STACK EMISSIONS MONITORING REPORT

2-4 Langlands Place
Kelvin South Business Park
East Kilbride
G75 0YF
Tel: 01355 246 730

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Operator & Address:
Exxon Mobil
Fife Ethylene Plant
Mossmorran
Cowdenbeath
KY4 8EP

Permit Reference:
PPC Permit: PPC/A/1013494

Release Point:
A9 Boiler A

Sampling Date(s):
16th June 2022

SOCOTEC Job Number:	LEK 13328
Report Date:	21-Jul-22
Version:	1
Report By:	[redacted]
MCERTS Number:	[redacted]
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Report Approved By:	[redacted]
MCERTS Number:	[redacted]
Business Title:	[redacted]
Technical Endorsements:	1, 2, 3 & 4
Signature:	[redacted]

UKAS TESTING 1015

mCERTS THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Exxon Mobil operates a ethylene production process at Fife Ethylene Plant which is subject to PPC Permit PPC/A/1013494, under the PPC regulations 2000.

SOCOTEC LTD were commissioned by Exxon Mobil 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 PPC Permit, PPC/A/1013494.

Plant

A9 Boiler A

Operator

Exxon Mobil
Fife Ethylene Plant
Mossmorran
Cowdenbeath
KY4 8EP

PPC Permit: PPC/A/1013494

Stack Emissions Monitoring Test House

SOCOTEC - East Kilbride Laboratory
2-4 Langlands Place
Kelvin South Business Park
East Kilbride
G75 0YF
UKAS and MCERTS Accreditation Number: 1015

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.
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.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Emission Limit Value (ELV)**	**Accreditation**
Total Particulate Matter	mg/m³	1.61	0.50	5	MCERTS
Particulate Emission Rate	g/hr	63.0	19.5	-	
Sulphur dioxide	mg/m³	2.65	0.28	35	MCERTS
Sulphur dioxide Emission Rate	g/hr	103	10.8	-	
Oxides of Nitrogen (as NO_2)	mg/m³	239	5.85	300	MCERTS
Oxides of Nitrogen (as NO_2) Emission Rate	g/hr	10540	258	-	
Carbon Monoxide	mg/m³	0.93	1.92	200	MCERTS
Carbon Monoxide Emission Rate	g/hr	41.0	84.8	-	
Oxygen	% v/v	3.96	0.01	-	MCERTS
Moisture	%	15.3	0.49	-	MCERTS
Stack Gas Temperature	°C	152	-	-	MCERTS
Stack Gas Velocity	m/s	11.0	0.27	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	79849	4106	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	50793	2612	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	43014	2212	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	40724	2094	-	

ND = None Detected,
Results at or below the limit of detection are highlighted by bold italic text.
The above volumetric flow rate is calculated using data from the preliminary survey. Mass emissions for non isokinetic tests are calculated using these values. For all isokinetic testing the mass emission is calculated using test specific flow data and not the above values.
Reference conditions are 273K, 101.3kPa, dry gas 3% Oxygen.

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
Total Particulate Matter Run 1	16 June 2022	11:31 - 12:35	64 minutes
Sulphur dioxide Run 1	16 June 2022	11:31 - 12:35	64 minutes
Combustion Gases	16 June 2022	11:31 - 12:31	60 minutes
Preliminary Stack Traverse	16 June 2022	11:10	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Ethylene Production
Continuous or batch	Continuous
Product Details	Boiler Generates process heat/steam
Part of batch to be monitored (if applicable)	Normal Operation
Normal load, throughput or continuous rating	69.41% MCR
Fuel used during monitoring	2.46 t/h Fuel Gas
Abatement	None
Plume Appearance	None

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	0.25 mg/m³	30.9%	9.97%
Sulphur dioxide	SRM - BS EN 14791	AE 112	1015	MCERTS	0.016 mg/m³	10.4%	0.79%
Oxides of Nitrogen	SRM - BS EN 14792:2017	AE 102	1015	MCERTS	0.5 mg/m³	2.5%	1.95%
Carbon Monoxide	SRM - BS EN 15058:2017	AE 102	1015	MCERTS	0.27 mg/m³	206.9%	1.0%
Oxygen	SRM - BS EN 14789:2017	AE 102	1015	MCERTS	0.01%	0.3%	N/A - No ELV
Moisture	BS EN 14790	AE 105	1015	MCERTS	0.01%	3.2%	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	-	5.1%	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 Analyis**	**Archive Period**
Total Particulate Matter	Gravimetric	AE 106	1015	MCERTS	SOCOTEC (East Kilbride)	N/A	8 Weeks
Sulphur dioxide	Ion Chromatography	ASC/SOP/110	1252	MCERTS	SOCOTEC (Bretby)	ASC/54228	8 Weeks

ON-SITE TESTING							
Species	**Analytical Technique**	**Analytical Procedure**	**UKAS Lab Number**	**Accreditation**	**Laboratory**	**Data Archive Location**	**Archive Period**
Oxides of Nitrogen	Chemiluminescence	AE 102	1015	MCERTS	SOCOTEC (East Kilbride)	SOCOTEC (East Kilbride)	5 years
Carbon Monoxide	Non Dispersive Infra Red	AE 102	1015	MCERTS	SOCOTEC (East Kilbride)	SOCOTEC (East Kilbride)	5 years
Oxygen	Paramagnetic	AE 102	1015	MCERTS	SOCOTEC (East Kilbride)	SOCOTEC (East Kilbride)	5 years
Moisture	Gravimetric	AE 105	1015	MCERTS	SOCOTEC (East Kilbride)	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	65	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	10.7	m/s	-	-	-
Highest Gas Velocity	11.3	m/s	-	-	-
Ratio of Gas Velocities	1.1	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	11.0	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	°	< 15°	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Circular	-
Depth	1.60	m
Width	-	m
Area	2.01	m^2
Port Depth	250	mm

SAMPLING LINES & POINTS		
	Isokinetic	**Non-Iso & Gases**
Sample port size	6" Flange	6" Flange
Number of lines used	1	1
Number of points / line	8	1
Duct orientation	Vertical	Vertical
Filtration	In Stack	Out Stack
Filtration for TPM	In Stack	-

SAMPLING PLATFORM	
General Platform Information	
Permanent / Temporary Platform / Ground level / Floor Level / Roof	Temporary
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	No
Depth of Platform = >Stack depth / diameter + wall and port thickness + 1.5m	No

Sampling Platform Improvement Recommendations (if applicable)

In order to comply with BS EN 15259 the platform should be extended/modified so that there is a minimum clearance of 2.6m from the sampling port to the edge of the plaform on both sample lines.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Sample Points

It is only possible to sample from one line therefore the number of sample points were doubled according to MID BS EN 13284.

APPENDICES

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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	1
Sulphur dioxide	SRM - BS EN 14791	AE 112	1015	MCERTS	1
Oxides of Nitrogen	SRM - BS EN 14792:2017	AE 102	1015	MCERTS	1
Carbon Monoxide	SRM - BS EN 15058:2017	AE 102	1015	MCERTS	1
Oxygen	SRM - 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	LEK 9.59	Horiba PG - 350 Analyser	LEK 12.22	Laboratory Balance	LEK 15.21
Box Thermocouples	LEK 9.60	FT-IR	-	Tape Measure	LEK 20.4
Meter In Thermocouple	LEK 9.60	FT-IR Oven Box	-	Stopwatch	-
Meter Out Thermocouple	LEK 9.60	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LEK 17.33	Signal 3030 FID	-	Barometer	LEK 16.1
Oven Box	-	Servomex	-	Digital Micromanometer	LEK 1.2
Probe	-	JCT Heated Head Filter	-	Digital Temperature Meter	LEK 2.11
Probe Thermocouple	-	Thermo FID	-	Stack Thermocouple	LEK 3.117
Probe	LEK 6.44	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	LEK 3.116	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LEK 6.44	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LEK 23.20	Chiller (JCT/MAK 10)	LEK 12.13	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	-	5m Heated Line (1)	LEK 8.33
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	LEK 15.1G	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-			15m Heated Line (1)	-
Heater Controller	-			20m Heated Line (1)	LEK 8.51
Inclinometer (Swirl Device)	LEK 24.7			20m Heated Line (2)	-

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

CALIBRATION GASES					
Gas (traceable to ISO 17025)	Cylinder I.D Number	Supplier	ppm	%	Analytical Tolerance +/- %
Oxygen	Ambient	BOC	-	20.95	-
Nitric Oxide	LEK 242	BOC	196	-	2.0
Carbon Monoxide	LEK 260	BOC	162.6	-	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
[redacted]	[redacted]	MCERTS Level 2	Oct-25	May-26	Nov-26	Dec-26	Mar-27	Oct-25
[redacted]	[redacted]	MCERTS Trainee	Apr-24	-	-	-	-	Apr-24

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY					
Parameter	**Sampling Times**	**Concentration mg/m³**	**Uncertainty mg/m³**	**ELV mg/m³**	**Emission Rate g/hr**
Run 1	11:31 - 12:35 16 June 2022	1.61	0.50	5	63.0
Blank	-	0.67	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 3% 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	AQ4825	0.14944	0.14944	0.00000	185.28850	185.28980	0.00130	0.00130

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	AQ4824	0.15214	0.15214	0.00000	202.72520	202.72580	0.00060	0.00060

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	100.4
Stack static pressure, P_{static}	pa	95.0
$P_s = P_b + P_{static}$	Kpa	100.5
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	129.1
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.1608586
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.999
Gas meter correction factor, Y_d		0.979
Mean dry gas meter temperature, T_m		298
Mean pressure drop across orifice, DH	mmH_2O	27.474
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$	m^3	0.890
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.0504
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		4.7
% oxygen reference condition		3
O_2 Reference Factor O_2 Ref $= \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		0.91
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	0.8065
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1531
	%	15.31
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Velocity pressure coefficient, C_p		0.84
Mean of velocity heads, DP_{avg}	Pa	68.85
Mean stack gas temperature, T_s	K	425
Gas density (wet, ambient), p		
p=(Ms*Ps)/(8.314*Ts)	kg/m^3	0.798
Stack Velocity, Vs $V_s = Cp\sqrt{\frac{\Delta DPavg}{p}}$	m/s	11.04

Molecular weight of dry gas, M_d		
CO_2	%	10.44
O_2	%	4.68
Total	%	15.12
N_2 (100 -Total)	%	84.88
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.86
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.04
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	2.01
$Q_a = (60)(A_s)(V_s)$	m^3/min	1331.7
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$	Dry	718.4
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$	@O_2ref	651.34
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$	Wet	848.30
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	6.96
Nozzle area, A_n	mm^2	38.05
Total sampling time, q	min	64
$\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	102.2
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00000
Mass collected in probe, M_p	g	0.00130
Total mass collected, M_n	g	0.00130
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	1.238
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	1.461
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	1.612
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		62.99

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER QUALITY ASSURANCE CHECKLIST

LEAK RATE						
Run	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable?
Run 1	15.28	0.20	-	-381	0.31	Yes

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

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	102.24	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m³	5% ELV mg/m³	LOD < 5% ELV
Run 1	0.25	0.3	N/A - ELV <5 mg/m³

The above is based on both the Filter and rinse uncertainty
Where installations have ELVs of 5 mg/m³ or less, it may not be practical to meet the 5% of ELV requirement. Under these circumstances, a minimum one hour sample time shall used.

BLANK VALUE				
Run	Overall Blank Value mg/m^3	Daily Emission mg/m^3	Acceptable Blank Value mg/m^3	Overall Blank Acceptable mg/m^3
Blank 1	0.67	5	1.0	Yes

*For ELVs of 5 mg/m3 and lower a blank value must be <20% of the ELV

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	152	180	160

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

SULPHUR DIOXIDE SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	ELV mg/m³	Emission Rate g/hr
Run 1	11:31 - 12:35 16 June 2022	2.65	0.016	35	103
Field Blank	-	0.093	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 3% Oxygen.

SULPHUR DIOXIDE QUALITY ASSURANCE CHECKLIST

	Barometric Pressure Kpa	Average Oxygen Value for %	Total Sample Volume @ ref Conditions m³	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	100.4	4.7	0.807	15.3	0.20	-	0.31	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	152	N/A	Glass	0.3% Hydrogen Peroxide

SULPHUR DIOXIDE ABSORPTION EFFICIENCY

Parameter	Total ug	IMP C ug	Absorption Efficiency %	Acceptable Absorption Efficiency %	Absorption Efficiency Acceptable ?
Run 1	2133.5	309.6	85	95	N/A - <30% ELV

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS 1 — Sulphur dioxide

Absolute pressure of stack gas, P_s			**Velocity of stack gas, V_s**		
Barometric pressure, P_b	kPa	100	Velocity pressure coefficient, C_p		0.84
Stack static pressure, P_{static}	Pa	95	Mean of velocity heads, DP_{avg}	Pa	68.85
$P_s = P_b + (P_{static})$	kPa	100.50	Mean stack gas temperature, T_s	K	425.00
			Gas density $_{(wet, ambient)}$, p		
Vol. of water vapour collected, V_{wstd}			p=(Ms*Ps)/(8.314*Ts)	kg/m^3	0.798
Moisture trap weight increase,Vlc	g	-	Stack Velocity, Vs $V_s = Cp\sqrt{\frac{\Delta DPavg}{p}}$		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-		m/s	11.04
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	0.9990	Area of stack, A_s	m^2	2.01
Gas meter correction factor, Y_d		0.979	$Q_a = (60)(A_s)(V_s)$	m^3/min	1332
Mean dry gas meter temperature, T_m	K	298.19	**Dry total flow of stack gas, Q_{std}**		
Mean pressure drop across orifice, DH	mmH_2O	27.47	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$	m^3	0.89	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$	m^3/min	718
Volume of gas metered wet, V_{mstw}			**Wet total flow of stack gas, Q_{stw}**		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.0504	$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$	m^3/min	848
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	$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$	m^3/min	651
% oxygen measured in gas stream, act%O_2		4.68	**Percent isokinetic, %I**		
% oxygen reference condition		3	Nozzle diameter, D_n	mm	6.96
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		0.91	Nozzle area, A_n	mm^2	38.05
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	0.8065	Total sampling time, q	min	64
Moisture content, B_{wo}			$\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	102
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.1531 15.31	Acceptable isokinetic range 95% to 115%		Yes
Moisture by FTIR	%	-	**Sulphur dioxide Concentration, C**		
Molecular weight of dry gas, M_d			Mass collected , M	ug	2134
CO_2		10.44	$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	2.031
O_2		4.68	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	2.398
Total		15.12			
N_2 (100 -Total)		84.88	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	2.645
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.86			
Molecular weight of wet gas, M_s			**Sulphur dioxide Emission Rates, E**		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.0	$E = [(C_{wet})(Q_{stw})(60)] / 1000$	g/hr	103.38

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GASES SUMMARY

Test	Sampling Time and Date	Concentration mg/m³	LOD mg/m³	ELV mg/m³	Emission Rate g/hr
Oxides of Nitrogen	11:31 - 12:31 16 June 2022	238.7	0.50	300	10540
Carbon Monoxide	11:31 - 12:31 16 June 2022	0.93	0.27	200	41.01

Test	Sampling Time and Date	Concentration %	LOD %
Oxygen	11:31 - 12:31 16 June 2022	2.52	0.01

Reference conditions are 273K, 101.3kPa, dry gas 3% Oxygen.

PRE-SAMPLING CALIBRATION DATA

Date	16 June 2022
Start Time	10:45
End Time	11:15

Chiller Temperature (°C)	2.8
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 %
Nitric Oxide	250	0.00	196.0	0.00	0.20	196.2	46	-0.10
Carbon Monoxide	200	0.00	162.6	0.10	0.20	160.9	40	1.05
Oxygen	25	0.00	20.95	0.00	0.02	20.91	39	0.19

POST-SAMPLING CALIBRATION DATA

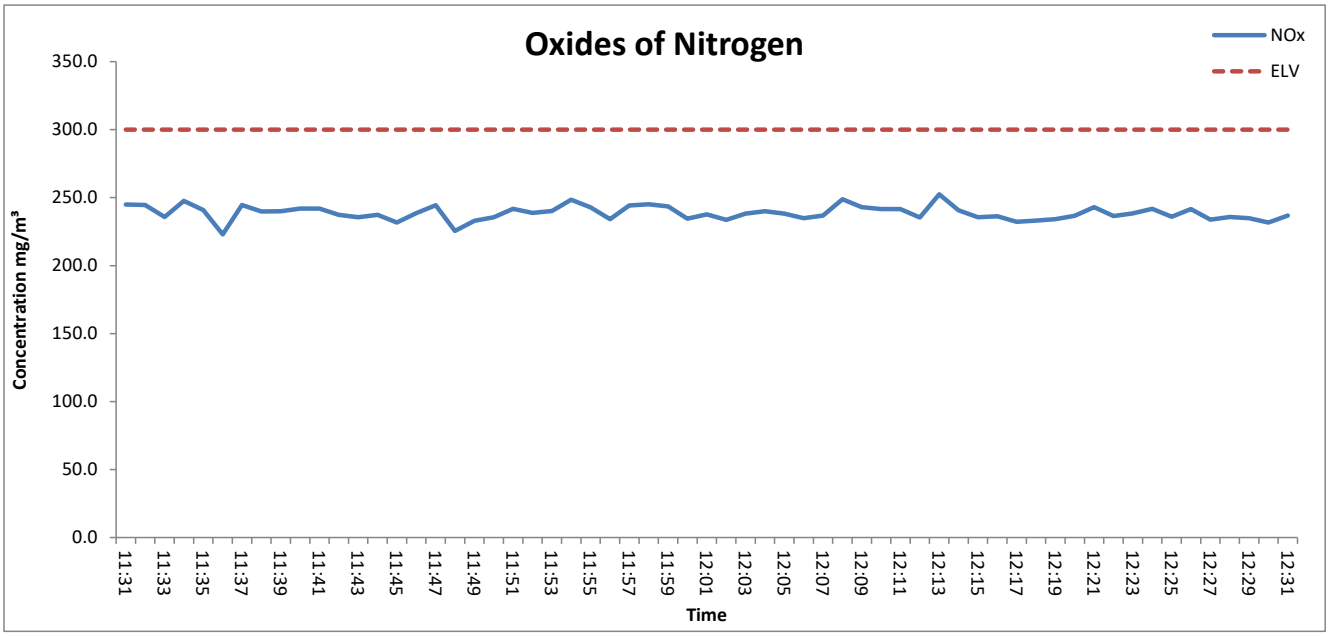
Date	16 June 2022
Start Time	12:40
End Time	12:55

Chiller Temperature (°C)	2.3
Requirement	< 4°C
Compliant	Yes

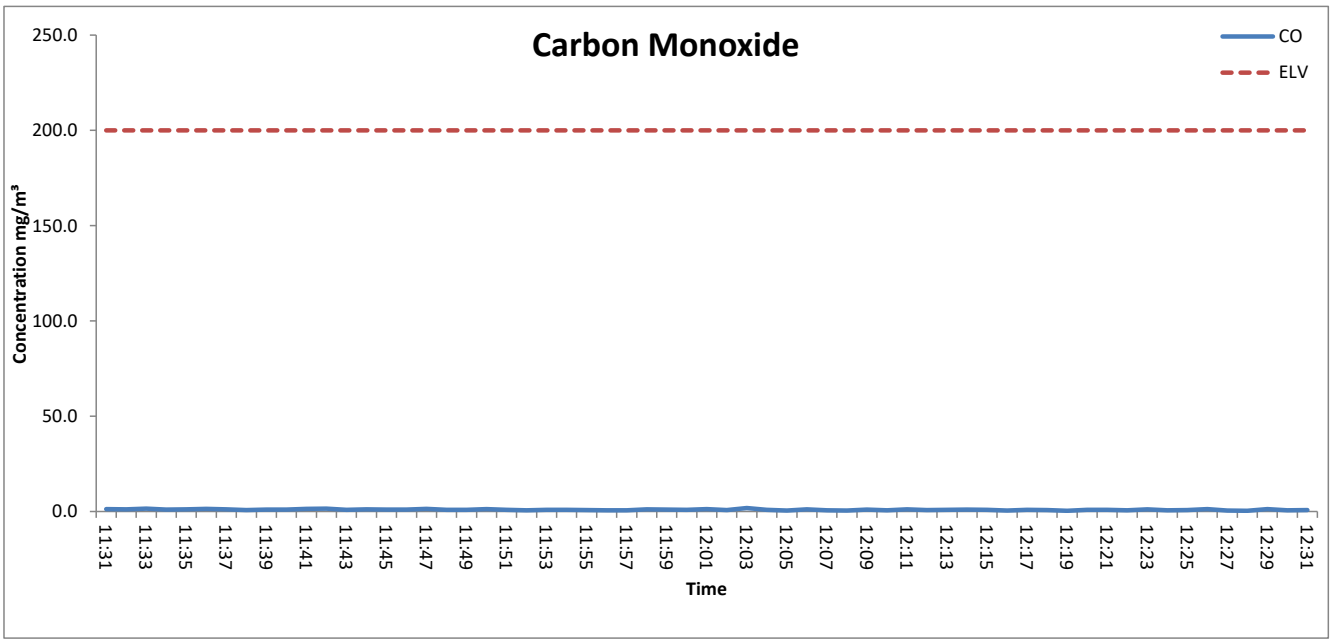
Gas	Zero Check at Analyser	Span Check at Analyser	Zero Drift (%)	Span Drift (%)	Corrected for Zero Drift	Corrected for Span Drift	Corrected Values ppm / %
Nitric Oxide	0.30	200.1	0.15	1.94	×	×	N/A - not corrected
Carbon Monoxide	0.10	160.9	0.00	-1.05	×	×	N/A - not corrected
Oxygen	0.03	20.96	0.14	-0.10	×	×	N/A - not corrected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

OXIDES OF NITROGEN (as NO_2) EMISSIONS CHART

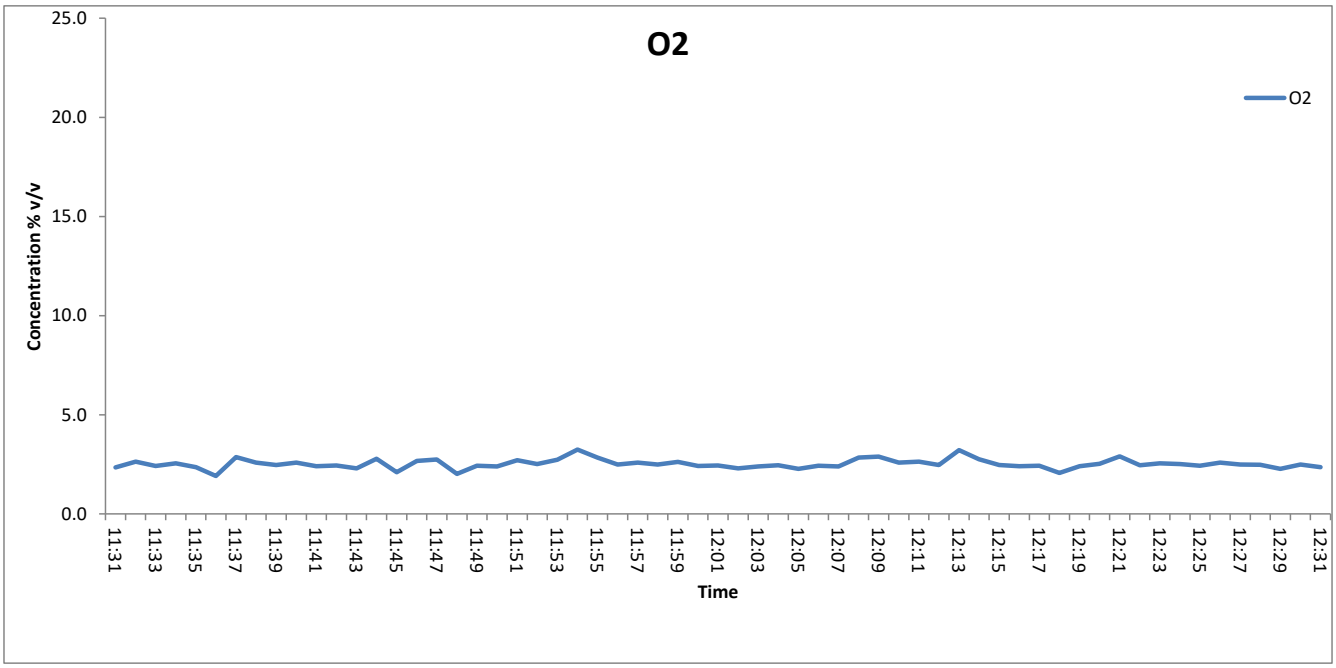


CARBON MONOXIDE EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

OXYGEN EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Isokinetic							
Test Number	Sampling Time and Date	Start Weight kg	End Weight kg	Total gain kg	Concentration %	LOD %	Uncertainty %
Run 1	11:31 - 12:35 16 June 2022	2.9132	3.0423	0.1291	15.3	0.01	3.2

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	64	1050	15.3	0.20	-	0.31	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	1.60	m
Stack Width, W	-	m
Stack Area, A	2.01	m^2
Average stack gas temperature	152	^oC
Stack static pressure	-0.084	kPa
Barometric Pressure	100.4	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	10.440571	0.104406	0.204955	8.841673	0.088417	0.173567
O_2	32	1.427679	3.958497	0.039585	0.056515	3.352282	0.033523	0.047860
N_2	28	1.249219	85.600931	0.856009	1.069343	72.491766	0.724918	0.905581
H_2O	18	0.803070	-	-	-	15.314279	0.153143	0.122984

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3308	kg/m^3
Wet Density (STP), P_{STW}	1.2500	kg/m^3
Dry Density (Actual), P_{Actual}	0.8465	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.795	kg/m^3

Where:

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

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

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

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	16 June 2022
Time of Survey	11:10
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_2O (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	66.6	6.8	152	10.9	21.9	-	-
2	0.17	70.6	7.2	152	11.2	22.5	-	-
3	0.31	70.6	7.2	152	11.2	22.5	-	-
4	0.52	72.5	7.4	152	11.3	22.8	-	-
5	1.08	70.6	7.2	152	11.2	22.5	-	-
6	1.29	66.6	6.8	152	10.9	21.9	-	-
7	1.43	64.7	6.6	152	10.7	21.5	-	-
8	1.55	66.6	6.8	152	10.9	21.9	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	68.6	7.0	152	11.0	22.2	-	-

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt Pa (average of 3 readings)	DP pt mmH_2O (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 mmH2O	End Value mmH2O	Difference %	Outcome	Start Value mmH2O	End Value mmH2O	Difference %	Outcome
Run 1	144	142	1.4	Pass	124	122	1.6	Pass

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

S-Type Pitot Stagnation Check				
Run	Stagnation (Pa)	Reference (Pa)	Difference (Pa)	Outcome (Permitted +/- 10 Pa)
Run 1	-84	-87	3.0	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	65	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	10.7	m/s	-	-
Highest Gas Velocity	11.3	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} x (1-e) * Ö(2 * DP_{pt} / $P_{ActualW}$)		
Where: K_{pt} = Pitot tube calibration coefficient (1-e) = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, Va	**11.0**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	152	0	°C
Total Pressure	100.316	101.3	kPa
Oxygen	4.0	3	%
Moisture	15.31	0.00	%
Pitot tube calibration coefficient, K_{pt}	0.84		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	11.03	m/s
Stack Area (A)	2.01	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	79848.80	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	50792.88	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	43014.32	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	40723.81	m^3/hr

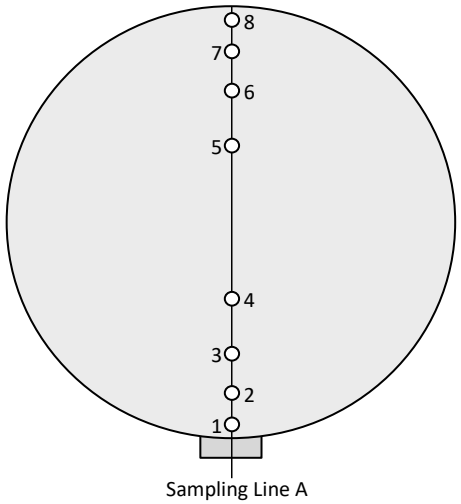
Where:
Q_{Actual} = Va x A x 3600
Q_{STP} = Q (Actual) x (Ts / Ta) x (Pa / Ps) x 3600
$Q_{STP,Dry}$ = Q (STP) / (100 - (100 / Ma)) x 3600
Q_{Ref} = Q (STP) x ((100 - Ma) / (100 - Ms)) x ((21 - O_2a) / (21 - O_2s))

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	1.60	m
Stack Width	-	m
Area	2.01	m^2



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

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	40	0.64	m

Isokinetic Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	3.2	0.05	< 15
2	10.5	0.17	< 15
3	19.4	0.31	< 15
4	32.3	0.52	< 15
5	67.7	1.08	< 15
6	80.6	1.29	< 15
7	89.5	1.43	< 15
8	96.8	1.55	< 15
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

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	0.002	2.0	0.50	1.0	0.1	0.20	-	-
as a %	0.20	0.47	0.50	1.0	2.14	4.96	1.31	0.012
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

*Where installations have ELVs of 5 mg/m³ or less, it may not be practical to meet the 5% of ELV requirement. Under these circumstances, a minimum one hour sample time shall used.

Run	Volume (STP)	Mass of particulate	O_2 Correction	Leak	Uncollected Mass	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	0.57	1.3000	1.1	0.0122	0.0003	-
MU as mg/m^3	0.02	0.2480	0.01	0.0122	0.0004	**0.25**
MU as %	1.25	15.3846	-	0.756	0.0266	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.50**	**mg/m^3**	**30.93**	**% Result**	**9.97**	**% ELV**

(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 SULPHUR DIOXIDE

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Limit of Detection	Leak
	m^3	K	kPa	% by volume	% by volume	% by mass	%
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**≤ 5% of ELV**	**<=2%**
Run 1	0.807	298	101.35	1.0	4.68	3.6	-
as a %	0.12	0.67	0.49	1.0	2.14	0.09	1.31
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP)	Mass of Sulphur dioxide	O2 Correction	Leak	Lab Uncertainty	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	0.7387	3.6380	1.1029	0.0200	-	-
MU as mg/m^3	0.0346	0.0317	0.0162	0.0200	0.1270	**0.1378**
MU as %	1.3083	1.1994	0.6127	0.7556	4.8	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.28**	**mg/m^3**	**10.42**	**% Result**	**0.79**	**% ELV**

(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	0.001779049	2.0	0.50	1.0	0.1	-
as a %	0.20	0.47	0.50	1.0	2.14	1.31
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	0.57	129100	1.1	1096.65	58	-
MU as % v/v	0.23	0.01	0.11	0.14	0.008	**0.29**
MU as %	1.25	0.08	0.61	0.76	0.04	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.58**	**% v/v**	**3.18**	**%**

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXIDES OF NITROGEN

Limit value	300	mg/m^3
Concentration @ Ref conditions	238.7	mg/m^3
Cal gas conc	402	mg/m^3
Analyser Full Scale	513	mg/m^3

	Value	Units	specification	MU Met?
Response time	46	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	60	minutes	-	-
Number of readings in measurement	60	-	-	-
Repeatability at zero	0.11	% full scale	<1 % range	Yes
Repeatability at span level	0.1	% full scale	<2 % range	Yes
Deviation from linearity	-0.40	% of value	<2 % range	Yes
Zero drift	0.15	% full scale	<5% range / 24hr	Yes
Span drift	1.94	% full scale	<5% range / 24hr	Yes
volume or pressure flow dependence	0.25	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.25	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence zero / span	0.00	% full scale/10K	<3% range / 10 K	Yes
Combined interference	-1.30	% range	<4% of Range	Yes
dependence on voltage	0.09	% full scale/10V	< 0.1%vol /10 volt	Yes
Influence of Vibration	N/A	% of upper limit of Cal range	<2%	-
losses in the line (leak)	0.09	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
repeatability	$U_r = S_r$	0.0037
lack of fit	U_{lof}	-0.2309
short term zero drift	$U_{d,z}$	0.0867
short term span drift	$U_{d,s}$	1.1194
influence of Ambient Temp at Zero	$U_{t,z}$	0.0000
influence of Ambient Temp at Span	$U_{t,s}$	1.9136
influence of sample gas pressure	U_p	-0.0048
influence of sample gas flow	U_{fit}	0.1732
influence of supply voltage	U_v	0.2637
Combined Interfence	U_i	-0.0018
Uncertainty of Cal gas	U_{adj}	1.9600

Measurement uncertainty (Concentration Measured)	239	mg/m^3
Combined uncertainty	2.99	mg/m^3
Expanded at a 95% confidence interval	5.85	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**1.95**	**% ELV**

Expanded uncertainty expressed with a level of confidence of 95%	**5.9**	**mg/m^3**

Expanded uncertainty expressed with a level of confidence of 95%	**2.5**	**% value**

Developed for the STA by [redacted], NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON MONOXIDE

Limit value	200	mg/m^3
Concentration @ Ref conditions	0.9	mg/m^3
Cal gas conc	203.3	mg/m^3
Analyser Full Scale	250	mg/m^3

Performance characteristics	Value	Units	specification	MU Met?
Response time	40	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	60	minutes	-	-
Number of readings in measurement	60	-	-	-
Repeatability at zero	0.1	% full scale	<1 % range	Yes
Repeatability at span level	0.2	% full scale	<2 % range	Yes
Deviation from linearity	0.61	% of value	<2 % range	Yes
Zero drift	0.00	% full scale	<5% range / 24hr	Yes
Span drift	-1.05	% 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	-0.8	% full scale/10K	<3% range / 10 K	Yes
Combined interference	-0.01	% of Range	<4% of Range	Yes
dependence on voltage	-0.06	% full scale/10V	< 0.1%vol /10 volt	Yes
Influence of Vibration	N/A	% of upper limit of Cal range	<2%	N/A
losses in the line (leak)	0.01	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.00	% of value	< 2% of value	Yes

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

Performance characteristic	Uncertainty	Value of uncertainty quantity
repeatability	$U_r = S_r$	0.003
lack of fit	U_{lof}	0.12
short term zero drift	$U_{d,z}$	0.35
short term span drift	$U_{d,s}$	0.00
influence of Ambient Temp zero	$U_{t,z}$	-0.03
influence of Ambient Temp span	$U_{t,s}$	0.15
influence of sample gas pressure	U_p	0.02
influence of sample gas flow	U_{fit}	0.14
influence of supply voltage	U_v	-0.09
Combined Interfence	U_i	-0.40
Uncertainty of Cal gas	U_{adj}	0.81

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

Expanded uncertainty expressed with a level of confidence of 95%	**1.0**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**2.0**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**206.9**	**% value**

Developed for the STA by [redacted], NPL

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

Reference	3	%vol
Reported Concentration	2.52	%vol
Calibration gas	20.95	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	39	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	60	minutes	-	-
Number of readings in measurement	60	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	Yes
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.13	% of value	<2 % range	Yes
Zero drift	0.14	% 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	-0.05	% full scale/10K	<3% range / 10 K	Yes
Combined interference	0.01	% range	<4% of Range	Yes
dependence on voltage	0.00	% full scale/10V	< 0.1%vol /10 volt	Yes
losses in the line (leak)	0.01	% of value	< 2% of value	Yes
Uncertainty of calibration gas	0.0	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
repeatability	$U_r = S_r$	0.0083
lack of fit	U_{lof}	0.0751
short term zero drift	$U_{d,z}$	0.0828
short term span drift	$U_{d,s}$	-0.0551
influence of Ambient Temp at Zero	$U_{t,z}$	0.0002
influence of Ambient Temp at Span	$U_{t,s}$	-0.0096
influence of sample gas pressure	U_p	-0.0009
influence of sample gas flow	U_{fit}	0.0173
influence of supply voltage	U_v	0.0001
Combined Interfence	U_i	0.0017
Uncertainty of Cal gas	U_{adj}	0.1048

Measurement uncertainty (Concentration Measured)	2.52	%
Combined uncertainty	0.16	%
Expanded uncertainty	0.32	%

Expanded uncertainty expressed with a level of confidence of 95%	**0.3**	**%**

Expanded uncertainty expressed with a level of confidence of 95%	**12.79**	**% vol**

Developed for the STA by [redacted], NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	11.0	m/s
Measured Volumetric Flow rate at Actual Conditions	79849	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	-	0.68		
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	11.84	<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	0.00005		
Uncertainty of temperature measurement	K	2.17	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	512		
Uncertainty associated with the calculation of density	kg/m3	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	0.14
Expanded uncertainty at a 95% Confidence Interval	0.27

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

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

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	2095
Expanded uncertainty at a 95% Confidence Interval	4106

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

Expanded Measurement Uncertainty of Volumetric Flow Rate at a 95% Confidence Interval	%
Expressed as a % of the Measured Volumetric Flow Rate	2.6
Expanded uncertainty at a 95% Confidence Interval	5.1

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