STACK EMISSIONS MONITORING REPORT

2-4 Langlands Place
Kelvin South Business Park
East Kilbride
G75 0YF
Tel: 01355 246 730
Fax: 01355 249 669

Your contact at SOCOTEC LTD
[redacted]
Tel: 01355 246 730
Fax: 01355 249 669
Email: [redacted]@socotec.com

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

Permit Reference:
EPR Permit: PPC/A/1013494

Release Point:
A10 Boiler C

Sampling Date(s):
19 October 2021

SOCOTEC Job Number:	LEK 12957
Report Date:	17-Nov-21
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

CONTENTS

EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Exxon Mobil operates a ethylene production process at Fife Ethylene Plant which is subject to EPR Permit PPC/A/1013494, under the Environmental Permitting Regulations 2010.

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 EPR Permit, PPC/A/1013494.

Plant

A10 Boiler C

Operator

Exxon Mobil
Fife Ethylene Plant
Mossmorran
Cowdenbeath
KY4 8EP

EPR 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 Particulate Emission Rate	mg/m³ g/hr	1.04 54.0	0.42 21.9	5 -	MCERTS
Sulphur dioxide Sulphur dioxide Emission Rate	mg/m³ g/hr	0.76 39.5	0.10 5.26	35 -	MCERTS
Oxides of Nitrogen (as NO_2) Oxides of Nitrogen (as NO_2) Emission Rate	mg/m³ g/hr	205 10652	4.05 211	300 -	MCERTS
Carbon Monoxide Carbon Monoxide Emission Rate	mg/m³ g/hr	3.11 162	3.42 178	200 -	MCERTS
Oxygen	% v/v	4.02	0.09	6	MCERTS
Moisture	%	14.7	0.45	-	MCERTS
Stack Gas Temperature	°C	140	-	-	MCERTS
Stack Gas Velocity	m/s	13.5	0.33	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	97429	5009	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	64667	3325	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	55140	2835	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	52077	2678	-	

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 3% Oxygen.

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
Total Particulate Matter Run 1	19 October 2021	14:19 - 15:23	64 minutes
Sulphur dioxide Run 1	19 October 2021	14:19 - 15:23	64 minutes
Combustion Gases	19 October 2021	14:10 - 15:10	60 minutes
Preliminary Stack Traverse	19 October 2021	13:25	-

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 production
Normal load, throughput or continuous rating	85.27 % MCR
Fuel used during monitoring	3.24 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	0.21 mg/m³	40.5%	8.44%
Sulphur dioxide	SRM - BS EN 14791	AE 112	1015	MCERTS	0.013 mg/m³	13.3%	0.29%
Oxides of Nitrogen	SRM - BS EN 14792:2017	AE 102	1015	MCERTS	0.54 mg/m³	2.0%	1.35%
Carbon Monoxide	SRM - BS EN 15058:2017	AE 102	1015	MCERTS	0.29 mg/m³	109.7%	1.6%
Oxygen	AM - BS EN 14789:2017	AE 102	1015	MCERTS	0.01%	2.3%	N/A - No ELV
Moisture	BS EN 14790	AE 105	1015	MCERTS	0.01%	3.0%	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 number	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)	ASC51261	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	Zirconia Cell	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	94	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	13.0	m/s	-	-	-
Highest Gas Velocity	13.9	m/s	-	-	-
Ratio of Gas Velocities	1.1	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	13.5	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	In Stack
Filtration for TPM	In Stack	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 extended/modified so that there is a minimum of 2.6m clearance from the sampling port to the edge of the platfrom 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 the 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	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	LEK 9.59	Horiba PG-250 Analyser	LEK 12.5	Laboratory Balance	LEK 15.21
Box Thermocouples	LEK 9.60	FT-IR Gasmet	-	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	LEK 6.44	JCT Heated Head Filter	-	Digital Temperature Meter	LEK 2.11
Probe Thermocouple	-	Thermo FID	-	Stack Thermocouple	LEK 3.117
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	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 12.16	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	LEK 8.33	5m Heated Line (1)	LEK 8.33
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	LEK 8.51	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	194920	BOC	-	4.04	2.0
Nitric Oxide	LEK 165	BOC	198.8	-	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	Apr-25	May-25	Nov-26	Dec-26	Mar-22	Apr-25
[redacted]	[redacted]	MCERTS Trainee	Mar-26	-	-	-	-	Mar-26

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	14:19 - 15:23 19 October 2021	1.04	0.42	5	54.0
Blank	-	0.80	-	-	-

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	AQ 4577	0.14550	0.14589	0.00039	201.96050	201.96120	0.00070	0.00109

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	AQ4432	0.15284	0.15373	0.00089	188.59990	188.59990	0.00000	0.00089

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	101.8
Stack static pressure, P_{static}	pa	-86.0
$P_s = P_b + P_{static}$	Kpa	101.7
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	153.8
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.1916348
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		1.219
Gas meter correction factor, Y_d		0.976
Mean dry gas meter temperature, T_m		296
Mean pressure drop across orifice, DH	mmH_2O	42.379
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$	m^3	1.109
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.3008
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		4.0
% oxygen reference condition		3
O_2 Reference Factor O_2 Ref $= \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		0.94
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$	m^3	1.0461
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1473
	%	14.73
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Velocity pressure coefficient, C_p		0.84
Mean of velocity heads, DP_{avg}	Pa	100.21
Mean stack gas temperature, T_s	K	411
Gas density (wet, ambient), p		
p=(Ms*Ps)/(8.314*Ts)	kg/m^3	0.793
Stack Velocity, Vs $V_s = Cp\sqrt{\frac{\Delta DPavg}{p}}$	m/s	13.35

Molecular weight of dry gas, M_d		
CO_2	%	0.00
O_2	%	4.02
Total	%	4.02
N_2 (100 -Total)	%	95.98
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.16
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	26.66
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	1611.2
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	915.1
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$	@O_2ref	863.08
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$	Wet	1073.23
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	7.03
Nozzle area, A_n	mm^2	38.86
Total sampling time, q	min	64
$\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	98.0
Acceptable isokinetic range 90% to 110%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00039
Mass collected in probe, M_p	g	0.00070
Total mass collected, M_n	g	0.00109
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	0.838
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	0.983
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	1.042
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		53.96

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	18.60	0.20	-	-508	0.37	Yes

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

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	98.00	Yes

Acceptable isokinetic range 90% to 110%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m³	5% ELV mg/m³	LOD < 5% ELV
Run 1	0.21	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	0.80	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	140	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	14:19 - 15:23 19 October 2021	0.76	0.013	35	40
Field Blank	-	0.03	-	-	-

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	101.8	4.0	1.046	18.6	0.20	0.20	0.37	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	140	Yes	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	798.7	13.3	98	95	Yes

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS 1 — Sulphur dioxide

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	kPa	102
Stack static pressure, P_{static}	Pa	-86
$P_s = P_b + (P_{static})$	kPa	101.71
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m	m^3	1.2190
Gas meter correction factor, Y_d		0.9764
Mean dry gas meter temperature, T_m	K	295.50
Mean pressure drop across orifice, DH	mmH_2O	42.38
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$	m^3	1.11
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.3008
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		4.02
% oxygen reference condition		3
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		0.94
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	1.0461
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1473
	%	14.73
Moisture by FTIR	%	-
Molecular weight of dry gas, M_d		
CO_2		0.00
O_2		4.02
Total		4.02
N_2 (100 -Total)		95.98
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.16
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	26.7

Velocity of stack gas, V_s		
Velocity pressure coefficient, C_p		0.84
Mean of velocity heads, DP_{avg}	Pa	100.21
Mean stack gas temperature, T_s	K	411.38
Gas density $_{(wet, ambient)}$, p		
p=(Ms*Ps)/(8.314*Ts)	kg/m^3	0.793
Stack Velocity, Vs $V_s = Cp\sqrt{\frac{\Delta DPavg}{p}}$	m/s	13.35
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	1611
Dry total flow of stack gas, Q_{std}		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$	m^3/min	915
Wet total flow of stack gas, Q_{stw}		
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$	m^3/min	1073
Dry total flow of stack gas at X% O_2, Q_{stdO2}		
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$	m^3/min	863
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	7.03
Nozzle area, A_n	mm^2	38.86
Total sampling time, q	min	64
$\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	98
Acceptable isokinetic range 95% to 115%		Yes
Sulphur dioxide Concentration, C		
Mass collected , M	ug	799
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	0.614
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	0.720
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	0.764
Sulphur dioxide Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$	g/hr	39.54

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	14:10 - 15:10 19 October 2021	205	0.54	300	10652
Carbon Monoxide	14:10 - 15:10 19 October 2021	3.11	0.29	200	162.2

Test	Sampling Time and Date	Concentration %	LOD %
Oxygen	14:10 - 15:10 19 October 2021	4.02	0.01

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

PRE-SAMPLING CALIBRATION DATA

Date	19 October 2021
Start Time	11:45
End Time	12:00

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	198.8	0.10	0.20	198.0	45	0.40
Carbon Monoxide	200	0.00	162.6	0.10	0.20	162.2	40	0.25
Oxygen	25	0.00	4.04	0.02	0.12	4.10	42	-1.49

POST-SAMPLING CALIBRATION DATA

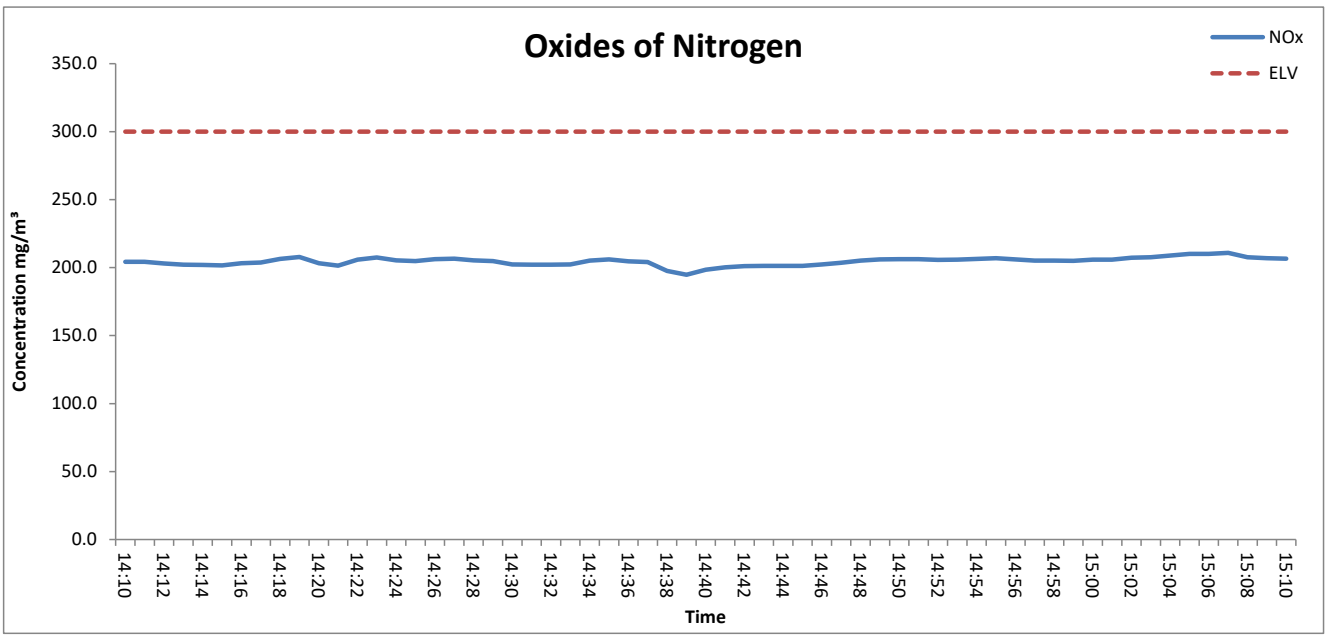
Date	19 October 2021
Start Time	15:15
End Time	15:30

Chiller Temperature (°C)	2.4
Requirement	< 4°C
Compliant	Yes

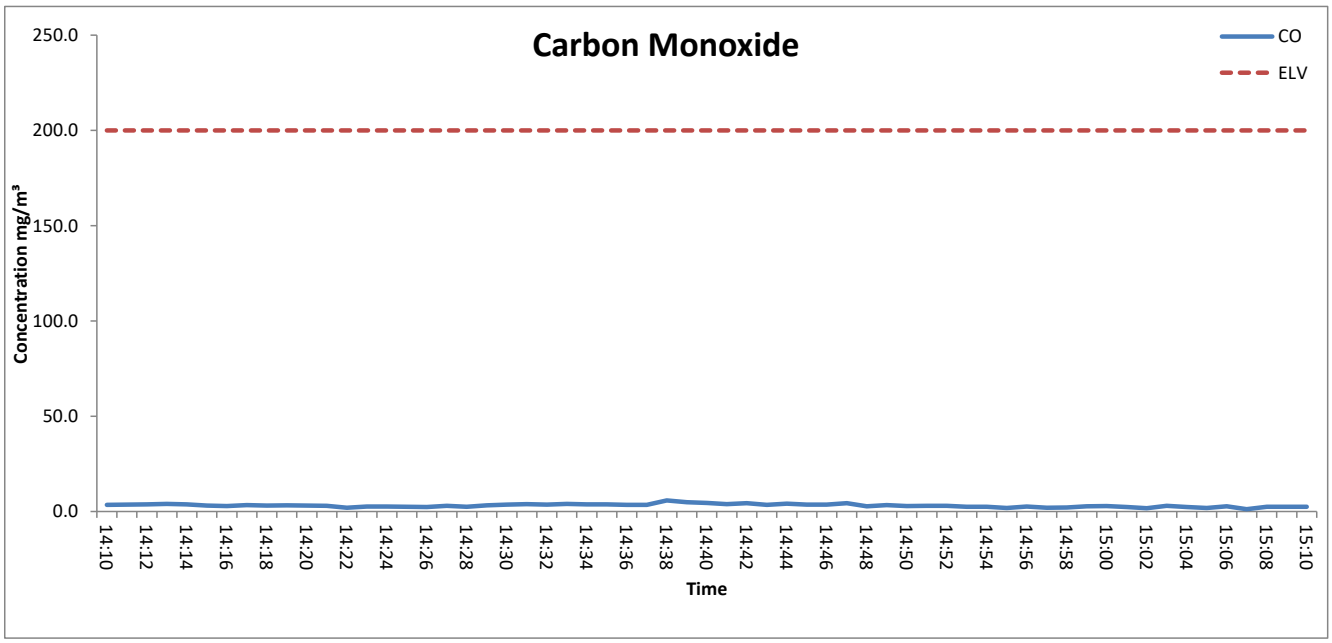
Gas	Zero Check at Analyser	Span Check at Analyser	Zero Drift (%)	Span Drift (%)	Corrected for Zero Drift	Corrected for Span Drift	Corrected Values ppm / %
Nitric Oxide	0.20	197.5	0.05	-0.70	×	×	N/A - not corrected
Carbon Monoxide	-0.70	161.4	-0.49	-0.25	×	×	N/A - not corrected
Oxygen	0.10	4.12	1.99	0.00	×	×	N/A - not corrected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

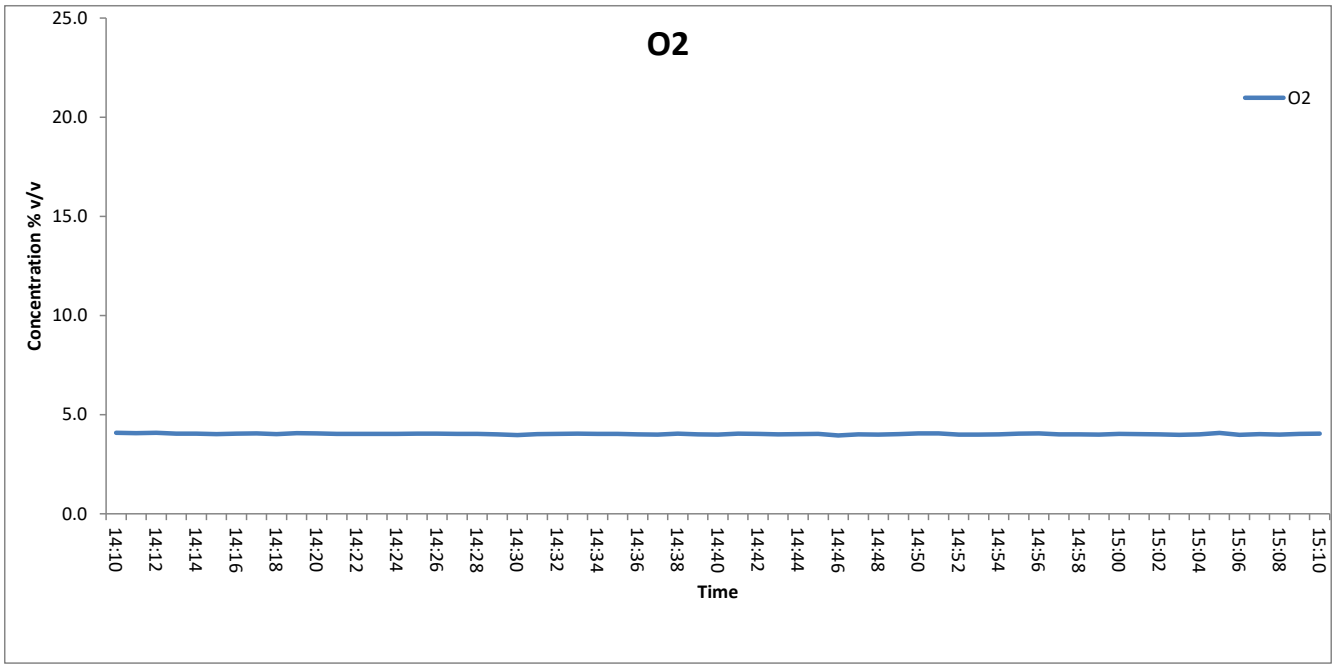
OXIDES OF NITROGEN (as NO_2) EMISSIONS CHART



CARBON MONOXIDE EMISSIONS CHART



OXYGEN EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Isokinetic							
Test Number	Sampling Time and Date	Start Weight kg	End Weight kg	Total gain kg	Concentration %	LOD %	Uncertainty %
Run 1	14:19 - 15:23 19 October 2021	3.4960	3.6498	0.1538	14.7	0.01	3.0

Moisture Quality Assurance							
Test Number	Sampling Duration mins	Total Volume Sampled l	Sampling Rate l/min	Start Leak Rate l/min	End Leak Rate l/min	Acceptable Leak Rate l/min	Leak Tests Acceptable?
Run 1	64	1301	18.6	0.20	-	0.37	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	140	^oC
Stack static pressure	-0.084	kPa
Barometric Pressure	101.8	kPa

Stack Gas Composition & Molecular Weights								
Component	Molar Mass M	Density kg/m^3 p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m^3 pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m^3 pi
CO_2	44	1.963059	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
O_2	32	1.427679	4.023607	0.040236	0.057444	3.430842	0.034308	0.048981
N_2	28	1.249219	95.976393	0.959764	1.198956	81.836980	0.818370	1.022323
H_2O	18	0.803070	-	-	-	14.732178	0.147322	0.118310

Where: p = M / 22.41 p*i* = r x p

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2564	kg/m^3
Wet Density (STP), P_{STW}	1.1896	kg/m^3
Dry Density (Actual), P_{Actual}	0.8339	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.790	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	19 October 2021
Time of Survey	13:25
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	96.0	9.8	140	13.1	26.3	-	-
2	0.17	100.0	10.2	140	13.4	26.9	-	-
3	0.31	101.9	10.4	140	13.5	27.1	-	-
4	0.52	103.9	10.6	140	13.6	27.4	-	-
5	1.08	107.8	11.0	140	13.9	27.9	-	-
6	1.29	105.8	10.8	140	13.8	27.7	-	-
7	1.43	101.9	10.4	140	13.5	27.1	-	-
8	1.55	94.1	9.6	140	13.0	26.1	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	101.4	10.4	140	13.5	27.1	-	-

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	94	92	2.1	Pass	144	144	0.0	Pass

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

S-Type Pitot Stagnation Check				
Run	Stagnation (Pa)	Reference (Pa)	Difference (Pa)	Outcome (Permitted +/- 10 Pa)
Run 1	-80	-88	8.0	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	94	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	13.0	m/s	-	-
Highest Gas Velocity	13.9	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} x (1-e) * O(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	**13.5**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	140	0	°C
Total Pressure	101.716	101.3	kPa
Oxygen	4.0	3	%
Moisture	14.73	0.00	%
Pitot tube calibration coefficient, K_{pt}	0.84		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	13.46	m/s
Stack Area (A)	2.01	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	97428.9	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	64666.6	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	55139.8	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	52076.5	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))

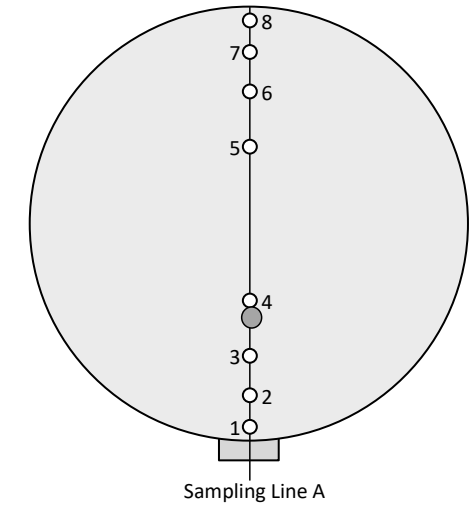
Nomenclature:

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	50	0.80	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	0.2200	-	-
as a %	0.20	0.49	0.49	1.0	2.49	4.20617	1.08	0.018
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	0.74	1.0900	1.1	0.0065	0.0005	-
MU as mg/m^3	0.01	0.2103	0.01	0.0065	0.0005	**0.21**
MU as %	1.25	20.1835	-	0.621	0.0471	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.42**	**mg/m^3**	**40.48**	**% Result**	**8.44**	**% 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 m³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**≤ 5% of ELV**	**<=2%**
Run 1	1.046	296	100.94	1.0	4.024	1.1	-
as a %	0.10	0.68	0.50	1.0	2.49	0.09	1.08
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP) m³	Mass of Sulphur dioxide mg	O2 Correction -	Leak mg/m³	Lab Uncertainty mg	Combined uncertainty
Run 1	0.9630	1.1270	1.0603	0.0047	-	-
MU as mg/m³	0.0100	0.0332	0.0045	0.0047	0.0366	**0.0509**
MU as %	1.3093	4.3526	0.5891	0.6209	4.8	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.10**	**mg/m³**	**13.33**	**% Result**	**0.29**	**% 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 - OXIDES OF NITROGEN

Limit value	300	mg/m^3
Concentration @ Ref conditions	204.5	mg/m^3
Cal gas conc	408	mg/m^3
Analyser Full Scale	513	mg/m^3

	Value	Units	specification	MU Met?
Response time	45	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	0.05	% full scale	<2% range / 24hr	Yes
Span drift	-0.70	% full scale	<2% 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	0.25	% full scale/10K	<3% range / 10 K	Yes
Combined interference	3.00	% range	<4% of Range	Yes
dependence on voltage	0.07	% 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)	0.07	% 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	$U_{d,z}$	0.0295
short term span drift	$U_{d,s}$	-0.4066
influence of Ambient Temp at Zero	$U_{t,z}$	0.0072
influence of Ambient Temp at Span	$U_{t,s}$	0.1299
influence of sample gas pressure	U_p	0.0000
influence of sample gas flow	U_{fit}	0.1732
influence of supply voltage	U_v	0.2076
Combined Interfence	U_i	0.0042
Uncertainty of Cal gas	U_{adj}	1.9880

Measurement uncertainty (Concentration Measured)	204.54	mg/m^3
Combined uncertainty	2.06	mg/m^3
Expanded at a 95% confidence interval	4.05	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**1.35**	**% ELV**

Expanded uncertainty expressed with a level of confidence of 95%	**4.0**	**mg/m^3**

Expanded uncertainty expressed with a level of confidence of 95%	**2.0**	**% 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	3.1	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	-0.49	% full scale	<2% range / 24hr	Yes
Span drift	-0.25	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	0.2	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.44	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence zero / span	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)	0.00	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.00	% of value	< 2% of value	Yes

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

Performance characteristic	Uncertainty	Value of uncertainty quantity
repeatability	$U_r = S_r$	0.003
lack of fit	U_{lof}	0.12
short term zero drift	$U_{d,z}$	0.35
short term span drift	$U_{d,s}$	-0.28
influence of Ambient Temp zero	$U_{t,z}$	-0.02
influence of Ambient Temp span	$U_{t,s}$	0.01
influence of sample gas pressure	U_p	0.00
influence of sample gas flow	U_{fit}	0.14
influence of supply voltage	U_v	-0.09
Combined Interfence	U_i	1.34
Uncertainty of Cal gas	U_{adj}	0.81

Measurement uncertainty (Concentration Measured)	2.9	mg/m^3
Combined uncertainty	1.6	mg/m^3
Expanded uncertainty	3.2	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**1.6**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**3.2**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**109.7**	**% 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	4.02	%vol
Calibration gas	4.04	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	42	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	1.99	% full scale	<2% range / 24hr	Yes
Span drift	0.00	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	0.03	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.05	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	-0.08	% 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	$U_{d,z}$	1.1490
short term span drift	$U_{d,s}$	0.0000
influence of Ambient Temp at Zero	$U_{t,z}$	0.0000
influence of Ambient Temp at Span	$U_{t,s}$	-0.0003
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 Interfence	U_i	0.0485
Uncertainty of Cal gas	U_{adj}	0.0202

Measurement uncertainty (Concentration Measured)	4.02	%
Combined uncertainty	1.15	%
Expanded uncertainty	2.26	%

Expanded uncertainty expressed with a level of confidence of 95%	**2.3**	**%**

Expanded uncertainty expressed with a level of confidence of 95%	**56.15**	**% 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	13.5	m/s
Measured Volumetric Flow rate at Actual Conditions	97429	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	-	0.90		
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	16.57	<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	2.11	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	519		
Uncertainty associated with the estimate of density	-	0.008		
Uncertainty associated with the measurement of local velocity	-	0.0001		
Uncertainty associated with the measurement of mean velocity	-	0.0002		

Measurement Uncertainty - Velocity	m/s
Combined uncertainty	0.17
Expanded uncertainty at a 95% Confidence Interval	0.33

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	2556
Expanded uncertainty at a 95% Confidence Interval	5009

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