STACK EMISSIONS MONITORING REPORT

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

Your contact at SOCOTEC LTD
Dominic Houghton Business Manager - North Tel: 0161 443 0981 Email: dominic.houghton@socotec.com

Operator & Address:
Novidon Coed Aben Road Wrexham Ind Est Wrexham LL13 9UH

Permit Reference:
N/A - Investigative Test

Release Point:
Scrubber

Sampling Date(s):
2nd August 2023

SOCOTEC Job Number:	LNO 17896
Report Date:	8th September 2023
Version:	1
Report By:	Mark Derbyshire
MCERTS Number:	MM 07 824
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Report Approved By:	Johnathon Orley
MCERTS Number:	MM 08 983
Business Title:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Signature:	

1015

CONTENTS

EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Novidon operates a wet scrubber process at Wrexham

SOCOTEC LTD were commissioned by Crestwood Environmental to carry out stack emissions monitoring to determine the release of prescribed pollutants from the following Plant under normal operating conditions.

Plant

Scrubber

Operator

Novidon
Coed Aben Road
Wrexham Ind Est
Wrexham
LL13 9UH

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.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Emission Limit Value (ELV)**	**Accreditation**
Total Particulate Matter Particulate Emission Rate	mg/m³ g/hr	0.99 0.05	0.44 0.02	- -	MCERTS
Total Volatile Organic Compounds Total Volatile Organic Compounds Emission Rate	mg/m³ g/hr	0.35 0.01	1.30 0.04	- -	MCERTS
Oxides of Nitrogen (as NO_2) Oxides of Nitrogen (as NO_2) Emission Rate	mg/m³ g/hr	0.77 0.02	2.3 0.07	- -	MCERTS
Sulphur Dioxide Sulphur Dioxide Emission Rate	mg/m³ g/hr	0.80 0.03	2.2 0.07	- -	MCERTS
Carbon Monoxide Carbon Monoxide Emission Rate	mg/m³ g/hr	1.13 0.04	1.84 0.06	- -	MCERTS
Carbon Dioxide	% v/v	0.01	0.0001	-	MCERTS
Oxygen	% v/v	20.9	0.277	-	MCERTS
Moisture	%	0.14	0.03	-	MCERTS
Stack Gas Temperature	°C	24	-	-	MCERTS
Stack Gas Velocity	m/s	1.5	0.71	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	35	16	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	32	15	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	32	15	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	32	15	-	

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 without correction for water vapour

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
Total Particulate Matter Run 1	02 August 2023	11:40 - 12:40	60 minutes
Total Volatile Organic Compounds Run 1	02 August 2023	11:40 - 12:40	60 minutes
Combustion Gases	02 August 2023	11:40 - 12:40	60 minutes
Preliminary Stack Traverse	02 August 2023	11:20	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Wet Scrubber
Continuous or batch	Batch
Product Details	-
Part of batch to be monitored (if applicable)	Whilst operational
Normal load, throughput or continuous rating	-
Fuel used during monitoring	None
Abatement	Wet Scrubber
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	0.22 mg/m³	45%	N/A - No ELV
Total Volatile Organic Compounds	SRM - BS EN 12619:2013	AE 102	1015	MCERTS	0 mg/m³	372%	N/A - No ELV
Oxides of Nitrogen	SRM - BS EN 14792:2017	AE 102	1015	MCERTS	0.2 mg/m³	296%	N/A - No ELV
Sulphur Dioxide	AM - PD CEN/TS 17021:2017	AE 102	1015	MCERTS	0.8 mg/m³	269%	N/A - No ELV
Carbon Monoxide	SRM - BS EN 15058:2017	AE 102	1015	MCERTS	0.27 mg/m³	163%	N/A - No ELV
Carbon Dioxide	SRM - CEN/TS 17405	AE 102	1015	MCERTS	0.1 %	0.52%	N/A - No ELV
Oxygen	SRM - BS EN 14789:2017	AE 102	1015	MCERTS	0.01%	1.3%	N/A - No ELV
Moisture	BS EN 14790	AE 105	1015	MCERTS	0.01%	23%	N/A - No ELV
Velocity	SRM - EN ISO 16911-1	AE 154	1015	MCERTS	5 Pa	46%	N/A - No ELV
Volumetric Flow Rate	SRM - EN ISO 16911-1	AE 154	1015	MCERTS	-	46.5%	N/A - No ELV

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

EXECUTIVE SUMMARY

Analytical Methods

The following tables list the analytical methods employed together with the custody 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 (Stockport)	N/A	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
Oxides of Nitrogen	Chemiluminescence	AE 102	1015	MCERTS	SOCOTEC (Stockport)	SOCOTEC (Stockport)	5 years
Sulphur Dioxide	Non Dispersive Infra Red	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
Carbon Dioxide	Non Dispersive Infra Red	AE 102	1015	MCERTS	SOCOTEC (Stockport)	SOCOTEC (Stockport)	5 years
Oxygen	Paramagnetic	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	2	Pa	>= 5 Pa	No	BS EN 15259
Lowest Gas Velocity	1.5	m/s	-	-	-
Highest Gas Velocity	1.5	m/s	-	-	-
Ratio of Gas Velocities	1.0	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	1.5	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	0.09	m
Width	-	m
Area	0.01	m^2
Port Depth	0	mm

SAMPLING LINES & POINTS		
	Isokinetic	**Non-Iso & Gases**
Sample port size	9cm	9cm
Number of lines used	1	1
Number of points / line	1	1
Duct orientation	Horizontal	Horizontal
Filtration	Out Stack	Out Stack
Filtration for TPM	Out Stack	-

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

M1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	Yes
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	Yes

Sampling Platform Improvement Recommendations (if applicable)

The sampling location meets all the requirements as specified in EA Guidance Note M1.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

In this instance there were no deviations from the sampling and analytical methods employed.

APPENDICES

CONTENTS

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
Total Volatile Organic Compounds	SRM - BS EN 12619:2013	AE 102	1015	MCERTS	1
Oxides of Nitrogen	SRM - BS EN 14792:2017	AE 102	1015	MCERTS	1
Sulphur Dioxide	AM - PD CEN/TS 17021:2017	AE 102	1015	MCERTS	1
Carbon Monoxide	SRM - BS EN 15058:2017	AE 102	1015	MCERTS	1
Carbon Dioxide	SRM - CEN/TS 17405	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	LNO 13-19	Horiba PG - 350 Analyser	LNO 21-58	Laboratory Balance	LNO 00-33/13
Box Thermocouples	LNO 03-19	FT-IR	-	Tape Measure	LNO 24-MD
Meter In Thermocouple	LNO 03-19	FT-IR Oven Box	-	Stopwatch	LNO 17-MD
Meter Out Thermocouple	LNO 03-19	Bernath 3006 FID	LNO 2107	Protractor	-
Control Box Timer	LNO 17-19	Signal 3030 FID	-	Barometer	LNO 08-MD
Oven Box	LNO 09-14	Servomex	-	Digital Micromanometer	LNO 01-MD
Probe	LNO 11-21	JCT Heated Head Filter	-	Digital Temperature Meter	LNO 03-MD
Probe Thermocouple	LNO 10-21	Thermo FID	-	Stack Thermocouple	LNO 10-MD
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LNO 06-MD	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LNO 14-MD	Chiller (JCT/MAK 10)	LNO 21-105	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	LNO 03-131	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	LNO 31-MD	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-			15m Heated Line (1)	-
Heater Controller	-			20m Heated Line (1)	LNO 18-87
Inclinometer (Swirl Device)	LNO 25-MD			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	HPC 2307	BOC	-	9.88	2.0
Propane	HPC 2178	BOC	80.7	-	2.0
Nitric Oxide	HPC 2253	BOC	40.1	-	2.0
Sulphur Dioxide	HPC 2153	BOC	34.2	-	2.0
Carbon Monoxide	HPC 2153	BOC	80.3	-	2.0
Carbon Dioxide	HPC 2243	BOC	-	8.01	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**
Mark Derbyshire	MM 07 824	MCERTS Level 2	May-26	Nov-26	Apr-27	May-28	Jul-27	Feb-27
Oliver Denty	MM22 1747	MCERTS Trainee	Sep-27	-	-	-	-	Sep-27

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	11:40 - 12:40 02 August 2023	0.99	0.44	-	0.05
Blank	-	1.4	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour

Acetone Blank Value mg/l	Acceptable Value mg/l
0.33	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	G4983	0.10426	0.10435	0.00009	61.35040	61.35120	0.00080	0.00089

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	G4956	0.10962	0.10966	0.00004	72.56380	72.56500	0.00120	0.00124

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	101.9
Stack static pressure, P_{static}	pa	5.0
$P_s = P_b + P_{static}$	Kpa	101.9
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	1.0
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.001246
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		1.002
Gas meter correction factor, Y_d		0.964
Mean dry gas meter temperature, T_m		295
Mean pressure drop across orifice, DH	mmH_2O	23.205
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$	m^3	0.901
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9022
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		20.9
% oxygen reference condition		21
O_2 Reference Factor O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		No O2 Ref
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	No O2 Ref
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0014
	%	0.14
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Velocity pressure coefficient, C_p		0.84
Mean of velocity heads, DP_{avg}	Pa	3.92
Mean stack gas temperature, T_s	K	297
Gas density $_{(wet,\ ambient)}$, p		
p=(Ms*Ps)/(8.314*Ts)	kg/m^3	1.190
Stack Velocity, Vs $V_s = \frac{\sum_{i=1}^{n} V_i}{n}$	m/s	2.16

Molecular weight of dry gas, M_d		
CO_2	%	0.01
O_2	%	20.90
Total	%	20.91
N_2 (100 -Total)	%	79.09
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.84
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.82
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.01
$Q_a = (60)(A_s)(V_s)$	m^3/min	0.8
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	0.8
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$	@O_2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$	Wet	0.76
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	11.82
Nozzle area, A_n	mm^2	109.74
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	114.3
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00009
Mass collected in probe, M_p	g	0.00080
Total mass collected, M_n	g	0.00089
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	0.986
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	0.988
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	No O2 Ref
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.05

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER QUALITY ASSURANCE CHECKLIST

LEAK RATE						
Run	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable?
Run 1	16.10	0.11	-	9753.6	0.32	Yes

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

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	114.29	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m³	5% ELV mg/m³	LOD < 5% ELV
Run 1	0.22	No ELV	N/A - No ELV

The above is based on both the Filter and rinse uncertainty

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	1.37	-	-	-

FILTERS					
Run	Filter Material	Filter Size mm	Max Filtration Temperature °C	Pre-use Filter Conditioning Temperature °C	Post-use Filter Conditioning Temperature °C
Run 1	Glass Fibre	47	0	180	160

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL VOLATILE ORGANIC COMPOUNDS SUMMARY

Test	Sampling Times	Concentration mg/m³	LOD mg/m³	ELV mg/m³	Emission Rate g/hr
Run 1	11:40 - 12:40 02 August 2023	0.35	0.40	-	0.01

Reference conditions are 273K, 101.3kPa without correction for water vapour

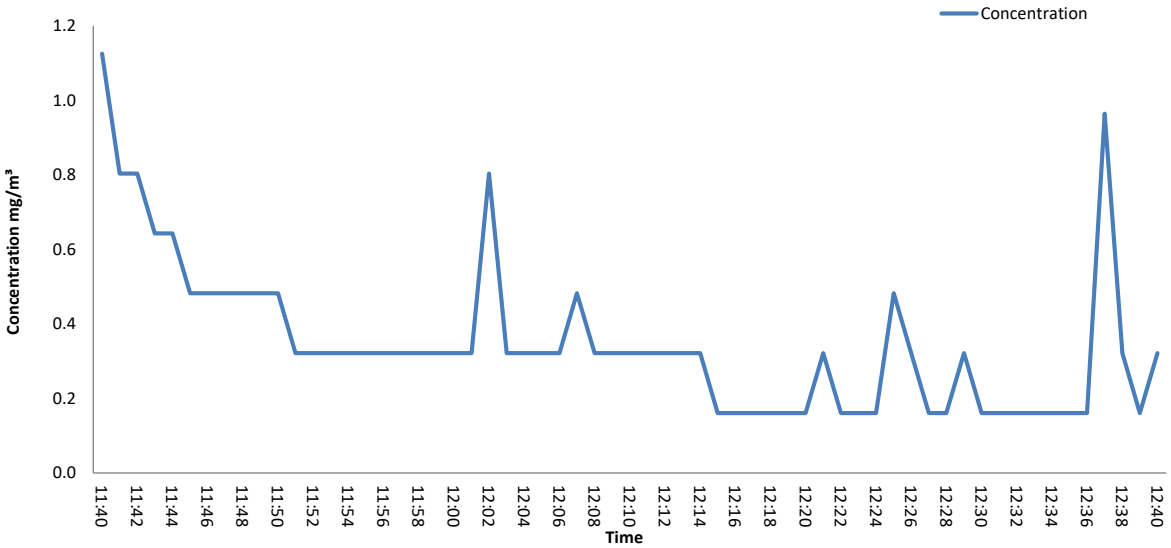
INSTRUMENTAL SPAN & ZERO CHECKS

PRE-SAMPLING CALIBRATION CHECKS								
Date	02 August 2023							
Start Time	11:15							
End Time	11:25							
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	0.01	0.03	80.6	0.12

Zero and Span gas contained 20% Oxygen

POST-SAMPLING CALIBRATION CHECKS								
Date	02 August 2023							
Start Time	15:50							
End Time	16:01							
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	0.41	0.11	79.9	0.10	-0.97	×	×	N/A - not corrected

TOTAL VOLATILE ORGANIC COMPOUNDS EMISSIONS CHART



Reference conditions are 273K, 101.3kPa without correction for water vapour

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	11:40 - 12:40 02 August 2023	0.77	0.20	-	0.02
Sulphur Dioxide	11:40 - 12:40 02 August 2023	0.80	0.80	-	0.03
Carbon Monoxide	11:40 - 12:40 02 August 2023	1.1	0.27	-	0.04

Test	Sampling Time and Date	Concentration %	LOD %
Carbon Dioxide	11:40 - 12:40 02 August 2023	0.10	0.100
Oxygen	11:40 - 12:40 02 August 2023	21.0	0.01

Reference conditions are 273K, 101.3kPa without correction for water vapour

PRE-SAMPLING CALIBRATION DATA

Date	02 August 2023
Start Time	11:10
End Time	11:24

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	100	0.00	40.1	0.02	0.03	40.1	15	-0.02
Sulphur Dioxide	200	0.00	34.2	0.03	0.05	34.1	15	0.29
Carbon Monoxide	200	0.00	80.3	0.06	0.07	80.1	15	0.25
Carbon Dioxide	10	0.00	8.01	0.02	0.05	8.00	15	0.12
Oxygen	25	0.00	9.88	0.01	0.03	9.87	15	0.10

POST-SAMPLING CALIBRATION DATA

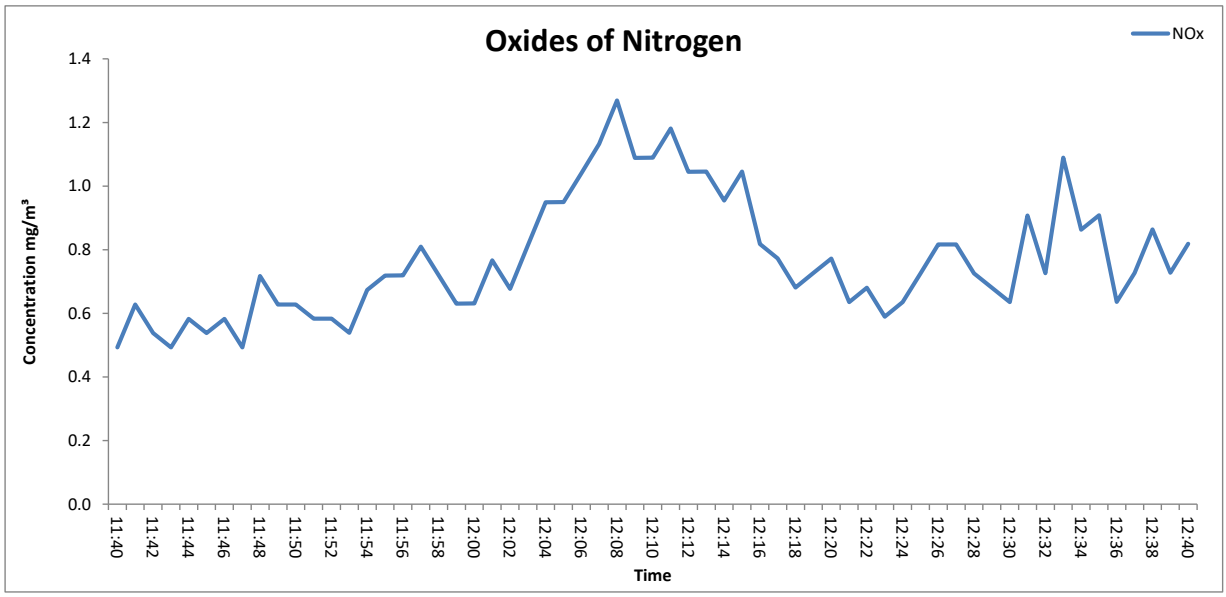
Date	02 August 2023
Start Time	15:50
End Time	16:08

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

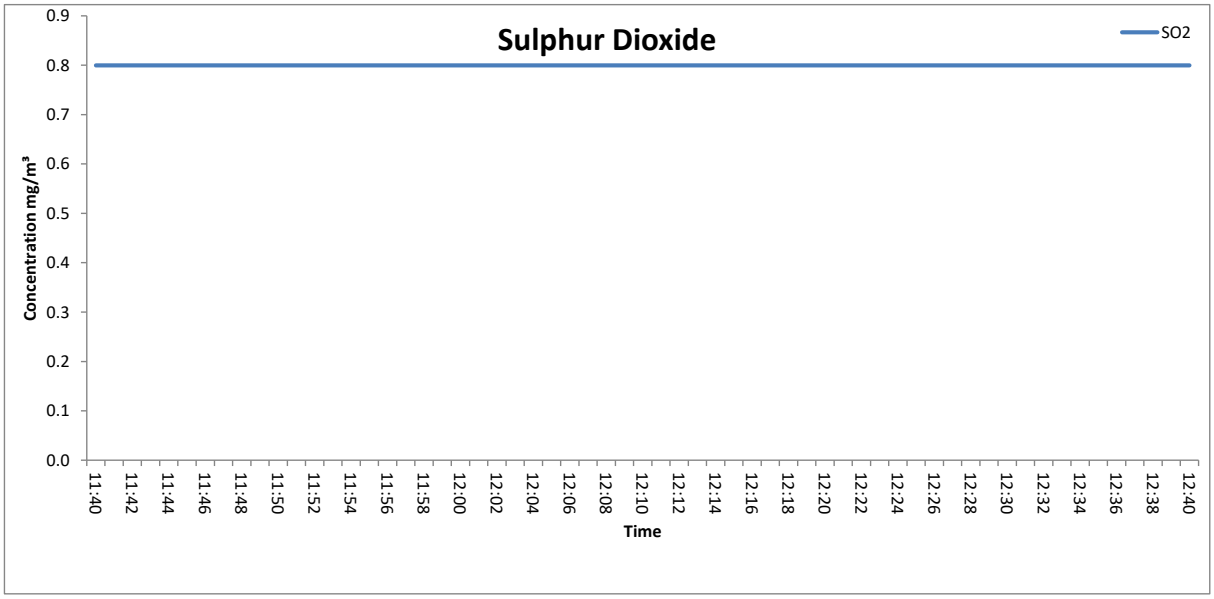
Gas	Zero Check at Analyser	Span Check at Analyser	Zero Drift (%)	Span Drift (%)	Corrected for Zero Drift	Corrected for Span Drift	Corrected Values ppm / %
Nitric Oxide	0.18	39.9	0.40	-0.90	×	×	N/A - not corrected
Sulphur Dioxide	0.14	34.0	0.33	-0.91	×	×	N/A - not corrected
Carbon Monoxide	0.90	80.1	1.06	-1.30	×	×	N/A - not corrected
Carbon Dioxide	0.10	8.00	1.02	-1.12	×	×	N/A - not corrected
Oxygen	0.08	9.86	0.72	-0.91	×	×	N/A - not corrected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

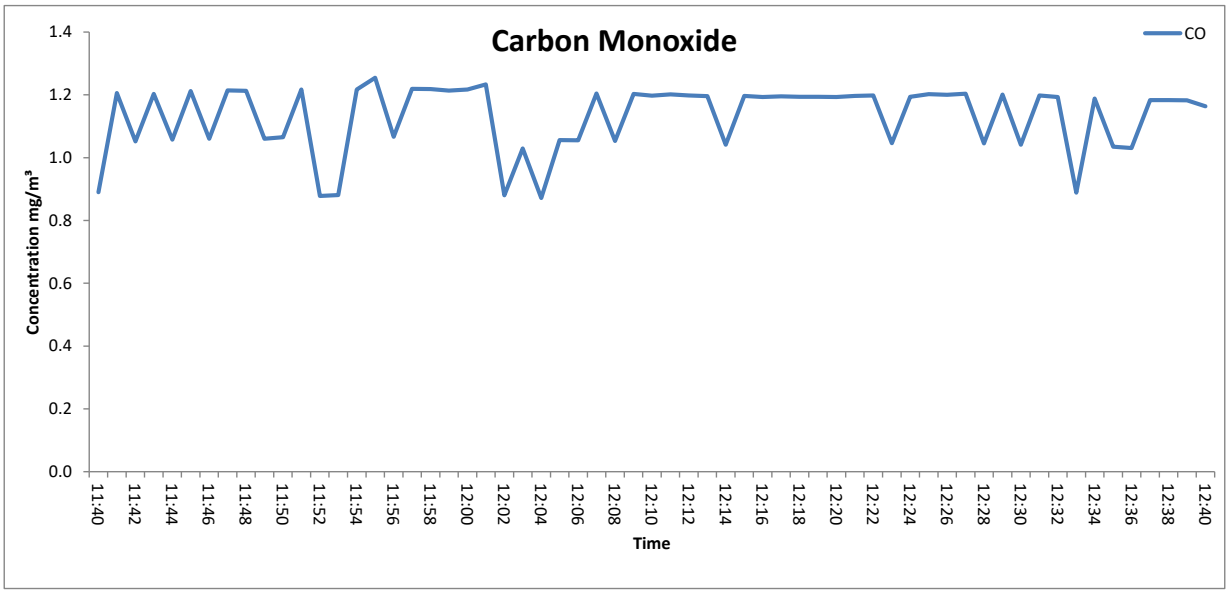
OXIDES OF NITROGEN (as NO_2) EMISSIONS CHART



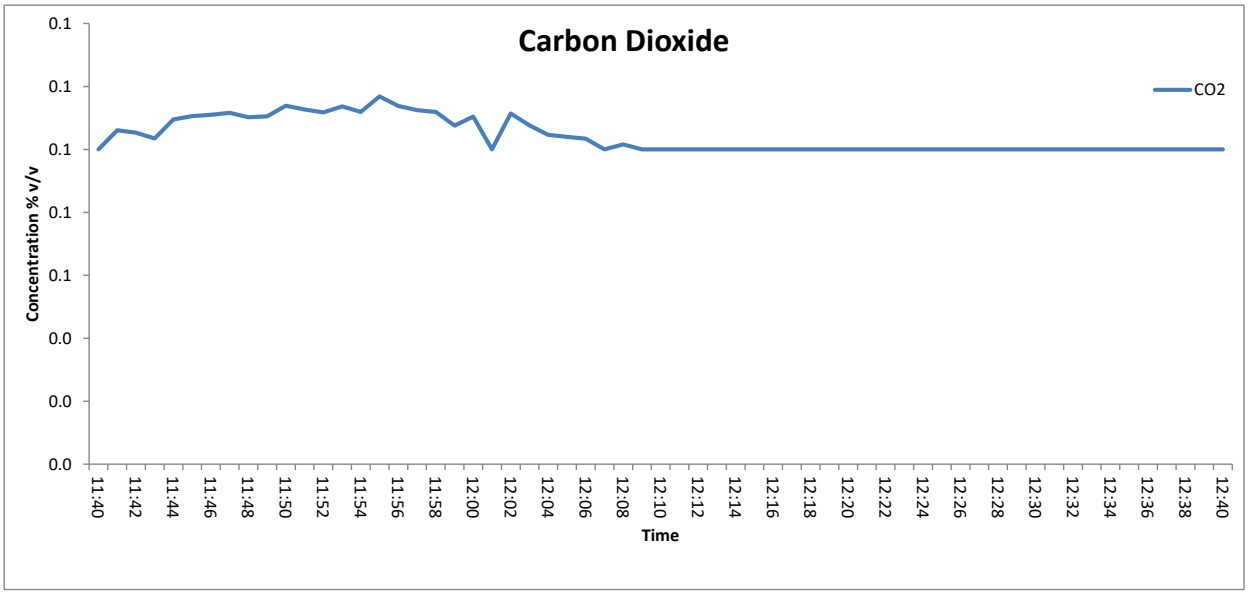
SULPHUR DIOXIDE EMISSIONS CHART



CARBON MONOXIDE EMISSIONS CHART

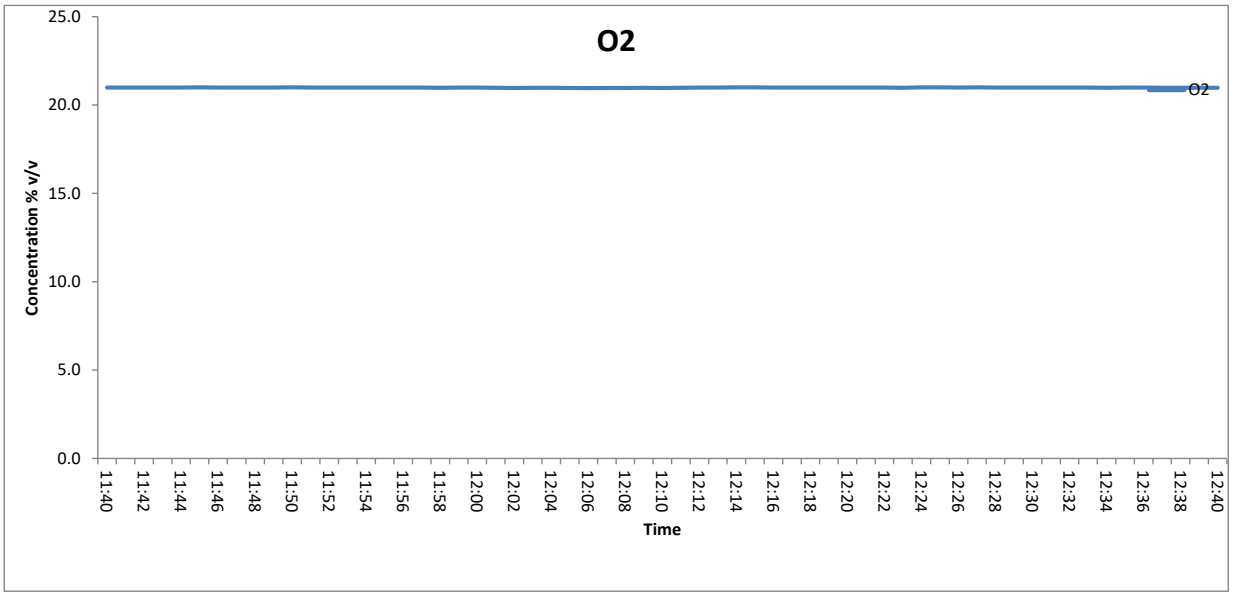


CARBON DIOXIDE EMISSIONS CHART



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	11:40 - 12:40 02 August 2023	3.1253	3.1263	0.0010	0.1	0.01	23.3

Moisture Quality Assurance							
Test Number	Sampling Duration mins	Total Volume Sampled l	Sampling Rate l/min	Start Leak Rate l/min	End Leak Rate l/min	Acceptable Leak Rate l/min	Leak Tests Acceptable?
Run 1	60	902	16.1	0.11	-	0.32	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.09	m
Stack Width, W	-	m
Stack Area, A	0.01	m^2
Average stack gas temperature	24	^oC
Stack static pressure	0.005	kPa
Barometric Pressure	101.9	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	0.011429	0.000114	0.000224	0.011413	0.000114	0.000224
O_2	32	1.427679	20.928582	0.209286	0.298793	20.899679	0.208997	0.298380
N_2	28	1.249219	79.059990	0.790600	0.987633	78.950807	0.789508	0.986269
H_2O	18	0.803070	-	-	-	0.138101	0.001381	0.001109

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2866	kg/m^3
Wet Density (STP), P_{STW}	1.2860	kg/m^3
Dry Density (Actual), P_{Actual}	1.1897	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	1.189	kg/m^3

Where:

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

P_{STW} = (P_{STD} + p*i* of H_2O) / (1 + (p*i* 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	02 August 2023
Time of Survey	11:20
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	0.04	2.0	0.2	24	1.5	0.0	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	2.0	0.2	24	1.5	0.0	-	-

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	137	135	1.5	Pass	149	147	1.3	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	5	5	0.0	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	2	Pa	>= 5 Pa	No
Lowest Gas Velocity	1.5	m/s	-	-
Highest Gas Velocity	1.5	m/s	-	-
Ratio of Gas Velocities	1.0	-	< 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	**1.5**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	24	0	°C
Total Pressure	101.905	101.3	kPa
Oxygen	20.9	21	%
Moisture	0.14	0.14	%
Pitot tube calibration coefficient, K_{pt}	0.84		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	1.53	m/s
Stack Area (A)	0.01	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	35.01	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	32.37	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	32.33	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	32.37	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))

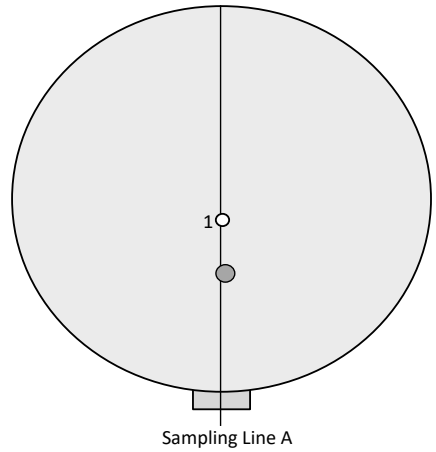
Nomenclature:
Ts = Absolute Temperature, Standard Conditions, 273 K
Ps = Absolute Pressure, Standard Conditions, 101.3 kPa
Ta = Absolute Temperature, Actual Conditions, K
Pa = Absolute Pressure, Actual Conditions, kPa
Ma = Water vapour, Actual Conditions, % Vol
Ms = Water vapour, Reference Conditions, % 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	0.09	m
Stack Width	-	m
Area	0.01	m^2

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	40	0.04	m



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

Isokinetic Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	44.4	0.04	< 15
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

SAMPLING LOCATION

Scrubber Vent

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	N/A	0.2000	-	-
as a %	0.20	0.67	0.49	1.0	N/A	N/A	0.68	N/A
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**N/A**	**Yes**	**N/A**

Run	Volume (STP)	Mass of particulate	O_2 Correction	Leak	Uncollected Mass	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	0.83	0.8900	1.0	0.0039	0.0007	-
MU as mg/m^3	0.01	0.2217	-	0.0039	0.0008	**0.22**
MU as %	1.32	22.4719	-	0.394	0.0804	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.44**	**mg/m^3**	**45.03**	**% Result**	**N/A**	**% 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	0.002	2.0	0.50	1.0	N/A	-
as a %	0.20	0.67	0.49	1.0	N/A	0.68
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m^3	Mass Gained mg	O_2 Correction -	Leak mg/m^3	Uncollected Mass mg	Combined uncertainty
Run 1	0.83	1000	1.0	4.38	58	-
MU as % v/v	0.00	0.01	-	0.00	0.008	**0.02**
MU as %	1.32	10.00	-	0.39	5.77	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**% v/v**	**23**	**%**

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 1

Measured Concentration	0.4	mg/m^3
Limit	-	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	10	seconds	<180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	60	minutes	-	-
Number of readings in measurement	60	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	Yes
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.70	% of value	<2 % range	Yes
Zero drift	0.10	% full scale	<5% range / 24hr	Yes
Span drift	-0.97	% 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)	0.12	% of value	< 2% of span gas value	Yes
Uncertainty of calibration gas	1.0	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	0.02
Standard deviation of repeatability at span level	urs	0.02
Lack of fit	ufit	0.65
Drift	u0dr	0.06
volume or pressure flow dependence	uspres	0.00
atmopsheric pressure dependence	uapres	0.04
ambient temperature dependence	utemp	0.00
Dependence on voltage	uvolt	0.14
losses in the line (leak)	uleak	0.00
Uncertainty of calibration gas	ucalib	0.00
Uncertainty in factor	uf	0.00

Measurement uncertainty Measured Concentration	0.35	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%	**-**	**% 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%	**372**	**% value**

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXIDES OF NITROGEN

Limit value	-	mg/m^3
Concentration @ Ref conditions	0.8	mg/m^3
Cal gas conc	82	mg/m^3
Analyser Full Scale	205	mg/m^3

	Value	Units	specification	MU Met?
Response time	15	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	0.40	% full scale	<5% range / 24hr	Yes
Span drift	-0.90	% full scale	<5% range / 24hr	Yes
volume or pressure flow dependence	0.1	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.10	% 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	-0.01	% range	<4% of Range	Yes
dependence on voltage	0.00	% 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)	0.00	% 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	$U_{d,z}$	0.2328
short term span drift	$U_{d,s}$	-0.5183
influence of Ambient Temp at Zero	$U_{t,z}$	0.0000
influence of Ambient Temp at Span	$U_{t,s}$	0.9000
influence of sample gas pressure	U_p	0.0000
influence of sample gas flow	U_{fit}	0.0693
influence of supply voltage	U_v	0.0003
Combined Interfence	U_i	-0.0018
Uncertainty of Cal gas	U_{adj}	0.4010

Measurement uncertainty (Concentration Measured)	0.77	mg/m^3
Combined uncertainty	1.16	mg/m^3
Expanded at a 95% confidence interval	2.28	mg/m^3

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

Expanded uncertainty expressed with a level of confidence of 95%	**2.3**	**mg/m^3**

Expanded uncertainty expressed with a level of confidence of 95%	**296**	**% value**

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - SULPHUR DIOXIDE

Limit value	-	mg/m^3
Concentration @ Ref conditions	0.8	mg/m^3
Cal gas conc	97.128	mg/m^3
Analyser Full Scale	572	mg/m^3

Performance characteristics	Value	Units	specification	MU Met?
Response time	15	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	60	minutes	-	-
Number of readings in measurement	60	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	Yes
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.70	% of value	<2 % range	Yes
Zero drift	0.65	% full scale	<5% range / 24hr	Yes
Span drift	-1.81	% full scale	<5% range / 24hr	Yes
volume or pressure flow dependence	0.6	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.00	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence zero / span	0.0021	% full scale/10K	<3% range / 10 K	Yes
Cross-sensitivity	0.00	% range	<4% of Range	Yes
dependence on voltage	-0.05	% full scale/10V	< 0.1%vol /10 volt	Yes
Influence of vibration	N/A	% of upper limit of Cal range	<2%	-

Uncertainty of calibration gas	% of value	Value of uncertainty quantity
repeatability	$U_r = S_r$	0.008
lack of fit	U_{lof}	0.404
short term zero drift	$U_{d,z}$	0.144
short term span drift	$U_{d,s}$	0.087
influence of Ambient Temp at Zero	$U_{t,z}$	-0.906
influence of Ambient Temp at Span	$U_{t,s}$	0.001
influence of sample gas pressure	U_p	0.000
influence of sample gas flow	U_{fit}	0.416
influence of supply voltage	U_v	-0.156
Combined Interfence	U_i	0.000
Uncertainty of Cal gas	U_{adj}	0.004

Measurement uncertainty (Concentration Measured)	0.8	mg/m^3
Combined uncertainty	1.1	mg/m^3
Expanded uncertainty	2.2	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**-**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**2.2**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**269**	**% value**

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON MONOXIDE

Limit value	-	mg/m^3
Concentration @ Ref conditions	1.1	mg/m^3
Cal gas conc	100.4	mg/m^3
Analyser Full Scale	250	mg/m^3

Performance characteristics	Value	Units	specification	MU Met?
Response time	15	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	1.06	% full scale	<5% range / 24hr	Yes
Span drift	-1.30	% 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)	0.00	% 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	$U_{d,s}$	0.61
influence of Ambient Temp zero	$U_{t,z}$	-0.36
influence of Ambient Temp span	$U_{t,s}$	0.18
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	-0.15
Uncertainty of Cal gas	U_{adj}	0.40

Measurement uncertainty (Concentration Measured)	1.1	mg/m^3
Combined uncertainty	0.9	mg/m^3
Expanded uncertainty	1.8	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**-**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**1.8**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**163**	**% value**

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON DIOXIDE

Limit value	-
Measured concentration	0.10
Calibration gas	8.01
Analyser Full Scale	10

Performance characteristics	Value	Units	specification	MU Met?
Response time	15	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	60.00000001	minutes	-	-
Number of readings in measurement	60.00000001	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.1	% vol at zero level	<5% range / 24hr	Yes
Span drift (during measurement period)	-0.11	% vol at span level	<5% range / 24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.56	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.124843945	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001807392
Lack of fit	ufit	0.0751
Drift	u0dr	0.05690997
volume or pressure flow dependence	uspres	0.0000
atmospheric pressure dependence	uapres	0.004888081
ambient temperature dependence	utemp	0.0005
Combined interference (from mcerts)	-	0.032331615
dependence on voltage	uvolt	0.086
losses in the line (leak)	uleak	7.50052E-05
Uncertainty of calibration gas	ucalib	0.000600792

Measurement uncertainty	0.10	%vol
Combined uncertainty	0.13	%vol
Expanded uncertainty	0.26	%

Expanded uncertainty expressed with a level of confidence of 95%	**0.52**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**497**	**% vol**

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

Reference	N/A	%vol
Reported Concentration	20.99	%vol
Calibration gas	9.88	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	15	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	0.72	% full scale	<5% range / 24hr	Yes
Span drift	-0.91	% 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	$U_{d,z}$	0.4138
short term span drift	$U_{d,s}$	-0.5259
influence of Ambient Temp at Zero	$U_{t,z}$	0.0013
influence of Ambient Temp at Span	$U_{t,s}$	0.0022
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	0.0017
Uncertainty of Cal gas	U_{adj}	0.0494

Measurement uncertainty (Concentration Measured)	20.99	%
Combined uncertainty	0.68	%
Expanded uncertainty	1.32	%

Expanded uncertainty expressed with a level of confidence of 95%	**1.3**	**%**
Expanded uncertainty expressed with a level of confidence of 95%	**6.3**	**% vol**

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	1.5	m/s
Measured Volumetric Flow rate at Actual Conditions	35	m³/hr

Performance Characteristics & Source of Value	Units	Values	Requirement	Compliant
Uncertainty of Local Gas Velocity Determination				
Uncertainty of pitot tube coefficient	-	0.010		
Uncertainty of mean local dynamic pressures	-	0.34		
Factor loading, function of the number of measurements.	3 readings	0.591	minimum 3	Yes
Range of measurment device	pa	1000		
Resolution	pa	1.00		
Calibration uncertainty	pa	2.24	<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	0.00003		
Uncertainty of temperature measurement	K	1.52	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	520		
Uncertainty associated with the calculation of density	kg/m3	0.007		
Uncertainty associated with the measurement of local velocity	-	0.0001		
Uncertainty associated with the measurement of mean velocity	-	0.0558		

Measurement Uncertainty - Velocity	m/s
Combined uncertainty	0.36
Expanded uncertainty at a 95% Confidence Interval	0.71

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	23.6
Expanded uncertainty at a 95% Confidence Interval	46.3

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	8
Expanded uncertainty at a 95% Confidence Interval	16

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	23.7
Expanded uncertainty at a 95% Confidence Interval	46.5

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