0.0624	%I = (4.6398E6)(T _s)(V _{mstd})	% 111
V _{mstd} + V _{wstd}	%	6.24	(P _s)(V _s)(A _n)(q)(1-B _{wo})	
Moisture by FTIR			Acceptable isokinetic range 95% to 115%	Yes
Molecular weight of dry gas, M_d			Hydrogen Chloride Concentration, C	
CO ₂	2.49		Mass collected, M	ug 218
O ₂	16.36		C _{wet} = M _n	mg/m ³ 0.195
Total	18.85		V _{mstw}	
N ₂ (100 -Total)	81.15		C _{dry} = M _n	mg/m ³ 0.208
			V _{mstd}	
M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)	29.05		C _{dry@X%O2} = M _n	mg/m ³ 0.447
			V _{mstd@X%oxygen}	
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 0.46

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS 2			Hydrogen Chloride	
Absolute pressure of stack gas, P_s			Velocity of stack gas, V_s	
Barometric pressure, P _b	kPa	99	Velocity pressure coefficient, C _p	0.85
Stack static pressure, P _{static}	Pa	7	Mean of velocity heads, DP _{avg}	Pa 36.83
P _s = P _b + (P _{static})	kPa	99.11	Mean stack gas temperature, T _s	K 358.83
Vol. of water vapour collected, V_{wstd}			Gas density (wet, ambient), ρ	kg/m ³ 0.942
Moisture trap weight increase, V _{lc}	g	-	p = (M _s *P _s)/(8.314*T _s)	
V _{wstd} = (0.001246)(V _{lc})	m ³	-	Stack Velocity, V _s	m/s 7.51
Volume of gas metered dry, V_{mstd}			Actual flow of stack gas, Q_a	
Volume of gas sample through gas meter, V _m	m ³	1.0620	Area of stack, A _s	m ² 0.12
Gas meter correction factor, Y _d		1.011070729	Q _a = (60)(A _s)(V _s)	m ³ /min 52
Mean dry gas meter temperature, T _m	K	302.17	Dry total flow of stack gas, Q_{std}	
Mean pressure drop across orifice, DH	mmH ₂ O	32.57	Conversion factor (K/mm.Hg)	0.3592
V _{mstd} = (0.3592)(V _m)(P _b +(DH/13.6))(Y _d)	m ³	0.95	Q _{std} = (Q _a)P _s (0.3592)(1-B _{wo})	m ³ /min 36
			(T _s)	
Volume of gas metered wet, V_{mstw}			Wet total flow of stack gas, Q_{stw}	
V _{mstw} = V _{mstd} + V _{wstd}	m ³	1.0152	Q _{stw} = (Q _a)P _s (0.3592)	m ³ /min 39
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O2}			(T _s)	
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)	No		Dry total flow of stack gas at X% O₂, Q_{stdO2}	
% oxygen measured in gas stream, act%O ₂	16.40		Q _{stdO2} = (Q _a)P _s (0.3592)(1-B _{wo})(O ₂ REF)	m ³ /min 17
% oxygen reference condition	11		(T _s)	
O ₂ Reference O ₂ Ref = 21.0 - act%O ₂	0.46		Percent isokinetic, %I	
Factor 21.0 - ref%O ₂			Nozzle diameter, D _n	mm 7.88
V _{mstd@X%oxygen} = (V _{mstd}) (O ₂ Ref)	m ³	0.4378	Nozzle area, A _n	mm ² 48.82
Moisture content, B_{wo}			Total sampling time, q	min 60
B _{wo} = V _{wstd}		0.0624	%I = (4.6398E6)(T _s)(V _{mstd})	% 103
V _{mstd} + V _{wstd}	%	6.24	(P _s)(V _s)(A _n)(q)(1-B _{wo})	
Moisture by FTIR			Acceptable isokinetic range 95% to 115%	Yes
Molecular weight of dry gas, M_d			Hydrogen Chloride Concentration, C	
CO ₂	2.49		Mass collected, M	ug 17
O ₂	16.40		C _{wet} = M _n	mg/m ³ 0.016
Total	18.89		V _{mstw}	
N ₂ (100 -Total)	81.11		C _{dry} = M _n	mg/m ³ 0.018
			V _{mstd}	
M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)	29.05		C _{dry@X%O2} = M _n	mg/m ³ 0.038
			V _{mstd@X%oxygen}	
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 0.04

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	kPa	99	Velocity pressure coefficient, C _p	0.85
Stack static pressure, P _{static}	Pa	7	Mean of velocity heads, DP _{avg}	Pa 43.12
P _s = P _b + (P _{static})	kPa	99.11	Mean stack gas temperature, T _s	K 362.08
Vol. of water vapour collected, V_{wstd}			Gas density (wet, ambient), ρ	kg/m ³ 0.934
Moisture trap weight increase, V _{lc}	g	-	p = (M _s *P _s)/(8.314*T _s)	
V _{wstd} = (0.001246)(V _{lc})	m ³	-	Stack Velocity, V _s	m/s 8.16
Volume of gas metered dry, V_{mstd}			Actual flow of stack gas, Q_a	
Volume of gas sample through gas meter, V _m	m ³	1.1260	Area of stack, A _s	m ² 0.12
Gas meter correction factor, Y _d		1.011070729	Q _a = (60)(A _s)(V _s)	m ³ /min 57
Mean dry gas meter temperature, T _m	K	304.92	Dry total flow of stack gas, Q_{std}	
Mean pressure drop across orifice, DH	mmH ₂ O	38.00	Conversion factor (K/mm.Hg)	0.3592
V _{mstd} = (0.3592)(V _m)(P _b +(DH/13.6))(Y _d)	m ³	1.00	Q _{std} = (Q _a)P _s (0.3592)(1-B _{wo})	m ³ /min 39
			(T _s)	
Volume of gas metered wet, V_{mstw}			Wet total flow of stack gas, Q_{stw}	
V _{mstw} = V _{mstd} + V _{wstd}	m ³	1.0672	Q _{stw} = (Q _a)P _s (0.3592)	m ³ /min 42
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O2}			(T _s)	
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)	No		Dry total flow of stack gas at X% O₂, Q_{stdO2}	
% oxygen measured in gas stream, act%O ₂	16.20		Q _{stdO2} = (Q _a)P _s (0.3592)(1-B _{wo})(O ₂ REF)	m ³ /min 19
% oxygen reference condition	11		(T _s)	
O ₂ Reference O ₂ Ref = 21.0 - act%O ₂	0.48		Percent isokinetic, %I	
Factor 21.0 - ref%O ₂			Nozzle diameter, D _n	mm 7.88
V _{mstd@X%oxygen} = (V _{mstd}) (O ₂ Ref)	m ³	0.4803	Nozzle area, A _n	mm ² 48.82
Moisture content, B_{wo}			Total sampling time, q	min 60
B _{wo} = V _{wstd}		0.0624	%I = (4.6398E6)(T _s)(V _{mstd})	% 101
V _{mstd} + V _{wstd}	%	6.24	(P _s)(V _s)(A _n)(q)(1-B _{wo})	
Moisture by FTIR			Acceptable isokinetic range 95% to 115%	Yes
Molecular weight of dry gas, M_d			Hydrogen Chloride Concentration, C	
CO ₂	2.49		Mass collected, M	ug 35
O ₂	16.20		C _{wet} = M _n	mg/m ³ 0.033
Total	18.69		V _{mstw}	
N ₂ (100 -Total)	81.31		C _{dry} = M _n	mg/m ³ 0.035
			V _{mstd}	
M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)	29.05		C _{dry@X%O2} = M _n	mg/m ³ 0.073
			V _{mstd@X%oxygen}	
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 0.08

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL VOLATILE ORGANIC COMPOUNDS SUMMARY

Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	10:12 - 16:12 12 April 2023	0.85	0.40	20	0.80

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

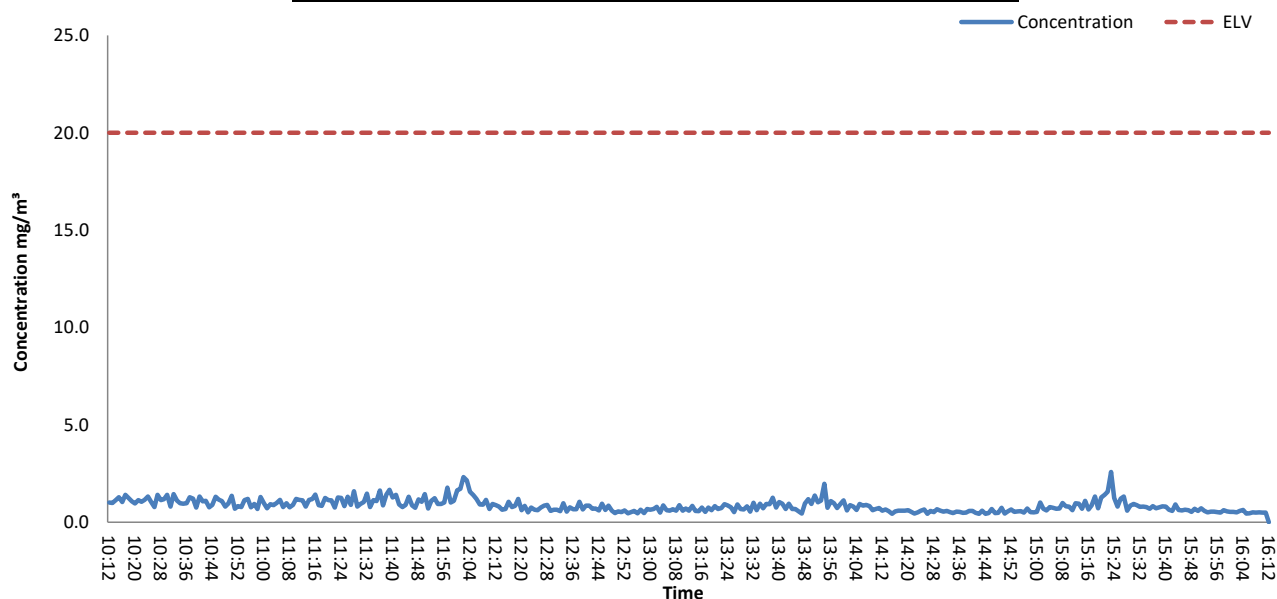
INSTRUMENTAL SPAN & ZERO CHECKS

PRE-SAMPLING CALIBRATION CHECKS								
Date	12 April 2023							
Start Time	09:30							
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	80.7	100	0.00	80.7	0.56	0.88	81.8	-1.36

Zero and Span gas contained 20% Oxygen

POST-SAMPLING CALIBRATION CHECKS								
Date	12 April 2023							
Start Time	16:35							
End Time	16:50							
Gas	Mean Raw Value ppm	Zero down line reading	Span down line reading	Zero Drift (%)	Span Drift (%)	Corrected for Zero Drift	Corrected for Span Drift	Corrected Values ppm / %
Propane	0.40	0.91	82.3	0.04	0.58	x	x	N/A - not corrected

TOTAL VOLATILE ORGANIC COMPOUNDS EMISSIONS CHART



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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GASES SUMMARY

Test	Sampling Time and Date	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Carbon Monoxide	10:12 - 16:12 12 April 2023	25	0.66	100	24

Test	Sampling Time and Date	Concentration %	LOD %
Oxygen	10:12 - 16:12 12 April 2023	16.7	0.01

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

PRE-SAMPLING CALIBRATION DATA

Date	12 April 2023
Start Time	09:30
End Time	09:50

Chiller Temperature (°C)	3.0
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 %
Carbon Monoxide	200	0.00	167.8	-0.30	0.50	165.3	45	1.49
Oxygen	25	0.00	20.90	0.02	0.08	20.92	40	-0.10

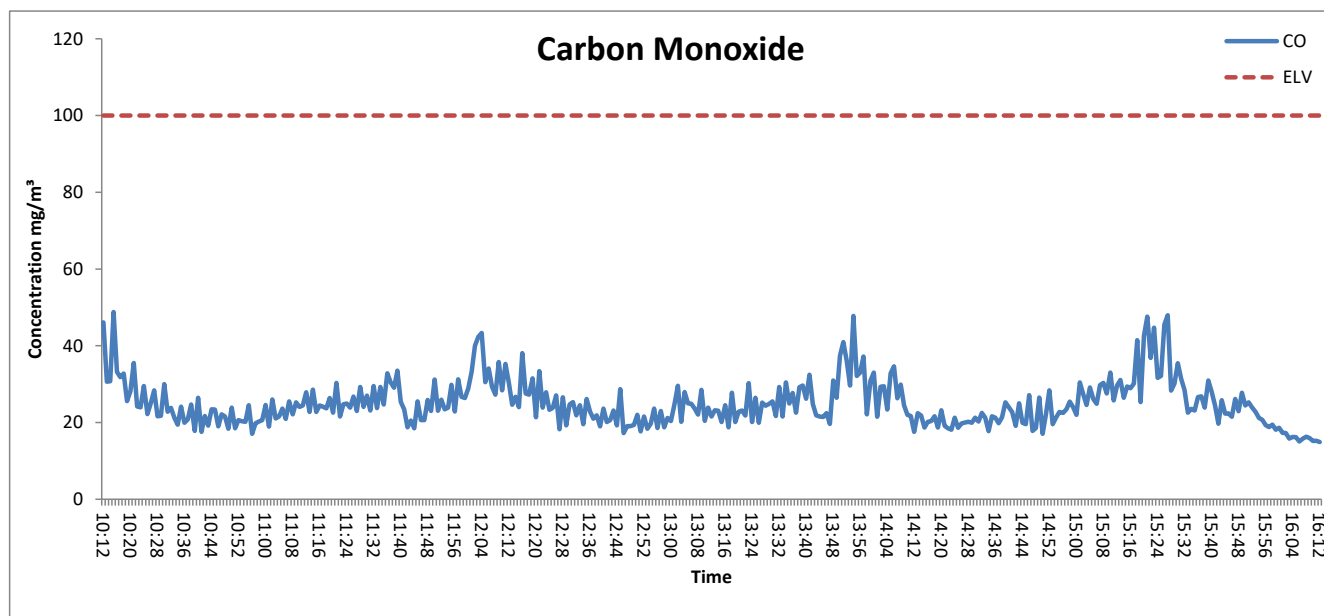
POST-SAMPLING CALIBRATION DATA

Date	12 April 2023
Start Time	16:35
End Time	16:50

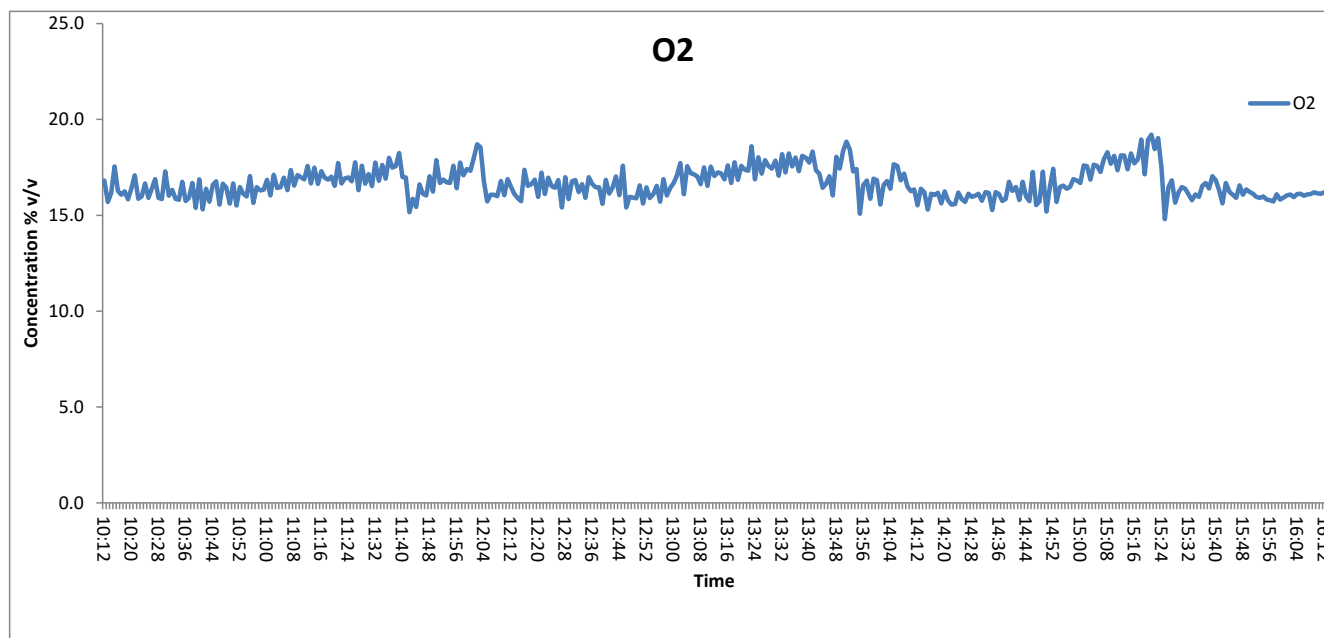
Chiller Temperature (°C)	3.1
Requirement	< 4°C
Compliant	Yes

Gas	Zero Check at Analyser	Span Check at Analyser	Zero Drift (%)	Span Drift (%)	Corrected for Zero Drift	Corrected for Span Drift	Corrected Values ppm / %
Carbon Monoxide	0.90	166.9	0.72	-1.25	x	x	N/A - not corrected
Oxygen	0.05	20.95	0.14	0.10	x	x	N/A - not corrected

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	End Weight	Total gain	Concentration	LOD	Uncertainty
		kg	kg	kg	%	%	%
Run 1	10:12 - 11:12 12 April 2023	3.2321	3.2882	0.0561	6.2	0.01	5.2

Moisture Quality Assurance							
Test Number	Sampling Duration	Total Volume Sampled	Sampling Rate	Start Leak Rate	End Leak Rate	Acceptable Leak Rate	Leak Tests Acceptable?
	mins	l	l/min	l/min	l/min	l/min	
Run 1	60	1120	19.0	0.21	-	0.38	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.34	m
Stack Width, W	0.34	m
Stack Area, A	0.12	m ²
Average stack gas temperature	69	°C
Stack static pressure	0.007	kPa
Barometric Pressure	99.1	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	2.493524	0.024935	0.048949	2.337845	0.023378	0.045893
O ₂	32	1.427679	16.496198	0.164962	0.235513	15.466282	0.154663	0.220809
N ₂	28	1.249219	81.010278	0.810103	1.011996	75.952518	0.759525	0.948813
H ₂ O	18	0.803070	-	-	-	6.243356	0.062434	0.050138

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2965	kg/m ³
Wet Density (STP), P_{STW}	1.2657	kg/m ³
Dry Density (Actual), P_{Actual}	1.0117	kg/m ³
Average Wet Density (Actual), $P_{ActualW}$	0.988	kg/m ³

Where:

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

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

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

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	12 April 2023
Time of Survey	10:00
Velocity Measurement Device:	S-Type Pitot

Sampling Line A								
Traverse Point	Distance into duct (m)	DP pt Pa (average of 3 readings)	DP pt mmH ₂ O (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m ³ /s	O ₂ % Vol	Angle of Swirl °
1	0.05	38.2	3.9	68	7.5	0.86	-	-
2	0.13	38.5	3.9	69	7.5	0.87	-	-
3	0.21	40.2	4.1	70	7.7	0.89	-	-
4	0.29	43.1	4.4	70	7.9	0.92	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	40.0	4.1	69	7.6	0.88	-	-

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt Pa (average of 3 readings)	DP pt mmH ₂ O (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 mmH ₂ O	End Value mmH ₂ O	Difference %	Outcome	Start Value mmH ₂ O	End Value mmH ₂ O	Difference %	Outcome
Run 1	112	110	1.8	Pass	122	122	0.0	Pass

To complete a compliant pitot leak check a pressure of over 80 mmH₂O (or 800 Pa) is applied and the pressure drop monitored over 5 mins. A drop of less than 5% must be observed.

S-Type Pitot Stagnation Check				
Run	Stagnation (Pa)	Reference (Pa)	Difference (Pa)	Outcome (Permitted +/- 10 Pa)
Run 1	7	6	1.0	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 Average Differential Pressure	38	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	7.5	m/s	-	-
Highest Gas Velocity	7.9	m/s	-	-
Ratio of Gas Velocities	1.1	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	°	< 15°	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, $V = K_{pt} \times (1-e) \times \sqrt{2 \times DP_{pt} / \rho_{ActualW}}$		
Where: K_{pt} = Pitot tube calibration coefficient $(1-e)$ = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, V_a	7.6	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	69	0	°C
Total Pressure	99.107	101.3	kPa
Oxygen	16.5	11	%
Moisture	6.24	0.00	%
Pitot tube calibration coefficient, K_{pt}	0.85		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (V_a)	7.65	m/s
Stack Area (A)	0.12	m ²
Gas Volumetric Flowrate (Actual), Q_{Actual}	3182.71	m ³ /hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	2483.77	m ³ /hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	2328.70	m ³ /hr
Gas Volumetric Flowrate (REF), Q_{Ref}	1048.80	m ³ /hr

Where:

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

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

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

$$Q_{Ref} = Q_{STP} \times ((100 - Ma) / (100 - Ms)) \times ((21 - O_{2a}) / (21 - O_{2s}))$$

Nomenclature:

T_s = Absolute Temperature, Standard Conditions, 273 K

P_s = Absolute Pressure, Standard Conditions, 101.3 kPa

T_a = Absolute Temperature, Actual Conditions, K

P_a = Absolute Pressure, Actual Conditions, kPa

Ma = Water vapour, Actual Conditions, % Vol

Ms = Water vapour, Reference Conditions, % Vol

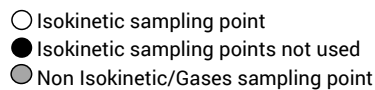
O_{2a} = Oxygen, Actual Conditions, % Vol

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

STACK DIAGRAM

	Value	Units
Stack Depth	0.34	m
Stack Width	0.34	m
Area	0.12	m ²

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	50	0.17	m

[illegible]

LNO 17793 / Version 1
12th April 2023
DEFRA Process Guidance Note: PG 5/2 (12)

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	0.002	2.0	0.50	1.0	0.1	0.20	-	-
as a %	0.20	0.56	0.50	1.0	0.61	2.05	1.11	0.0050
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Run 2	0.001	2.0	0.50	1.0	0.1	0.20	-	-
as a %	0.20	0.66	0.50	1.0	0.61	2.28	1.23	0.0050
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Run 3	0.001	2.0	0.50	1.0	0.1	0.20	-	-
as a %	0.20	0.66	0.50	1.0	0.62	2.08	1.05	0.0050
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	0.79	2.4000	2.2	0.0315	0.0006	-
MU as mg/m ³	0.06	0.4106	0.11	0.0315	0.0012	0.43
MU as %	1.28	8.3333	-	0.638	0.0238	-
Run 2	0.39	0.2000	2.2	0.0032	0.0006	-
MU as mg/m ³	0.01	0.4568	0.01	0.0032	0.0013	0.46
MU as %	1.3	100.0000	-	0.710	0.2858	-
Run 3	0.42	2.2100	2.1	0.0280	0.0006	-
MU as mg/m ³	0.06	0.4164	0.10	0.0280	0.0012	0.43
MU as %	1.32	9.0498	-	0.609	0.0259	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.86	mg/m³	17.45	% Result	4.30	% ELV
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R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.91	mg/m³	200.07	% Result	4.57	% ELV
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R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.87	mg/m³	18.80	% Result	4.33	% ELV
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(k is a coverage factor which gives a 95% confidence in the quoted figures)

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MERCURY

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Leak %
MU required	<=2%	<2.5 k	<=1%	<=1%	<=5%	<5%	<=2%
Run 1	0.001	2.0	0.50	1.0	0.10	0.000053	-
as a %	0.20	0.6	0.50	1.0	0.60	3.00	1.07
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Run	Volume (STP) m ³	O2 Correction -	Mass of Mercury mg	Leak mg/m ³	Lab Uncertainty mg	Combined
Run 1	0.3677	2.3107	0.9514	0.000014	-	-
MU as mg/m ³	0.000030	0.000052	0.0012	0.000014	0.00011	0.0012
MU as %	1.3152	2.3107	53.8916	0.6157	5.00000	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.00243	mg/m³	108.38	% Result	0.49	% ELV
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(k is a coverage factor which gives a 95% confidence in the quoted figures)

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - ISOKINETIC HYDROGEN CHLORIDE

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %
MU required	<=2%	<2.5 k	<=1%	<=1%	<=5%	≤ 5% of ELV	<=2%
Run 1	0.487	291	99.17	1.0	16.36	0.36	-
as a %	0.21	0.69	0.50	1.0	0.61	0.02	1.11
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Run 2	0.438	302	99.17	1.0	16.4	0.035	-
as a %	0.23	0.66	0.50	1.0	0.61	0.01	1.23
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Run 3	0.480	305	99.17	1.0	16.2	0.057	-
as a %	0.21	0.66	0.50	1.0	0.62	0.02	1.05
compliant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Run	Volume (STP) m ³	Mass of Hydrogen Chloride mg	O2 Correction -	Leak mg/m ³	Lab Uncertainty mg	Combined uncertainty
Run 1	0.4477	0.3620	2.1552	0.0029	-	-
MU as mg/m ³	0.0060	0.0054	0.0096	0.0029	0.0215	0.0250
MU as %	1.3331	1.2129	2.1552	0.6384	4.8	-
Run 2	0.387	0.035	2.174	0.00027	-	-
MU as mg/m ³	0.001	0.003	0.001	0.00027	0.002	0.004
MU as %	1.326	9.096	2.174	0.710	4.800	-
Run 3	0.421	0.057	2.083	0.00044	-	-
MU as mg/m ³	0.001	0.005	0.002	0.00044	0.003	0.006
MU as %	1.319	6.256	2.083	0.609	4.800	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.05	mg/m³	11.20	% Result	0.17	% ELV
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R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.01	mg/m³	21.24	% Result	0.03	% ELV
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R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.01	mg/m³	16.57	% Result	0.04	% ELV
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(k is a coverage factor which gives a 95% confidence in the quoted figures)

Reference – SOCOTEC 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	0.0021	2.0	0.50	1.0	0.1	-
as a %	0.20	0.56	0.50	1.0	0.61	1.11
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	0.79	56100	2.2	341.19	58	-
MU as % v/v	0.086	0.01	0.14	0.04	0.0069	0.17
MU as %	1.28	0.18	2.16	0.64	0.10	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.35	% v/v	5.19	%
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 1

Measured Concentration	0.9	mg/m ³
Limit	20	mg/m ³
Calibration Gas Concentration	129.12	mg/m ³
Range	160	mg/m ³

Performance characteristics	Value	Units	specification	MU Met?
Response time	40	seconds	<180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	360	minutes	-	-
Number of readings in measurement	360	-	-	-
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	0.04	% full scale	<5% range / 24hr	Yes
Span drift	0.58	% full scale	<5% 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)	-1.36	% 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	0.01
Standard deviation of repeatability at span level	urs	0.01
Lack of fit	ufit	0.65
Drift	u0dr	0.02
volume or pressure flow dependence	uspres	0.00062
atmospheric pressure dependence	uapres	0.03910
ambient temperature dependence	utemp	0.00001
Dependence on voltage	uvolt	0.13795
losses in the line (leak)	uleak	-0.00670
Uncertainty of calibration gas	ucalib	0.00491
Uncertainty in factor	uf	0.00627

Measurement uncertainty Measured Concentration	0.85	mg/m ³
Combined uncertainty	0.66	mg/m ³
Expanded uncertainty	1.30	mg/m ³

Expanded uncertainty expressed with a level of confidence of 95%	6.50	% ELV
Expanded uncertainty expressed with a level of confidence of 95%	1.30	mg/m ³
Expanded uncertainty expressed with a level of confidence of 95%	152.64	% value

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON MONOXIDE

Limit value	100	mg/m ³
Concentration @ Ref conditions	25.0	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	45	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	360	minutes	-	-
Number of readings in measurement	360	-	-	-
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	0.72	% full scale	<5% range / 24hr	Yes
Span drift	-1.25	% full scale	<5% 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	1	% full scale/10K	<3% range / 10 K	Yes
Combined interference	0.03	% 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	$U_{d,s}$	0.42
influence of Ambient Temp zero	$U_{t,z}$	0.2029
influence of Ambient Temp span	$U_{t,s}$	0.0812
influence of sample gas pressure	U_p	0.0000
influence of sample gas flow	U_{fit}	0.1386
influence of supply voltage	U_v	-0.0919
Combined Interference	U_i	1.51
Uncertainty of Cal gas	U_{adj}	0.84

Measurement uncertainty (Concentration Measured)	10.5	mg/m ³
Combined uncertainty	1.8	mg/m ³
Expanded uncertainty	3.6	mg/m ³

Expanded uncertainty expressed with a level of confidence of 95%	3.6	% ELV
Expanded uncertainty expressed with a level of confidence of 95%	3.6	mg/m ³
Expanded uncertainty expressed with a level of confidence of 95%	34.2	% value

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

Reference	11	%vol
Reported Concentration	16.67	%vol
Calibration gas	20.9	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	40	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	360	minutes	-	-
Number of readings in measurement	360	-	-	-
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	0.14	% full scale	<5% range / 24hr	Yes
Span drift	0.10	% full scale	<5% range / 24hr	Yes
volume or pressure flow dependence	0.03	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.05	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	-0.08	% full scale/10K	<3% range / 10 K	Yes
Combined interference	0.14	% range	<4% of Range	Yes
dependence on voltage	0.00	% full scale/10V	< 0.1%vol /10 volt	Yes
losses in the line (leak)	0.14	% of value	< 2% of value	Yes
Uncertainty of calibration gas	0.1	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
repeatability	$U_r = S_r$	0.0083
lack of fit	U_{lof}	0.0751
short term zero drift	$U_{d,z}$	0.0828
short term span drift	$U_{d,s}$	0.0552
influence of Ambient Temp at Zero	$U_{t,z}$	-0.0005
influence of Ambient Temp at Span	$U_{t,s}$	-0.0030
influence of sample gas pressure	U_p	0.0000
influence of sample gas flow	U_{fit}	0.0173
influence of supply voltage	U_v	0.0001
Combined Interference	U_i	0.0485
Uncertainty of Cal gas	U_{adj}	0.1045

Measurement uncertainty (Concentration Measured)	16.67	%
Combined uncertainty	0.17	%
Expanded uncertainty	0.33	%

Expanded uncertainty expressed with a level of confidence of 95%	0.3	%
Expanded uncertainty expressed with a level of confidence of 95%	2.01	% vol

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	7.6	m/s
Measured Volumetric Flow rate at Actual Conditions	3183	m ³ /hr

Performance Characteristics & Source of Value	Units	Values	Requirement	Compliant
Uncertainty of Local Gas Velocity Determination	-	0.010		
Uncertainty of pitot tube coefficient	-	0.51		
Uncertainty of mean local dynamic pressures	-	0.591	minimum 3	Yes
Factor loading, function of the number of measurements.	3 readings	1000		
Range of measurement device	pa	1.00		
Resolution	pa	7.72	<1% of Value or 20 Pa whichever is greater	Yes
Calibration uncertainty	pa	0.10		
Drift	% range	0.06	<2% of value	Yes
Linearity	% range	0.00009		
Uncertainty of gas density determination	kg/mol	1.75	<1% of value	Yes
Uncertainty of molar mass determination	K	506		
Uncertainty of temperature measurement	pa	0.008		
Uncertainty of absolute pressure in the duct	kg/m ³	0.0001		
Uncertainty associated with the calculation of density	-	0.0002		
Uncertainty associated with the measurement of local velocity	-			
Uncertainty associated with the measurement of mean velocity	-			

Measurement Uncertainty - Velocity	m/s
Combined uncertainty	0.09
Expanded uncertainty at a 95% Confidence Interval	0.19

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

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

Measurement Uncertainty Volumetric Flow Rate	m ³ /hr
Combined uncertainty	91
Expanded uncertainty at a 95% Confidence Interval	179

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

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

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

END OF REPORT

Thank you for choosing SOCOTEC 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