

STACK EMISSIONS MONITORING REPORT



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Operator & Address:
Camira Fabrics Holmfirth Dyers Ribbledon Dye Works Dunford Road Holmfirth West Yorkshire HD9 2DP

Permit Reference:
N/A - Investigative Test

Release Point:
Tenter Abatement System - Wool (non FR Treated)

Sampling Date(s):
22nd October 2019

SOCOTEC Job Number:	LNO 15349
Report Date:	29th November 2019
Version:	1
Report By:	Keith Bird
MCERTS Number:	MM 07 825
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Report Approved By:	Scott Wilson
MCERTS Number:	MM 03 327
Business Title:	MCERTS Level 2 - FTIR Manager
Technical Endorsements:	1, 2, 3 & 4
Signature:	



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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Camira Fabrics operates a fabric dyeing process at Holmfirth Dyers

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

Plant

Tenter Abatement System - Wool (non FR Treated)

Operator

Camira Fabrics
Holmfirth Dyers
Ribblesdon Dye Works
Dunford Road
Holmfirth
West Yorkshire
HD9 2DP

No Permit Applicable: Investigative

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

EMISSIONS SUMMARY					
Parameter	Units	Result	Calculated Uncertainty +/-	Emission Limit Value (ELV)	MCERTS accredited result
Total Particulate Matter	mg/m ³	1.6	0.55	-	✓
Particulate Emission Rate	g/hr	38	13	-	✓
Hydrogen Chloride	mg/m ³	0.33	0.04	-	✓
Hydrogen Chloride Emission Rate	g/hr	8.0	1.0	-	✓
Formaldehyde	mg/m ³	0.19	0.05	-	✓
Formaldehyde Emission Rate	g/hr	4.6	1.1	-	✓
Ammonia	mg/m ³	0.52	0.25	-	✓
Ammonia Emission Rate	g/hr	11.0	5.2	-	✓
Formic Acid	mg/m ³	0.27	0.31	-	✗
Formic Acid Emission Rate	g/hr	5.6	6.5	-	✗
Acetic Acid	mg/m ³	0.27	0.31	-	✗
Acetic Acid Emission Rate	g/hr	5.6	6.5	-	✗
VOC Screening	mg/m ³	0.33	0.14	-	✗
VOC Screening Emission Rate	g/hr	7.0	2.9	-	✗
Total Volatile Organic Compounds	mg/m ³	8.8	1.3	-	✓
Total Volatile Organic Compounds Emission Rate	g/hr	185	28	-	✓
Oxides of Nitrogen (as NO ₂)	mg/m ³	4.5	3.3	-	✓
Oxides of Nitrogen (as NO ₂) Emission Rate	g/hr	96	70	-	✓
Sulphur Dioxide	mg/m ³	9.3	1.8	-	✓
Sulphur Dioxide Emission Rate	g/hr	197	38	-	✓
Carbon Monoxide	mg/m ³	21	3.1	-	✓
Carbon Monoxide Emission Rate	g/hr	436	65	-	✓
Carbon Dioxide	% v/v	0.64	0.004	-	✓
Oxygen	% v/v	20.3	0.35	-	✓
Moisture	%	3.4	0.10	-	✓
Stack Gas Temperature	°C	43	-	-	✓
Stack Gas Velocity	m/s	10.9	0.26	-	
Gas Volumetric Flow Rate (Actual)	m ³ /hr	24871	1274	-	
Gas Volumetric Flow Rate (STP, Wet)	m ³ /hr	21073	1079	-	
Gas Volumetric Flow Rate (STP, Dry)	m ³ /hr	20351	1042	-	
Gas Volumetric Flow Rate at Reference Conditions	m ³ /hr	21073	1079	-	

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	22 October 2010	12:40 - 13:12	32 minutes
Hydrogen Chloride Run 1	22 October 2019	12:40 - 13:12	32 minutes
Formaldehyde Run 1	22 October 2010	12:40 - 13:12	32 minutes
Ammonia Run 1	22 October 2019	13:30 - 14:00	30 minutes
Formic Acid Run 1	22 October 2019	13:20 - 13:50	30 minutes
Acetic Acid Run 1	22 October 2019	13:58 - 14:28	30 minutes
VOC Screening Run 1	22 October 2019	12:40 - 13:10	30 minutes
Total Volatile Organic Compounds Run 1	22 October 2019	12:30 - 14:30	120 minutes
Combustion Gases	22 October 2019	12:30 - 14:30	120 minutes
Preliminary Stack Traverse	22 October 2019	09:40	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Fabric dyeing
Continuous or batch	Batch
Product Details	Wool Non FR Treated Unitech 2
Part of batch to be monitored (if applicable)	During normal running
Normal load, throughput or continuous rating	Normal Load
Fuel used during monitoring	N/A
Abatement	ESP
Plume Appearance	Not visible from sampling location

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 Note (Monitoring) M2.

MONITORING METHODS							
Species	Method Standard Reference Method / Alternative Method	SOCOTEC Technical Procedure	UKAS Lab Number	MCERTS Accredited Method	Limit of Detection (LOD)	Calculated MU +/- % Result	Calculated MU +/- % ELV
Total Particulate Matter	SRM - BS EN 13284-1	AE 104	1015	Yes	0.27 mg/m ³	35%	N/A - No ELV
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	0.01 mg/m ³	12.6%	N/A - No ELV
Formaldehyde	US EPA Method 316	AE114	1015	Yes	0.01 mg/m ³	24.5%	N/A - No ELV
Ammonia	SRM - BS EN 14791	AE 115	1015	Yes	0.067 mg/m ³	47.7%	N/A - No ELV
Formic Acid	SRM - PD CEN-TS 13649:2014	AE 118	1015	Yes	0.133 mg/m ³	115.9%	N/A - No ELV
Acetic Acid	SRM - PD CEN-TS 13649:2014	AE 118	1015	Yes	0.133 mg/m ³	115.9%	N/A - No ELV
VOC Screening	SRM - PD CEN-TS 13649:2014	AE 118	1015	Yes	0.067 mg/m ³	41.7%	N/A - No ELV
Total Volatile Organic Compounds	SRM - BS EN 12619:2013	AE 102	1015	Yes	0.64 mg/m ³	14.9%	N/A - No ELV
Oxides of Nitrogen	SRM - BS EN 14792:2017	AE 102	1015	Yes	0.4 mg/m ³	73.0%	N/A - No ELV
Sulphur Dioxide	AM - PD CEN/TS 17021:2017	AE 102	1015	Yes	0.77 mg/m ³	19.1%	N/A - No ELV
Carbon Monoxide	SRM - BS EN 15058:2017	AE 102	1015	Yes	0.27 mg/m ³	14.9%	N/A - No ELV
Carbon Dioxide	SRM - ISO 12039	AE 102	1015	Yes	0.003 %	0.6%	N/A - No ELV
Oxygen	AM - BS EN 14789:2017	AE 102	1015	Yes	0.01%	1.7%	N/A - No ELV
Moisture	SRM - BS EN 14790	AE 105	1015	Yes	0.02%	2.84%	N/A - No ELV
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	5 Pa	2.4%	N/A - No ELV
Volumetric Flow Rate	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	-	5.1%	N/A - No ELV
-	-	-	-	-	-	-	-

BS EN 14790 has been validated over a range of 4 - 40%. It is however the preferred 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	UKAS Accredited Lab Analysis	Analysis Lab	Analysis Report number	Archive Period
Total Particulate Matter	Gravimetric	AE 106	1015	Yes	SOCOTEC (Stockport)	N/A	8 Weeks
Hydrogen Chloride	Ion Chromatography	C27(U)	1252	Yes	RPS	WK19-10263	8 Weeks
Formaldehyde	Ion Chromatography	M103(U)	0605	Yes	RPS	WK19-10263	8 Weeks
Ammonia	Ion Chromatography	ASC/SOP/108	1252	Yes	SOCOTEC (Bretby)	ASC/41699	8 Weeks
Formic Acid	Ion Chromatography	C28(N)	0605	No	RPS	WK19-10662	8 Weeks
Acetic Acid	Ion Chromatography	C28(N)	0605	No	RPS	WK19-10662	8 Weeks
VOC Screening	GC-MS	IHM	1252	No	SOCOTEC (Bretby)	ASC/41700	8 Weeks

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

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	Value	Units	Requirement	Compliant	Method
Lowest Differential Pressure	78	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	10.6	m/s	-	-	-
Highest Gas Velocity	11.1	m/s	-	-	-
Ratio of Gas Velocities	1.1	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	10.9	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	0.90	m
Width	-	m
Area	0.64	m ²
Port Depth	90	mm

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

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

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	N/A
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

Sampling Points

The upper sample port was not used for the isokinetic tests due to the glassware being used. Therefore the number of sample points was doubled on the available line used.

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APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

APPENDIX 3 - Measurement Uncertainty Budget Calculations

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	Method Standard Reference Method / Alternative Method	SOCOTEC Technical Procedure	UKAS Lab Number	MCERTS Accredited Method	Number of Samples
Total Particulate Matter	SRM - BS EN 13284-1	AE 104	1015	Yes	1
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	1
Formaldehyde	US EPA Method 316	AE114	1015	Yes	1
Ammonia	SRM - BS EN 14791	AE 115	1015	Yes	1
Formic Acid	SRM - PD CEN-TS 13649:2014	AE 118	1015	Yes	1
Acetic Acid	SRM - PD CEN-TS 13649:2014	AE 118	1015	Yes	1
VOC Screening	SRM - PD CEN-TS 13649:2014	AE 118	1015	Yes	1
Total Volatile Organic Compounds	SRM - BS EN 12619:2013	AE 102	1015	Yes	1
Oxides of Nitrogen	SRM - BS EN 14792:2017	AE 102	1015	Yes	1
Sulphur Dioxide	AM - PD CEN/TS 17021:2017	AE 102	1015	Yes	1
Carbon Monoxide	SRM - BS EN 15058:2017	AE 102	1015	Yes	1
Carbon Dioxide	SRM - ISO 12039	AE 102	1015	Yes	1
Oxygen	AM - BS EN 14789:2017	AE 102	1015	Yes	1
Moisture	SRM - BS EN 14790	AE 105	1015	Yes	1
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	1

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

CALIBRATEABLE EQUIPMENT CHECKLIST					
Extractive Sampling		Instrumental Analyser/s		Miscellaneous	
Equipment	Equipment I.D.	Equipment	Equipment I.D.	Equipment	Equipment I.D.
Control Box DGM	LNO 13-21	Horiba PG-250 Analyser	LNO 21-12	Laboratory Balance	LNO 00-12 / 00-13
Box Thermocouples	LNO 03-21	FT-IR Gasmeter	-	Tape Measure	LNO 24-KB
Meter In Thermocouple	-	FT-IR Oven Box	-	Stopwatch	LNO 17-KB
Meter Out Thermocouple	-	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17-21	Signal 3030 FID	-	Barometer	LNO 08-KB
Oven Box	LNO 09-12	Servomex	-	Digital Micromanometer	LNO 01-KB
Probe	LNO 11-26	JCT Heated Head Filter	-	Digital Temperature Meter	LNO 03-KB
Probe Thermocouple	LNO 10-26	Thermo FID	LNO 21-03	Stack Thermocouple	LNO 10-KB
Probe	-	Stackmaster	-	Mass Flow Controller	LNO 29-78
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	LNO 29-78
S-Pitot	LNO 06-KB	Anemometer	-	Mass Flow Controller	LNO 29-79
L-Pitot	-	Ecophysics NOx Analyser	-	MFC Display module	LNO 29-79
Site Balance	LNO 14-KB	Chiller (JCT/MAK 10)	LNO 21-39	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	LNO 03-133	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	LNO 31-KB	Site temperature Logger	LNO 12-KB	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	LNO 03-41		-	20m Heated Line (1)	LNO 18-133
Inclinometer (Swirl Device)	LNO 23-KB		-	20m Heated Line (2)	-

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

CALIBRATION GASES					
Gas (traceable to ISO 17025)	Cylinder I.D Number	Supplier	ppm	%	Analytical Tolerance +/- %
Propane	HPC 1082	BOC	80	-	2.0
Nitric Oxide	HPC 2077	BOC	84.8	-	2.0
Sulphur Dioxide	HPC 2061	BOC	158	-	2.0
Carbon Monoxide	HPC 2078	BOC	163	-	2.0
Carbon Dioxide	HPC 2092	BOC	-	8.15	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
Keith Bird	MM 07 825	MCERTS Level 2	Sep-20	Dec-23	Dec-24	Sep-20	Sep-24	Feb-22
Pete Watson	MM 08 953	MCERTS Level 1	Apr-24	-	-	-	-	Ape-24

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY

Parameter	Sampling Times	Concentration mg/m ³	Uncertainty mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	12:40 - 13:12 22 October 2010	1.6	0.55	-	38
Blank	-	0.27	-	-	-

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

Acetone Blank Value mg/l	Acceptable Value mg/l
2.0	10

FILTER INFORMATION

SAMPLES

Test	Filter & Probe Rinse Number	Filter Start Weight g	Filter End Weight g	Mass Gained on Filter g	Probe Rinse Start Weight g	Probe Rinse End Weight g	Mass Gained on Probe g	Combined Total Mass Gained g
Run 1	Q1091	0.14576	0.14902	0.00326	172.10050	172.09850	-0.00200	0.00126

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	Q1089	0.14286	0.14271	-0.00015	188.65640	188.65630	-0.00010	0.00022

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			Molecular weight of dry gas, M_d
Barometric pressure, P _b	Kpa	100.1	CO ₂ % 2.00
Stack static pressure, P _{static}	pa	-750	O ₂ % 20.50
P _s = P _b + P _{static}	Kpa	99.4	Total % 22.50
Vol. of water vapour collected, V_{wstd}			N ₂ (100 - Total) % 77.50
Moisture trap weight increase, V _{lc}	g	22.1	M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)
V _{wstd} = (0.001246)(V _{lc})	m ³	0.0275366	Molecular weight of wet gas, M_s
Volume of gas metered dry, V_{mstd}			M _s = M _d (1 - B _{wo}) + 18(B _{wo}) g/gmol
Volume of gas sample through gas meter, V _m		0.844	Actual flow of stack gas, Q_a
Gas meter correction factor, Y _d		0.980	Area of stack, A _s m ² 0.64
Mean dry gas meter temperature, T _m		290	Q _a = (60)(A _s)(V _s) m ³ /min 478.9
Mean pressure drop across orifice, DH mmH ₂ O		74.930	Total flow of stack gas, Q
V _{mstd} = $\frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m}$	m ³	0.776	Conversion factor (K/mm.Hg) 0.3592
Volume of gas metered wet, V_{mstw}			Q _{std} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$ Dry 387.8
V _{mstw} = V _{mstd} + V _{wstd}	m ³	0.8037	Q _{stdO2} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$ @O ₂ ref No O2 Ref
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O2}			Q _{stw} = $\frac{(Q_a)P_s(0.3592)}{(T_s)}$ Wet 401.52
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)		No	Percent isokinetic, %I
% oxygen measured in gas stream, act%O ₂		20.5	Nozzle diameter, D _n mm 6.77
% oxygen reference condition		21	Nozzle area, A _n mm ² 36.00
O ₂ Reference O ₂ Ref = 21.0 - act%O ₂		No O2 Ref	Total sampling time, q min 32
Factor $\frac{21.0 - ref\%O_2}{21.0 - act\%O_2}$		No O2 Ref	%I = $\frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ % 110.5
V _{mstd@X%oxygen} = (V _{mstd})(O ₂ Ref)	m ³	No O2 Ref	Acceptable isokinetic range 95% to 115% Yes
Moisture content, B_{wo}			Particulate Concentration, C
B _{wo} = $\frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0343	Mass collected on filter, M _f g 0.00326
		3.43	Mass collected in probe, M _p g -0.00200
Moisture by FTIR			Total mass collected, M _n g 0.00126
Velocity of stack gas, V_s			C _{wet} = $\frac{M_n}{V_{mstw}}$ mg/m ³ 1.568
Velocity pressure coefficient, C _p		0.98	C _{dry} = $\frac{M_n}{V_{mstd}}$ mg/m ³ 1.623
Mean of velocity heads, DP _{avg} Pa		88.20	C _{dry@X%O2} = $\frac{M_n}{V_{mstd@X\%oxygen}}$ mg/m ³ No O2 Ref
Mean stack gas temperature, T _s K		319	Particulate Emission Rates, E
Gas density (wet, ambient), p			E = $[(C_{wet})(Q_{stw})(60)] / 1000$
p = (M _s *P _s)/(8.314*T _s)	kg/m ³	1.076	
Stack Velocity, V _s $V_s = Cp \sqrt{\frac{\Delta DP_{avg}}{p}}$	m/s	12.55	

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	25.8	0.12	-	9296.4	0.52	Yes

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

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	110.54	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m ³	5% ELV mg/m ³	LOD < 5% ELV
Run 1	0.27	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 Limit Value mg/m ³	Acceptable Blank Value mg/m ³	Overall Blank Acceptable mg/m ³
Blank 1	0.27	-	-	-

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	47	180	160

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HYDROGEN CHLORIDE SUMMARY					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	12:40 - 13:12 22 October 2019	0.33	0.01	-	8.0
Field Blank	-	0.01	-	-	-

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

HYDROGEN CHLORIDE QUALITY ASSURANCE CHECKLIST

Leak Test Results	Total Sample Volume @ ref Conditions m ³	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	0.80	25.8	0.12	0.15	0.52	Yes

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

HYDROGEN CHLORIDE ABSORPTION EFFICIENCY

Parameter	Total ug	IMP C ug	Absorption Efficiency %	Acceptable Absorption Efficiency %	Absorption Efficiency Acceptable ?
Run 1	267.9	5.4	98	95	Yes

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS 1			Hydrogen Chloride	
Absolute pressure of stack gas, P_s			Velocity of stack gas, V_s	
Barometric pressure, P _b	kPa	100.1	Velocity pressure coefficient, C _p	0.98
Stack static pressure, P _{static}	Pa	-750	Mean of velocity heads, DP _{avg}	Pa 88.20
P _s = P _b + (P _{static})	kPa	99.35	Mean stack gas temperature, T _s	K 319.25
Vol. of water vapour collected, V_{wstd}			Gas density (wet, ambient), ρ	
Moisture trap weight increase, V _{lc}	g	-	$\rho = (M_s \cdot P_s) / (8.314 \cdot T_s)$	kg/m ³ 1.076
V _{wstd} = (0.001246)(V _{lc})	m ³	-	Stack Velocity, V _s	$V_s = C_p \sqrt{\frac{\Delta DP_{avg}}{\rho}}$ m/s 12.55
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	0.8440	Area of stack, A _s	m ² 0.64
Gas meter correction factor, Y _d		0.98	Q _a = (60)(A _s)(V _s)	m ³ /min 479
Mean dry gas meter temperature, T _m	K	289.50	Dry total flow of stack gas, Q_{std}	
Mean pressure drop across orifice, DH	mmH ₂ O	74.93	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	0.78	Q _{std} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$	m ³ /min 388
Volume of gas metered wet, V_{mstw}			Wet total flow of stack gas, Q_{stw}	
V _{mstw} = V _{mstd} + V _{wstd}	m ³	0.8037	Q _{stw} = $\frac{(Q_a)P_s(0.3592)}{(T_s)}$	m ³ /min 402
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O2}			Dry total flow of stack gas at X% O₂, 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 No O2 Ref
% oxygen measured in gas stream, act%O ₂	20.50		Percent isokinetic, %I	
% oxygen reference condition	21		Nozzle diameter, D _n	mm 6.77
O ₂ Reference Factor $\frac{O_2 Ref = 21.0 - act\%O_2}{21.0 - ref\%O_2}$	No O2 Ref		Nozzle area, A _n	mm ² 36.00
V _{mstd@X%oxygen} = (V _{mstd}) (O ₂ Ref)	m ³	No O2 Ref	Total sampling time, q	min 32
Moisture content, B_{wo}			%I = $\frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ % 111	
B _{wo} = $\frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	3.43	Acceptable isokinetic range 95% to 115%	
Moisture by FTIR			Hydrogen Chloride Concentration, C	
%			-	
Molecular weight of dry gas, M_d			Hydrogen Chloride Emission Rates, E	
CO ₂		2.00	Mass collected, M	ug 268
O ₂		20.50	C _{wet} = $\frac{M_n}{V_{mstw}}$	mg/m ³ 0.333
Total		22.50	C _{dry} = $\frac{M_n}{V_{mstd}}$	mg/m ³ 0.345
N ₂ (100 -Total)		77.50	C _{dry@X%O2} = $\frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m ³ No O2 Ref
M _d = 0.44(%CO ₂) + 0.32(%O ₂) + 0.28(%N ₂)		29.14	E = [(C _{wet})(Q _{stw})(60)] / 1000 g/hr 8.03	
Molecular weight of wet gas, M_s				
M _s = M _d (1 - B _{wo}) + 18(B _{wo})	g/gmol	28.8		

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

FORMALDEHYDE SUMMARY					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	12:40 - 13:12 22 October 2010	0.19	0.01	-	4.6
Field Blank	-	0.02	-	-	-

Please note figures in bold italic font are at the limit of detection

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

FORMALDEHYDE QUALITY ASSURANCE CHECKLIST

Leak Test Results	Total Sample Volume @ ref Conditions m ³	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	0.8	25.8	0.12	0.15	0.52	Yes

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

FORMALDEHYDE ABSORPTION EFFICIENCY

Parameter	Total ug	IMP C ug	Absorption Efficiency %	Acceptable Absorption Efficiency %	Absorption Efficiency Acceptable ?
Run 1	153	27	82	95	N/A - No ELV

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS 1			Formaldehyde	
Absolute pressure of stack gas, P_s			Velocity of stack gas, V_s	
Barometric pressure, P _b	kPa	100.1	Velocity pressure coefficient, C _p	0.98
Stack static pressure, P _{static}	Pa	-750	Mean of velocity heads, DP _{avg}	Pa 88.20
P _s = P _b + (P _{static})	kPa	99.35	Mean stack gas temperature, T _s	K 319.25
Vol. of water vapour collected, V_{wstd}			Gas density (wet, ambient), ρ	
Moisture trap weight increase, V _{lc}	g	-	$\rho = (M_s \cdot P_s) / (8.314 \cdot T_s)$	kg/m ³ 1.077
V _{wstd} = (0.001246)(V _{lc})	m ³	-	Stack Velocity, V _s	$V_s = C_p \sqrt{\frac{\Delta DP_{avg}}{\rho}}$ m/s 12.54
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	0.8440	Area of stack, A _s	m ² 0.64
Gas meter correction factor, Y _d		0.98	Q _a = (60)(A _s)(V _s)	m ³ /min 479
Mean dry gas meter temperature, T _m	K	289.50	Dry total flow of stack gas, Q_{std}	
Mean pressure drop across orifice, DH	mmH ₂ O	74.93	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	0.78	Q _{std} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$	m ³ /min 388
Volume of gas metered wet, V_{mstw}			Wet total flow of stack gas, Q_{stw}	
V _{mstw} = V _{mstd} + V _{wstd}	m ³	0.8037	Q _{stw} = $\frac{(Q_a)P_s(0.3592)}{(T_s)}$	m ³ /min 401
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O2}			Dry total flow of stack gas at X% O₂, 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 No O2 Ref
% oxygen measured in gas stream, act%O ₂	20.9		Percent isokinetic, %I	
% oxygen reference condition	21		Nozzle diameter, D _n	mm 6.77
O ₂ Reference Factor $\frac{O_2 Ref = 21.0 - act\%O_2}{21.0 - ref\%O_2}$	No O2 Ref		Nozzle area, A _n	mm ² 36.00
V _{mstd@X%oxygen} = (V _{mstd}) (O ₂ Ref)	m ³	No O2 Ref	Total sampling time, q	min 32
Moisture content, B_{wo}			%I = $\frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	% 111
B _{wo} = $\frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0343	3.43	Acceptable isokinetic range 95% to 115%
Moisture by FTIR		%	-	Hydrogen Chloride Concentration, C
Molecular weight of dry gas, M_d			Mass collected, M	
CO ₂		2.00	C _{wet} = $\frac{M_n}{V_{mstw}}$	ug 153
O ₂		20.9		mg/m ³ 0.190
Total		22.90	C _{dry} = $\frac{M_n}{V_{mstd}}$	mg/m ³ 0.197
N ₂ (100 -Total)		77.10	C _{dry@X%O2} = $\frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m ³ No O2 Ref
M _d = 0.44(%CO ₂) + 0.32(%O ₂) + 0.28(%N ₂)		29.16	Hydrogen Chloride Emission Rates, E	
Molecular weight of wet gas, M_s			E = [(C _{wet})(Q _{stw})(60)] / 1000	
M _s = M _d (1 - B _{wo}) + 18(B _{wo})	g/gmol	28.8		g/hr 4.59

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts
APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

AMMONIA SUMMARY					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	13:30 - 14:00 22 October 2019	0.52	0.07	-	11
Field Blank	-	0.39	-	-	-

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

AMMONIA QUALITY ASSURANCE CHECKLIST

Leak Test Results	Total Sample Volume @ ref Conditions m ³	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	0.06	2.0	0.03	0.03	0.04	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	150	N/A	Glass	0.1M Sulphuric Acid

AMMONIA ABSORPTION EFFICIENCY

Parameter	Total ug	IMP C ug	Absorption Efficiency %	Acceptable Absorption Efficiency %	Absorption Efficiency Acceptable ?
Run 1	32.432	ND	100	95	Yes

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

FORMIC ACID SUMMARY					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	13:20 - 13:50 22 October 2019	0.27	0.13	-	5.6
Field Blank	-	0.13	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour
Please note figures in bold italic font are at the limit of detection

FORMIC ACID QUALITY ASSURANCE CHECKLIST

Leak Test Results	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	0.50	0.002	0.002	0.01	Yes

	Type of tube	Max. Tube Temperature °C	Max. Storage / Transit Temp.
Run 1	Treated Silica	18	Yes

Tube sampling temperature should be < 40°C

FORMIC ACID ADSORPTION EFFICIENCY

Parameter	Total ug	Back ug	Adsorption Efficiency %	Acceptable Adsorption Efficiency %	Adsorption Efficiency Acceptable ?
Run 1	ND	ND	100	95	Yes

N/A - As Formic Acid does not have an emission limit an adsorption efficiency is not required.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ACETIC ACID SUMMARY					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	13:58 - 14:28 22 October 2019	0.27	0.13	-	5.6
Field Blank	-	0.13	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour
Please note figures in bold italic font are at the limit of detection

ACETIC ACID QUALITY ASSURANCE CHECKLIST

Leak Test Results	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	0.50	0.002	0.003	0.01	Yes

	Type of tube	Max. Tube Temperature °C	Temperature during storage / transit <25°C
Run 1	Treated Silica	18	Yes

Tube sampling temperature should be < 40°C

ACETIC ACID ADSORPTION EFFICIENCY

Parameter	Total ug	Back ug	Adsorption Efficiency %	Acceptable Adsorption Efficiency %	Adsorption Efficiency Acceptable ?
Run 1	ND	ND	100	95	Yes

N/A - As Acetic Acid does not have an emission limit an adsorption efficiency is not required.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

VOC SCREENING SUMMARY					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	12:40 - 13:10 22 October 2019	0.33	0.07	-	7.0
Field Blank	-	0.07	-	-	-

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

VOC SCREENING RESULTS							
Substance	LOD (ng)	Run 1 (ng)		Run 1 (mg/m ³)			Mass Emission (g/hr)
		Front	Back	Front	Back	Total	
3-methyl Hexane	20	240	20	0.080	0.007	0.09	1.8
2-methyl Hexane	20	100	20	0.033	0.007	0.04	0.84
2,3-dimethyl-Pentane	20	100	20	0.033	0.007	0.04	0.84
Toluene	20	100	20	0.033	0.007	0.04	0.84
Heptane	20	60	20	0.020	0.007	0.03	0.56
Unknown	20	50	20	0.017	0.007	0.02	0.49
Unknown	20	40	20	0.013	0.007	0.02	0.42
Tetrachloroethylene	20	40	20	0.013	0.007	0.02	0.42
Acetic acid	20	30	20	0.010	0.007	0.02	0.35
Unknown	20	30	20	0.010	0.007	0.02	0.35
Total	200	790	200	0.26	0.07	0.33	7.0

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

VOC SCREENING RESULTS BLANK			
Substance	LOD (ng)	Blank (ng)	
		(ng)	mg/m ³
3-methyl Hexane	20	20	0.007
2-methyl Hexane	20	20	0.007
2,3-dimethyl-Pentane	20	20	0.007
Toluene	20	20	0.007
Heptane	20	20	0.007
Unknown	20	20	0.007
Unknown	20	20	0.007
Tetrachloroethylene	20	20	0.007
Acetic acid	20	20	0.007
Unknown	20	20	0.007
Total	200	200	0.07

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

VOC SCREENING QUALITY ASSURANCE

Leak Test Results	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	0.1	0.001	0.001	0.002	Yes

	Type of tube	Max. Tube Temperature °C	Temperature during storage / transit <25°C
Run 1	ATD	18	Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL VOLATILE ORGANIC COMPOUNDS SUMMARY

Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Run 1	12:30 - 14:30 22 October 2019	8.8	0.40	-	185

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

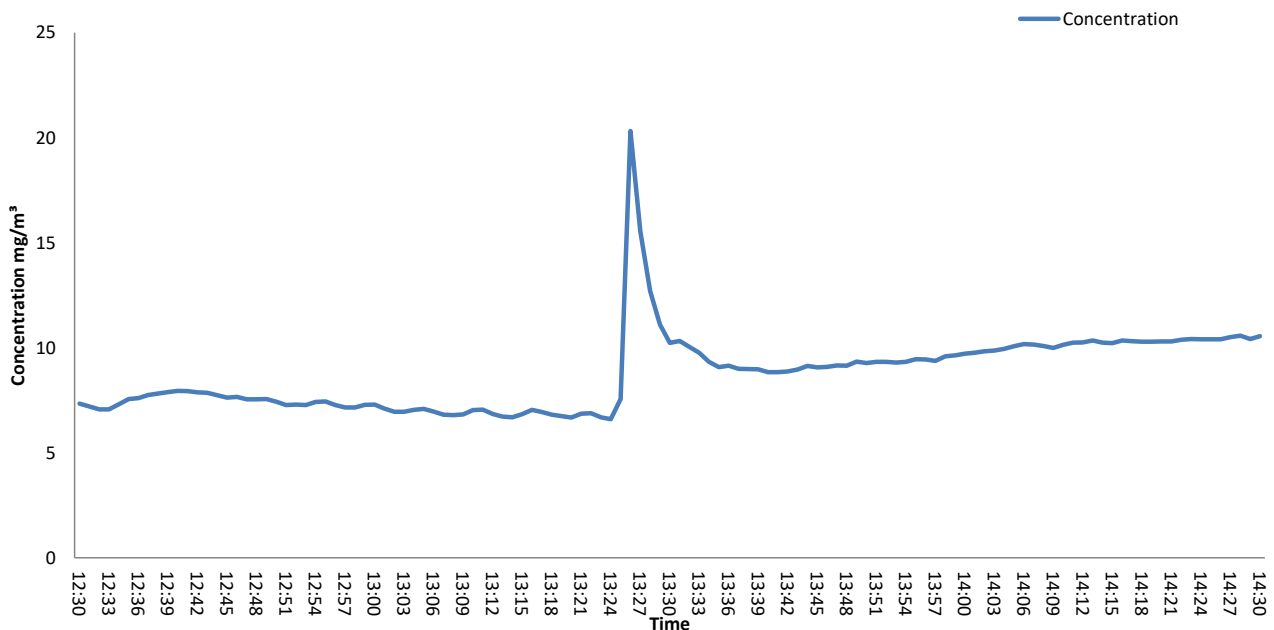
INSTRUMENTAL SPAN & ZERO CHECKS

PRE-SAMPLING CALIBRATION CHECKS								
Date	22 October 2019							
Start Time	09:55							
End Time	10:05							
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	80.0	100	0.00	80.0	0.10	0.10	79.6	0.50

Zero and Span gas contained 10% Oxygen

POST-SAMPLING CALIBRATION CHECKS								
Date	22 October 2019							
Start Time	14:40							
End Time	14:45							
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	5.45	0.20	80.0	0.00	0.12	x	x	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/m ³	LOD mg/m ³	ELV mg/m ³	Emission Rate g/hr
Oxides of Nitrogen	12:30 - 14:30 22 October 2019	4.5	0.40	-	96
Sulphur Dioxide	12:30 - 14:30 22 October 2019	9.3	0.77	-	197
Carbon Monoxide	12:30 - 14:30 22 October 2019	21	0.27	-	436

Test	Sampling Time and Date	Concentration %	LOD %
Carbon Dioxide	12:30 - 14:30 22 October 2019	0.64	0.003
Oxygen	12:30 - 14:30 22 October 2019	20.3	0.01

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

PRE-SAMPLING CALIBRATION DATA

Date	22 October 2019
Start Time	10:05
End Time	10:20

Chiller Temperature (°C)	2.3
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	200	0.00	84.8	0.10	0.20	83.6	60	1.42
Sulphur Dioxide	200	0.00	158.0	0.10	0.10	156.0	70	1.27
Carbon Monoxide	200	0.00	163.0	0.20	0.30	162.0	40	0.61
Carbon Dioxide	25	0.00	8.15	0.06	0.10	8.12	40	0.37
Oxygen	25	0.00	20.90	0.04	0.12	20.93	40	-0.14

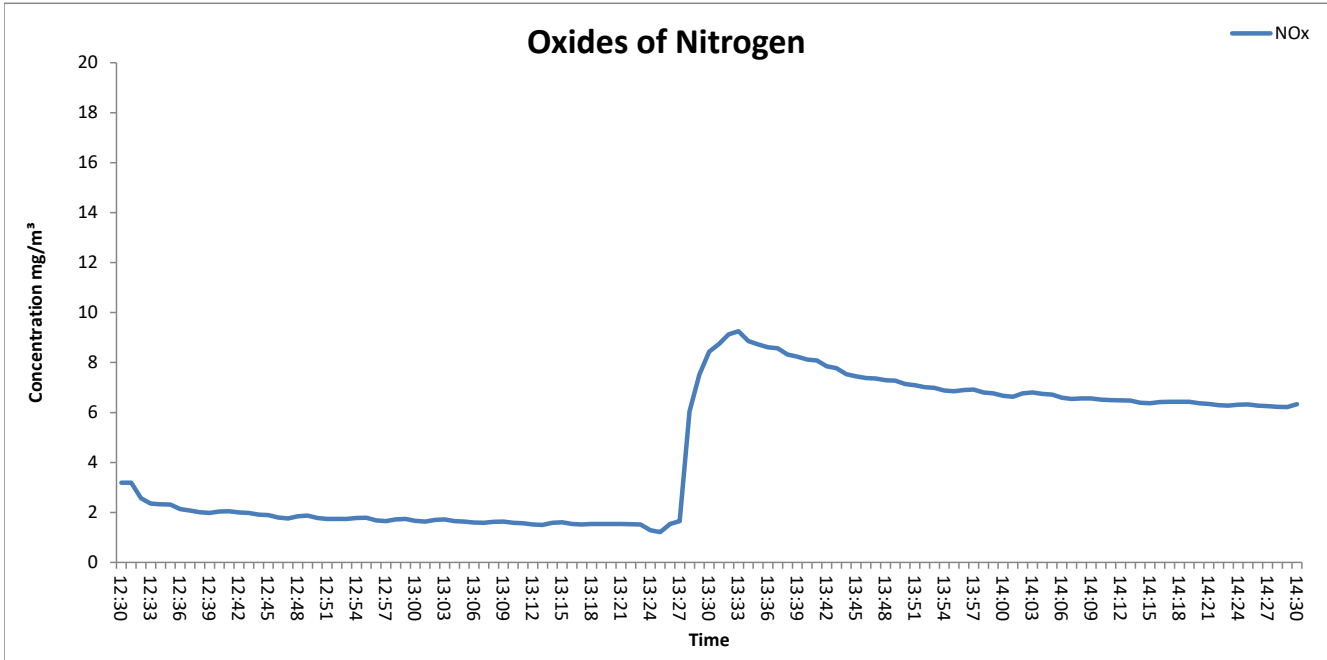
POST-SAMPLING CALIBRATION DATA

Date	22 October 2019
Start Time	14:35
End Time	14:45

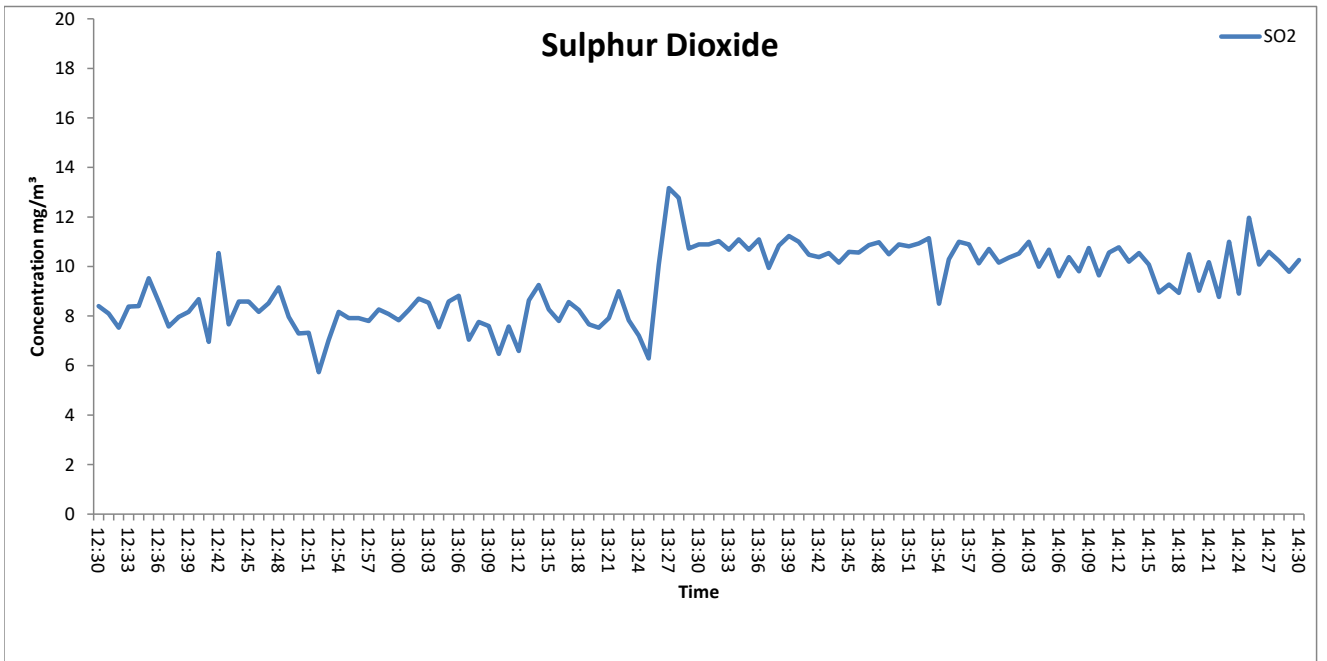
Chiller Temperature (°C)	2.6
Requirement	< 4°C
Compliant	Yes

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	0.10	83.4	0.00	-1.65	x	x	N/A - not corrected
Sulphur Dioxide	0.10	157.9	0.00	-0.06	x	x	N/A - not corrected
Carbon Monoxide	0.20	162.3	0.00	-0.43	x	x	N/A - not corrected
Carbon Dioxide	0.06	8.11	0.00	-0.49	x	x	N/A - not corrected
Oxygen	0.08	20.93	0.19	-0.05	x	x	N/A - not corrected

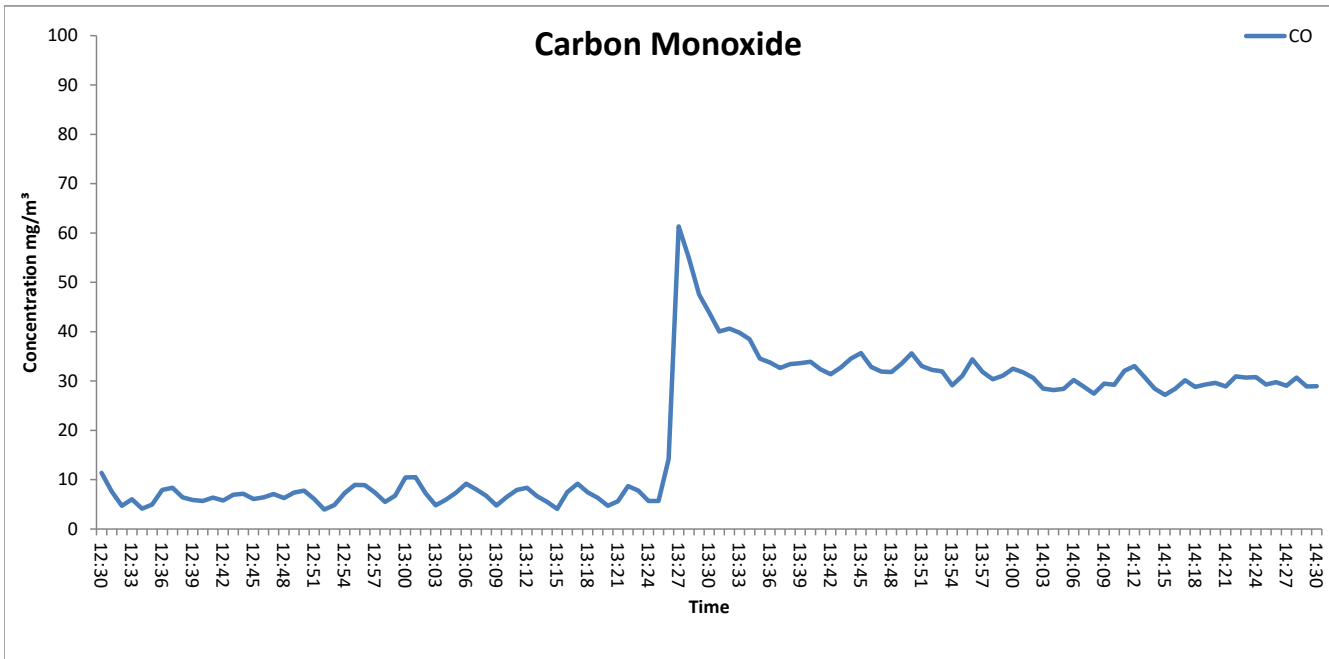
APPENDIX 2 - Summaries, Calculations, Raw Data and Charts
OXIDES OF NITROGEN (as NO₂) EMISSIONS CHART



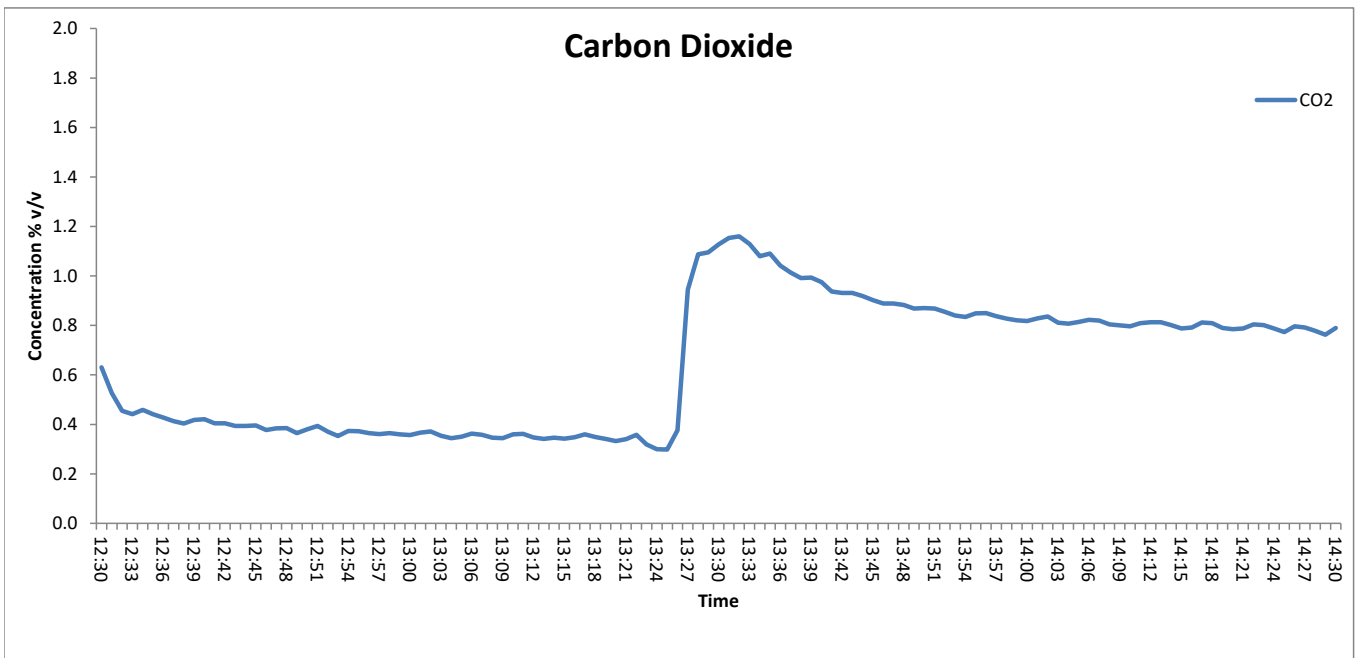
SULPHUR DIOXIDE EMISSIONS CHART



CARBON MONOXIDE EMISSIONS CHART

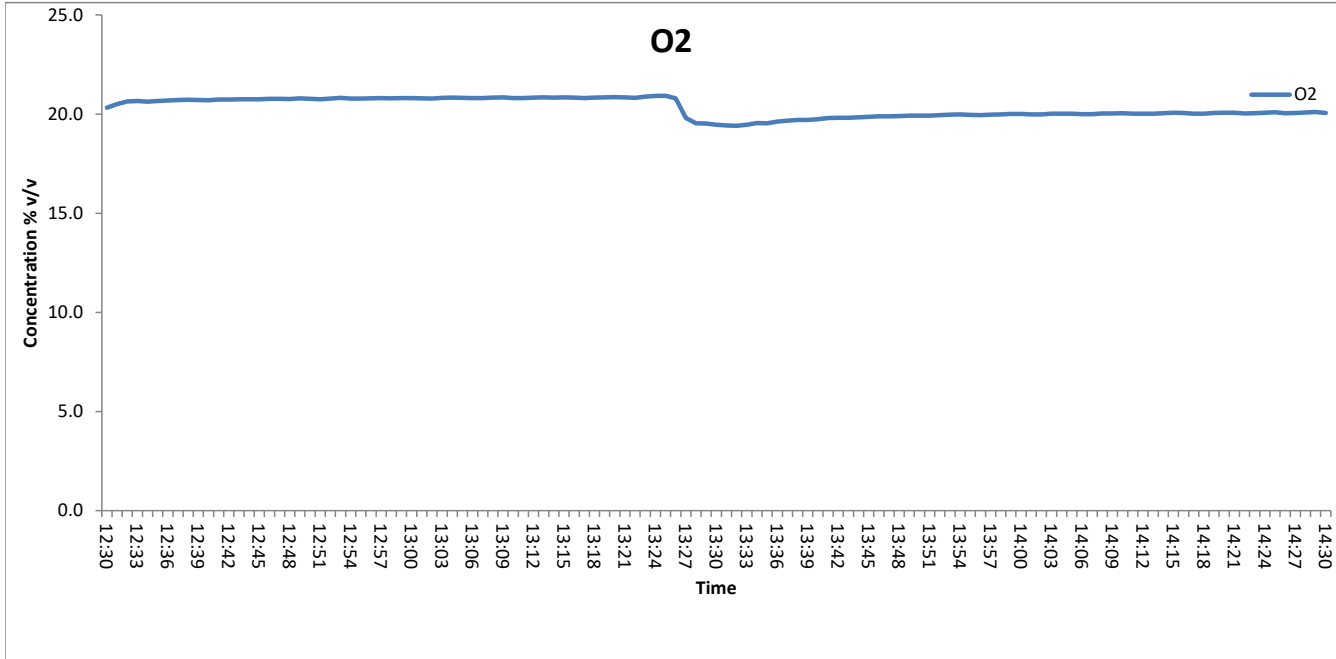


CARBON DIOXIDE EMISSIONS CHART



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	End Weight	Total gain	Concentration	LOD	Uncertainty
		kg	kg	kg	%	%	%
Run 1	12:40 - 13:12 22 October 2010	3.2534	3.2755	0.0221	3.4	0.02	2.8

Moisture Quality Assurance							
Test Number	Sampling Duration	Total Volume Sampled	Sampling Rate	Start Leak Rate	End Leak Rate	Acceptable Leak Rate	Leak Tests Acceptable?
	mins	l	l/min	l/min	l/min	l/min	
Run 1	32	804	25.8	0.12	-	0.52	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.90	m
Stack Width, W	-	m
Stack Area, A	0.64	m ²
Average stack gas temperature	43	°C
Stack static pressure	-0.75	kPa
Barometric Pressure	100.1	kPa

Stack Gas Composition & Molecular Weights								
Component	Molar Mass M	Density kg/m ³ p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m ³ pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m ³ pi
CO ₂	44	1.963059	0.640000	0.006400	0.012564	0.618071	0.006181	0.012133
O ₂	32	1.427679	20.311494	0.203115	0.289983	19.615543	0.196155	0.280047
N ₂	28	1.249219	79.048506	0.790485	0.987489	76.339992	0.763400	0.953654
H ₂ O	18	0.803070	-	-	-	3.426394	0.034264	0.027516

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2900	kg/m ³
Wet Density (STP), P_{STW}	1.2734	kg/m ³
Dry Density (Actual), P_{Actual}	1.0930	kg/m ³
Average Wet Density (Actual), $P_{ActualW}$	1.079	kg/m ³

Where:

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

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

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

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	22 October 2019
Time of Survey	09:40
Velocity Measurement Device:	S-Type Pitot

Sampling Line A								
Traverse Point	Distance into duct (m)	DP pt Pa (average of 3 readings)	DP pt mmH ₂ O (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m ³ /s	O ₂ % Vol	Angle of Swirl °
1	0.06	81.3	8.3	43	10.6	6.7	-	<15
2	0.23	90.5	9.2	43	11.1	7.1	-	<15
3	0.68	89.8	9.2	43	11.1	7.1	-	<15
4	0.84	82.6	8.4	43	10.6	6.8	-	<15
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	86.1	8.8	43	10.9	6.9	-	-

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt Pa (average of 3 readings)	DP pt mmH ₂ O (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m ³ /s	O ₂ % Vol	Angle of Swirl °
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	-	-

PRELIMINARY STACK SURVEY QUALITY ASSURANCE CHECKLIST

PITOT LEAK CHECK								
Run	Pre Traverse Leak Rate				Post Traverse Leak Rate			
	Start Value mmH ₂ O	End Value mmH ₂ O	Difference %	Outcome	Start Value mmH ₂ O	End Value mmH ₂ O	Difference %	Outcome
Run 1	116	113	2.6	Pass	124	119	4.0	Pass

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

S-Type Pitot Stagnation Check				
Run	Stagnation (Pa)	Reference (Pa)	Difference (Pa)	Outcome (Permitted +/- 10 Pa)
Run 1	-750	-750	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 Differential Pressure	81	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	10.6	m/s	-	-
Highest Gas Velocity	11.1	m/s	-	-
Ratio of Gas Velocities	1.1	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	°	< 15°	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, $V = K_{pt} \times (1-e) \times \sqrt{2 * DP_{pt} / P_{ActualW}}$		
Where:		
K_{pt} = Pitot tube calibration coefficient		
(1-e) = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, Va	10.9	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	43	0	°C
Total Pressure	99.35	101.3	kPa
Oxygen	20.5	21	%
Moisture	3.43	3.43	%
Pitot tube calibration coefficient, K_{pt}	0.86		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	10.86	m/s
Stack Area (A)	0.64	m ²
Gas Volumetric Flowrate (Actual), Q_{Actual}	24871	m ³ /hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	21073	m ³ /hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	20351	m ³ /hr
Gas Volumetric Flowrate (REF), Q_{Ref}	21073	m ³ /hr

Where:

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

$$Q_{STP} = Q (Actual) \times (Ts / Ta) \times (Pa / Ps) \times 3600$$

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

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

Nomenclature:

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 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - TOTAL PARTICULATE MATTER

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %	Uncollected Mass mg
MU required	≤ 2%	≤ 2%	≤ 1%	≤ 1%	≤ 10%	≤ 5% of ELV	≤ 2%	≤ 10% of ELV
Run 1	0.001	2.0	0.50	1.0	N/A	0.22	-	-
as a %	0.13	0.63	0.50	1.0	N/A	N/A	0.46	N/A
compliant?	Yes	Yes	Yes	Yes	N/A	N/A	Yes	N/A

Run	Volume (STP) m ³	Mass of particulate mg	O ₂ Correction -	Leak mg/m ³	Uncollected Mass mg	Combined uncertainty
Run 1	0.66	1.3	1.0	0.004	0.0001	-
MU as mg/m ³	0.02	0.27	-	0.004	0.0002	0.27
MU as %	1.3	17	-	0.27	0.01	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.55	mg/m³	35.0	% Result	N/A	% ELV
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(k is a coverage factor which gives a 95% confidence in the quoted figures)

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - ISOKINETIC HYDROGEN CHLORIDE

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %
MU required	<=2%	<2.5 k	<=1%	<=1%	<=5%	≤ 5% of ELV	<=2%
Run 1	0.80	290	93	1.0	-	0.39	-
as a %	0.12	0.69	0.54	1.0	-	-	0.58
compliant?	Yes	Yes	Yes	Yes	N/A	N/A	Yes

Run	Volume (STP) m ³	Mass of Hydrogen Chloride mg	O2 Correction -	Leak mg/m ³	Lab Uncertainty mg	Combined uncertainty
Run 1	0.69	0.39	-	0.0011	-	-
MU as mg/m ³	0.004	0.01	-	0.0011	0.0160	0.0210
MU as %	1.3	3.8	-	0.34	4.8	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.04	mg/m³	12.59	% Result	-	% ELV
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(k is a coverage factor which gives a 95% confidence in the quoted figures)

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - ISOKINETIC FORMALDEHYDE

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %
MU required	<=2%	<2.5 k	<=1%	<=1%	<=5%	≤ 5% of ELV	<=2%
Run 1	0.80	289.50	92.6	1.0	-	0.27	-
as a %	0.12	0.69	0.54	1.0	-	-	0.58
compliant?	Yes	Yes	Yes	Yes	N/A	N/A	Yes

Run	Volume (STP) m ³	Mass of Formaldehyde mg	O2 Correction -	Leak mg/m ³	Lab Uncertainty mg	Combined uncertainty
Run 1	0.6928	0.2700	-	0.0006	-	-
MU as mg/m ³	0.0025	0.0212	-	0.0006	0.0095	0.0234
MU as %	1.3378	11.1161	-	0.3351	5.0	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.05	mg/m³	24.53	% Result	-	% ELV
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(k is a coverage factor which gives a 95% confidence in the quoted figures)

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - NON-ISOKINETIC AMMONIA

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %
MU required	<=2%	<2.5 k	<=1%	<=1%	<=5%	≤ 5% of ELV	<=2%
Run 1	0.00004	2.000	0.50	1.00	0.100	0.013	-
as a %	0.064	0.685	0.50	1.00	-	N/A	1.600
compliant?	Yes	Yes	Yes	Yes	N/A	N/A	Yes

Run	Volume (STP) m ³	Mass of Ammonia mg	O2 Correction -	Leak mg/m ³	Lab Uncertainty mg	Combined uncertainty
Run 1	0.0574	0.0544	-	0.0048	-	-
MU as mg/m ³	0.0069	0.1205	-	0.0048	0.0303	0.125
MU as %	1.3128	23.0819	-	0.9238	5.8	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.25	mg/m³	47.71	% Result	-	% ELV
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(k is a coverage factor which gives a 95% confidence in the quoted figures)

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - FORMIC ACID

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %	Uncollected Mass mg
MU required	≤ 2%	≤ 2%	≤ 1%	≤ 1%	≤ 10%	≤ 5% of ELV	≤ 2%	≤ 10% of ELV
Run 1	0.00001	2.0	0.50	1.0	N/A	0.002	-	-
as a %	0.07	0.69	0.50	1.0	N/A	N/A	0.40	N/A
compliant?	Yes	Yes	Yes	Yes	N/A	N/A	Yes	N/A

Run	Volume (STP) m ³	Mass of Formic Acid mg	O2 Correction -	Leak mg/m ³	Uncollected Mass mg	Lab Uncertainty mg	Combined uncertainty
Run 1	0.014	0.004	1.000	0.001	0.001	-	-
MU as mg/m ³	0.00001	0.13	-	0.001	0.077	0.013	0.155
MU as %	0.004	50	-	0.231	28.868	5.0	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.309	mg/m³	115.90	% Result	N/A	% ELV
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Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - ACETIC ACID

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %	Uncollected Mass mg
MU required	≤ 2%	≤ 2%	≤ 1%	≤ 1%	≤ 10%	≤ 5% of ELV	≤ 2%	≤ 10% of ELV
Run 1	0.00001	2.0	0.50	1.0	N/A	0.002	-	-
as a %	0.07	0.68	0.50	1.0	N/A	N/A	0.60	N/A
compliant?	Yes	Yes	Yes	Yes	N/A	N/A	Yes	N/A

Run	Volume (STP) m ³	Mass of Acetic Acid mg	O2 Correction -	Leak mg/m ³	Uncollected Mass mg	Lab Uncertainty mg	Combined uncertainty
Run 1	0.014	0.004	1.000	0.001	0.001	-	-
MU as mg/m ³	0.00001	0.13	-	0.001	0.08	0.013	0.15
MU as %	0.004	50	-	0.35	29	5.0	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.309	mg/m³	115.9	% Result	N/A	% ELV
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Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VOC SCREENING

Standard Uncertainty

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %	Uncollected Mass mg
MU required	≤ 2%	≤ 2%	≤ 1%	≤ 1%	≤ 10%	≤ 5% of ELV	≤ 2%	≤ 10% of ELV
Run 1	0.0006	2.00	0.50	1.0	N/A	0.0002	-	-
as a %	2.0	0.69	0.50	1.0	N/A	N/A	1.0	N/A
compliant?	Yes	Yes	Yes	Yes	N/A	N/A	Yes	N/A

Run	Volume (STP) m ³	Mass of Total VOC mg	O2 Correction -	Leak mg/m ³	Uncollected Mass mg	Lab Uncertainty mg	Combined uncertainty
Run 1	0.003	0.001	1.000	0.002	0.00001	-	-
MU as mg/m ³	0.00001	0.067	-	0.002	0.004	0.017	0.069
MU as %	0.002	20	-	0.58	1.166	5.0	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.14	mg/m³	42	% Result	N/A	% ELV
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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	0.001	2.0	0.50	1.0	N/A	-
as a %	0.13	0.63	0.50	1.0	N/A	0.46
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	0.66	22100	1.0	76.32	58	-
MU as % v/v	0.05	0.02	-	0.01	0.009	0.05
MU as %	1.29	0.45	-	0.27	0.26	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.10	% v/v	2.84	%
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 1

Measured Concentration	8.8	mg/m ³
Limit	-	mg/m ³
Calibration Gas Concentration	128	mg/m ³
Range	160	mg/m ³

Performance characteristics	Value	Units	specification	MU Met?
Response time	40	seconds	<180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	120	minutes	-	-
Number of readings in measurement	120	-	-	-
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	0.00	% full scale	<2% range / 24hr	Yes
Span drift	0.12	% full scale	<2% range / 24hr	Yes
volume or pressure flow dependence	0.02	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.80	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	0.01	% full scale/10K	<3% range / 10 K	Yes
dependence on voltage	0.10	% full scale/10V	< 0.1%vol /10 volt	Yes
losses in the line (leak)	0.50	% of value	< 2% of span gas value	Yes
Uncertainty of calibration gas	1.0	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	0.01
Standard deviation of repeatability at span level	urs	0.01
Lack of fit	ufit	0.65
Drift	u0dr	0.00
volume or pressure flow dependence	uspres	0.00
atmospheric pressure dependence	uapres	0.04
ambient temperature dependence	utemp	0.00
Dependence on voltage	uvolt	0.14
losses in the line (leak)	uleak	0.03
Uncertainty of calibration gas	ucalib	0.05
Uncertainty in factor	uf	0.00

Measurement uncertainty Measured Concentration	8.76	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
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Expanded uncertainty expressed with a level of confidence of 95%	1.30	mg/m ³
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Expanded uncertainty expressed with a level of confidence of 95%	14.87	% value
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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	4.5	mg/m ³
Cal gas conc	174	mg/m ³
Analyser Full Scale	410	mg/m ³

	Value	Units	specification	MU Met?
Response time	60	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	120	minutes	-	-
Number of readings in measurement	120	-	-	-
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	0.00	% full scale	<2% range / 24hr	Yes
Span drift	-1.65	% 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	0.20	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence zero / span	0.20	% full scale/10K	<3% range / 10 K	Yes
Combined interference	2.40	% 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	$U_r = S_r$	0.004
lack of fit	U_{lof}	-0.231
short term zero drift	U_{dz}	0.000
short term span drift	U_{ds}	-0.953
influence of Ambient Temp at Zero	U_{tz}	0.060
influence of Ambient Temp at Span	U_{ts}	1.080
influence of sample gas pressure	U_p	0.000
influence of sample gas flow	U_{fit}	0.139
influence of supply voltage	U_v	0.004
Combined Interference	U_i	0.004
Uncertainty of Cal gas	U_{adj}	0.848

Measurement uncertainty (Concentration Measured)	4.55	mg/m ³
Combined uncertainty	1.69	mg/m ³
Expanded at a 95% confidence interval	3.32	mg/m ³

Expanded uncertainty expressed with a level of confidence of 95%	-	% ELV
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Expanded uncertainty expressed with a level of confidence of 95%	3.3	mg/m³
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Expanded uncertainty expressed with a level of confidence of 95%	73.0	% value
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Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - SULPHUR DIOXIDE

Limit value	-	mg/m ³
Concentration @ Ref conditions	9.3	mg/m ³
Cal gas conc	448.72	mg/m ³
Analyser Full Scale	572	mg/m ³

Performance characteristics	Value	Units	specification	MU Met?
Response time	70	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	120	minutes	-	-
Number of readings in measurement	120	-	-	-
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	0.00	% full scale	<2% range / 24hr	Yes
Span drift	-0.06	% full scale	<2% 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	0.2	% full scale/10K	<3% range / 10 K	Yes
Cross-sensitivity	0.00	% range	<4% of Range	Yes
dependence on voltage	0.22	% 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	$U_{t,z}$	-0.019
influence of Ambient Temp at Span	$U_{t,s}$	0.060
influence of sample gas pressure	U_p	0.000
influence of sample gas flow	U_{fit}	0.416
influence of supply voltage	U_v	0.721
Combined Interference	U_i	0.000
Uncertainty of Cal gas	U_{adj}	0.048

Measurement uncertainty (Concentration Measured)	9.7	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/m³
Expanded uncertainty expressed with a level of confidence of 95%	19.1	% 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	20.7	mg/m ³
Cal gas conc	203.8	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	120	minutes	-	-
Number of readings in measurement	120	-	-	-
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	<2% range / 24hr	Yes
Span drift	-0.43	% 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)	0.01	% 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	$U_{t,z}$	0.06
influence of Ambient Temp span	$U_{t,s}$	0.11
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 Interference	U_i	1.34
Uncertainty of Cal gas	U_{adj}	0.82

Measurement uncertainty (Concentration Measured)	21.4	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%	-	% ELV
Expanded uncertainty expressed with a level of confidence of 95%	3.2	mg/m³
Expanded uncertainty expressed with a level of confidence of 95%	14.9	% value

Developed for the STA by R Robinson, NPL

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	0.64
Calibration gas	8.15
Analyser Full Scale	25

Performance characteristics	Value	Units	specification	MU Met?
Response time	40	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	0	-
Measurement period	120	minutes	0	-
Number of readings in measurement	120	-	0	-
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	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.04	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% 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)	0.36809816	% 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	0.0013
Lack of fit	ufit	0.0751
Drift	u0dr	-0.0018
volume or pressure flow dependence	uspres	0.0000
atmospheric pressure dependence	uapres	0.0122
ambient temperature dependence	utemp	0.0005
Combined interference (from mcerts)	-	0.0808
dependence on voltage	uvolt	0.0862
losses in the line (leak)	uleak	0.0014
Uncertainty of calibration gas	ucalib	0.0037

Measurement uncertainty	0.64	%vol
Combined uncertainty	0.14	%vol
Expanded uncertainty	0.00	%

Expanded uncertainty expressed with a level of confidence of 95%	0.55	% of value
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Expanded uncertainty expressed with a level of confidence of 95%	85.59	% vol
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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	20.31	%vol
Calibration gas	20.9	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	40	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	120	minutes	-	-
Number of readings in measurement	120	-	-	-
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	0.19	% full scale	<2% range / 24hr	Yes
Span drift	-0.05	% 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	$U_{d,z}$	0.1105
short term span drift	$U_{d,s}$	-0.0276
influence of Ambient Temp at Zero	$U_{t,z}$	-0.0009
influence of Ambient Temp at Span	$U_{t,s}$	0.0000
influence of sample gas pressure	U_p	0.0000
influence of sample gas flow	U_{fit}	0.0173
influence of supply voltage	U_v	0.0001
Combined Interference	U_i	0.0485
Uncertainty of Cal gas	U_{adj}	0.1045

Measurement uncertainty (Concentration Measured)	20.31	%
Combined uncertainty	0.18	%
Expanded uncertainty	0.35	%

Expanded uncertainty expressed with a level of confidence of 95%	0.4	%
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Expanded uncertainty expressed with a level of confidence of 95%	1.73	% vol
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Developed for the STA by R Robinson, NPL

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	10.9	m/s
Measured Volumetric Flow rate at Actual Conditions	24871	m ³ /hr

Performance Characteristics & Source of Value	Units	Values	Requirement	Compliant
Uncertainty of Local Gas Velocity Determination	-	0.010		
Uncertainty of pitot tube coefficient	-	0.80		
Uncertainty of mean local dynamic pressures	-	0.591	minimum 3	Yes
Factor loading, function of the number of measurements.	3 readings			
Range of measurement device	pa	1000		
Resolution	pa	1.00		
Calibration uncertainty	pa	14.36	<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	1.61	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	507		
Uncertainty associated with the estimate of density	-	0.007		
Uncertainty associated with the measurement of local velocity	-	0.0001		
Uncertainty associated with the measurement of mean velocity	-	0.0001		

Measurement Uncertainty - Velocity	m/s
Combined uncertainty	0.13
Expanded uncertainty at a 95% Confidence Interval	0.26

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

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

Measurement Uncertainty Volumetric Flow Rate	m ³ /hr
Combined uncertainty	650
Expanded uncertainty at a 95% Confidence Interval	1274

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