STACK EMISSIONS MONITORING REPORT

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Operator & Address:
Medite Europe Ltd. Redmonstown Clonmel Co. Tipperary Ireland

Permit Reference:
IPPC Licence: P0027-04

Release Point:
A2-21 (EP9)

Sampling Date(s):
11 January 2018

SOCOTEC UK Job Number:	LEK 10972 / Q1
Report Date:	14-Feb-18
Version:	1
Report By: MCERTS Number: MCERTS Level: Technical Endorsements:	Hugh McMahon MM 15 1347 MCERTS Level 2 - Team Leader 1, 2, 3 & 4
Report Approved By: MCERTS Number: Business Title: Technical Endorsements: Signature:	Matthew Green MM 04 499 MCERTS Level 2 - Team Leader 1, 2, 3 & 4

UKAS TESTING 1015

mCERTS THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

CONTENTS

EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Medite Europe Ltd. operates a wood fibre drier process at Clonmel which is subject to IPPC Licence P0027-04, under the EPA Act 1992.

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

The results of these tests shall be used to demonstrate compliance with a set of emission limit values for prescribed pollutants as specified in the Plant's IPPC Licence, P0027-04.

Plant

A2-21 (EP9)

Operator

Medite Europe Ltd.
Redmonstown
Clonmel
Co. Tipperary
Ireland

IPPC Licence: P0027-04

Stack Emissions Monitoring Test House

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

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.
MCERTS accredited results will only be claimed where both the sampling and analytical stages are UKAS accredited.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Limit**	**MCERTS accredited result**
Total Particulate Matter	mg/m³	8.12	0.50	20	✓
Particulate Emission Rate	g/hr	2382	145	-	
Formaldehyde	mg/m³	0.44	0.05	20	✓
Formaldehyde Emission Rate	g/hr	128	13.9	-	
Oxides of Nitrogen (as NO_2)	mg/m³	66.8	5.47	110	✓
Oxides of Nitrogen (as NO_2) Emission Rate	g/hr	12909	1058	-	
Carbon Monoxide	mg/m³	5.37	11.6	600	✓
Carbon Monoxide Emission Rate	g/hr	1037	2250	-	
Oxygen	% v/v	20.3	4.11	-	✓
Moisture	%	16.4	0.42	-	✓
Stack Gas Temperature	°C	60.0	-	-	
Stack Gas Velocity	m/s	15.8	0.40	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	236634	12286	-	✓
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	193231	10033	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	161547	8388	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	193231	10033	174160	

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	11 January 2018	09:22 - 10:22	60 minutes
Formaldehyde Run 1	11 January 2018	09:22 - 10:22	60 minutes
Combustion Gases	11 January 2018	09:25 - 10:25	60 minutes
Preliminary Stack Traverse	11 January 2018	08:49	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Wood fibre drier
Continuous or batch	Continuous
Product Details	Wood fibre board
Part of batch to be monitored (if applicable)	N/A
Normal load, throughput or continuous rating	Normal
Fuel used during monitoring	N/A
Abatement	Cyclone
Plume Appearance	Heavy moisture plume visible

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by SOCOTEC UK is determined, wherever possible by the hierarchy of method selection outlined in Environment Protection Agency Technical Guidance Note (Monitoring) AG2.

MONITORING METHODS						
Species	**Method** Standard Reference Method / Alternative Method	**SOCOTEC UK Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Limit of Detection (LOD)**	**Calculated MU +/- %**
TPM	SRM - EN 13284-1	AE 104	1015	Yes	0.22 mg/m³	6.1%
Formaldehyde	USEPA M316	AE 114	1015	Yes	0.01 mg/m³	10.8%
NO_X	SRM - EN 14792:2017	AE 102	1015	Yes	0.86 mg/m³	8.2%
CO	SRM - EN 15058:2017	AE 102	1015	Yes	0.57 mg/m³	216.9%
O_2	AM - EN 14789:2017	AE 102	1015	Yes	0.01%	20.3%
H_2O	SRM - EN 14790	AE 105	1015	Yes	0.01%	2.55%
Velocity	SRM - EN ISO 16911-1	AE 154	1015	Yes	5 Pa	2.54%
-	-	-	-	-	-	-

EXECUTIVE SUMMARY

Analytical Methods

The following tables list the analytical methods employed together with the custody and archiving details:

SAMPLING METHODS WITH SUBSEQUENT ANALYSIS							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	UKAS Accredited Lab Analysis	Analysis Lab	Sample Archive Location	Archive Period
TPM	Gravimetric	AE 106	1015	Yes	SOCOTEC UK (East Kilbride)	SOCOTEC UK (East Kilbride)	8 Weeks
Formaldehyde	Spectrophotometry	M103	0605	Yes	RPS	RPS	8 Weeks
-	-	-	-	-	-	-	-

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	MCERTS Accredited Analysis	Laboratory	Data Archive Location	Archive Period
NO_X	Chemiluminescence	AE 102	1015	Yes	SOCOTEC UK (East Kilbride)	SOCOTEC UK (East Kilbride)	5 years
CO	Non Dispersive Infra Red	AE 102	1015	Yes	SOCOTEC UK (East Kilbride)	SOCOTEC UK (East Kilbride)	5 years
O_2	Zirconia Cell	AE 102	1015	Yes	SOCOTEC UK (East Kilbride)	SOCOTEC UK (East Kilbride)	5 years
H_2O	Gravimetric	AE 105	1015	Yes	SOCOTEC UK (East Kilbride)	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	1	Pa	>= 5 Pa	No	EN 15259
Lowest Gas Velocity	1.2	m/s	-	-	-
Highest Gas Velocity	34.8	m/s	-	-	-
Ratio of Gas Velocities	28.8	: 1	< 3 : 1	No	EN 15259
Mean Velocity	15.8	m/s	-	-	-
Maximum angle of flow with regard to duct axis	NM	°	< 15°	-	EN 15259
No local negative flow	Yes	-	-	Yes	EN 15259

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Circular	-
Depth	2.30	m
Width	-	m
Area	4.16	m^2
Port Depth	90	mm

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

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

AG1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	No
Platform has 2 levels of handrails (approximately 0.5 m & 1.0 m high)	Yes
Platform has vertical base boards (approximately 0.25 m high)	Yes
Platform has removable chains / self closing gates at the top of ladders	Yes
Handrail / obstructions do not hamper insertion of sampling equipment	No
Depth of Platform = >Stack depth / diameter + wall and port thickness + 1.5m	No

Sampling Platform Improvement Recommendations (if applicable)

Although the monitoring position doesn't comply with most of the sampling plane validation criteria described in AG1, EN 15259, EN 16911-1, it is the safest & only real means of access practically possible.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Nozzle size

Due to the high velocities at the sampling point selected in the stack a 4mm nozzle was required to achieve isokinetic monitoring, this does not completely adhere to EN 13284-1.

Sample Line & Sample Point

It was only possible to sample from one representative sampling point for all isokinetic monitoring due to a number of factors i.e. flow being excessively high, swirl being greater than 15° & negative flow experienced throughout sample point locations. This sampling location does not therefore comply with all the requirements of AG1 & IS EN 16911-1.

Velocity & Volumetric Flow Rates

As this sampling location shows high levels of turbulence throughout the results from the standard flow traverse are only indicative. In the past, reports detailing the volumetric flow rate according to fan rating have been used to calculate mass emission rates for this stack.

Negative Flow

During instances of negative flow during the traverse a default figure of 0.01 mmH2O was entered into the traverse data spreadsheet.

Flow Traverse

Due to the erratic nature of the flow at the sampling position a 45 point flow traverse was carried out on each line.

APPENDICES

CONTENTS

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	**Method** Standard Reference Method / Alternative Method	**SOCOTEC UK Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Number of Samples**
TPM	SRM - EN 13284-1	AE 104	1015	Yes	1
Formaldehyde	USEPA M316	AE 114	1015	Yes	1
NOx	SRM - EN 14792:2017	AE 102	1015	Yes	1
CO	SRM - EN 15058:2017	AE 102	1015	Yes	1
O_2	AM - EN 14789:2017	AE 102	1015	Yes	1
H_2O	SRM - EN 14790	AE 105	1015	Yes	1
Velocity	SRM - 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	LEK 9.30	Horiba PG-250 Analyser	LEK 12.2	Laboratory Balance	LEK 15.21
Box Thermocouples	LEK 9.30	FT-IR Gasmet	-	Tape Measure	-
Meter In Thermocouple	LEK 9.31	FT-IR Oven Box	-	Stopwatch	LEK 17.11
Meter Out Thermocouple	LEK 9.31	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LEK 17.11	Signal 3030 FID	-	Barometer	LEK 16.8
Oven Box	-	Servomex	-	Digital Micromanometer	-
Probe	LEK 6.2	JCT Heated Head Filter	-	Digital Temperature Meter	-
Probe Thermocouple	LEK 3.7	Thermo FID	-	Stack Thermocouple	LEK 3.90
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LEK 9.18	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LEK 23.12	Chiller (JCT/MAK 10)	-	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	LEK 8.23	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	-	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	LEK 8.23
Inclinometer (Swirl Device)	LEK 24.10		-	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 +/- %
Nitric Oxide	LEK 123	BOC	200.9	-	2.0
Carbon Monoxide	LEK 116	BOC	164	-	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**
Hugh Mcmahon	MM 15 1347	MCERTS Level 2	Sep-20	Feb-22	May-22	Jul-22	Feb-22	Sep-20
Shane Thompstone	MM 16 1395	MCERTS Level 1	Oct-21	-	-	-	-	Oct-21

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY					
Parameter	**Sampling Times**	**Concentration mg/m³**	**Uncertainty mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	09:22 - 10:22 11 January 2018	8.12	0.49	20	2382
Blank	-	0.22	-	-	-

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	AC8748	0.09503	0.10112	0.00609	185.29110	185.29260	0.00150	0.00759

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	AC8760	0.09691	0.09687	-0.00004	202.72920	202.72930	0.00010	0.00021

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	mm Hg	778.51
Stack static pressure, P_{static}	mm H_2O	61.59
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	783.04
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	123.0
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.153258
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.845
Gas meter correction factor, Y_d		0.937
Mean dry gas meter temperature, T_m		10.750
Mean pressure drop across orifice, DH	mmH_2O	18.405
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		0.781
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9347
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		17.6
% 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}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1640
	%	16.40
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.88
Mean of velocity heads, DP_{avg}	mm H_2O	35.83
Mean square root of velocity heads, ÖDP		5.99
Mean stack gas temperature, T_s	°C	57
$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	22.97

Molecular weight of dry gas, M_d		
CO_2	%	1.76
O_2	%	17.63
Total	%	19.39
N_2 (100 -Total)	%	80.61
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.99
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.19
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	4.16
$Q_a = (60)(A_s)(V_s)$	m³/min	5727.1
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	4087.1
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	4888.71
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	4.00
Nozzle area, A_n	mm^2	12.57
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	105.3
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00609
Mass collected in probe, M_p	g	0.00150
Total mass collected, M_n	g	0.00759
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	8.121
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	9.713
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	No O2 Ref
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		2381.96

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER QUALITY ASSURANCE CHECKLIST

LEAK RATE						
Run	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable?
Run 1	13.19	0.01	0.01	-558.8	0.26	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	105.35	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	1.0	Yes

The above is based on both the Filter and rinse uncertainty

BLANK VALUE				
Run	Overall Blank Value mg/m^3	Daily Emission Limit Value mg/m^3	Acceptable Blank Value mg/m^3	Overall Blank Acceptable mg/m^3
Blank 1	0.22	20	2.0	Yes

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

FORMALDEHYDE SUMMARY					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	09:22 - 10:22 11 January 2018	0.44	0.01	20	128
Field Blank	-	0.01	-	-	-

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	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	13.2	0.01	0.01	0.26	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Max. Storage / Transit Temp. °C	Type of Absorbers	Absorption Solutions
Run 1	Glass Fibre	47	160	23	Glass	HPLC Water

FORMALDEHYDE ABSORPTION EFFICIENCY

Parameter	**Total ug**	**IMP C ug**	**Absorption Efficiency %**	**Acceptable Absorption Efficiency %**	**Absorption Efficiency Acceptable ?**
Run 1	409.35	150	63	95	N/A- < 1mg/m³

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	mm Hg	779	Pitot tube velocity constant, K_p		34.97
Stack static pressure, P_{static}	mm H_2O	62	Velocity pressure coefficient, C_p		0.88
$P_s = P_b + (P_{static})$ / 13.6	mm Hg	783	Mean of velocity heads, DP_{avg}	mm H_2O	35.83
			Mean square root of velocity heads, ÖDP		5.99
Vol. of water vapour collected, V_{wstd}			Mean stack gas temperature, T_s	°C	57
Moisture trap weight increase,Vlc	g	-			
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$V_s = (K_p)(C_p)(ÖDP)(Ö(T_s + 273)) / (M_s)(P_s)$	m/s	23.0
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		0.8450	Area of stack, A_s	m^2	4.16
Gas meter correction factor, Y_d		0.9367	$Q_a = (60)(A_s)(V_s)$	m³/min	5727
Mean dry gas meter temperature, T_m		10.75	**Dry total flow of stack gas, Q_{std}**		
Mean pressure drop across orifice, DH	mmH_2O	18.41	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = (0.3592)(V_m)(P_b+(DH/13.6))(Y_d) / T_m + 273$		0.78	$Q_{std} = (Q_a)P_s(0.3592)(1-B_{wo}) / (T_s) +273$	m³/min	4087
Volume of gas metered wet, V_{mstw}			**Wet total flow of stack gas, Q_{stw}**		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.9347	$Q_{stw} = (Q_a)P_s(0.3592) / (T_s) +273$	m³/min	4889
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Dry total flow of stack gas at X% O_2, Q_{stdO2}**		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	$Q_{stdO2} = (Q_a)P_s(0.3592)(1-B_{wo})(O_2REF) / (T_s) +273$	m³/min	No O2 Ref
% oxygen measured in gas stream, act%O_2		17.63			
% oxygen reference condition		21	**Percent isokinetic, %I**		
O_2 Reference Factor: $O2\ Ref = 21.0 - act\%O2 / 21.0 - ref\%O2$		No O2 Ref	Nozzle diameter, D_n	mm	4.00
			Nozzle area, A_n	mm^2	12.57
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	No O2 Ref	Total sampling time, q	min	60
Moisture content, B_{wo}			$\%I = (4.6398E6)(T_s+273)(V_{mstd}) / (P_s)(V_s)(A_n)(q)(1-B_{wo})$	%	105
$B_{wo} = V_{wstd} / (V_{mstd} + V_{wstd})$		0.1640			
	%	16.40	Acceptable isokinetic range 95% to 115%		Yes
Moisture by FTIR	%	-	**Formaldehyde Concentration, C**		
Molecular weight of dry gas, M_d			Mass collected , M	ug	409
CO_2		1.76	$C_{wet} = M_n / V_{mstw}$	mg/m³	0.438
O_2		17.63			
Total		19.39	$C_{dry} = M_n / V_{mstd}$	mg/m³	0.524
N_2 (100 -Total)		80.61			
			$C_{dry@X\%O2} = M_n / V_{mstd@X\%oxygen}$	mg/m³	No O2 Ref
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.99			
Molecular weight of wet gas, M_s			**Formaldehyde Emission Rates, E**		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.2	$E = [(C_{wet})(Q_{stw})(60)] / 1000$	g/hr	128.47

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GASES SUMMARY

Test	Sampling Time and Date	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
NOx	09:25 - 10:25 11 January 2018	66.8	0.86	110	12909
CO	09:25 - 10:25 11 January 2018	5.37	0.57	600	1037

Test	Sampling Time and Date	Concentration %	LOD %
O_2	09:25 - 10:25 11 January 2018	20.3	0.01

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

PRE-SAMPLING CALIBRATION DATA

Date	11 January 2018
Start Time	08:55
End Time	09:02

Chiller Temperature (°C)	2.5
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 %
NO	500	2.00	198.9	0.50	1.00	199.4	66	-0.25
CO	500	3.00	166.0	0.20	0.80	163.2	45	1.69
O_2	25	0.00	20.90	0.10	0.10	20.93	37	-0.14

POST-SAMPLING CALIBRATION DATA

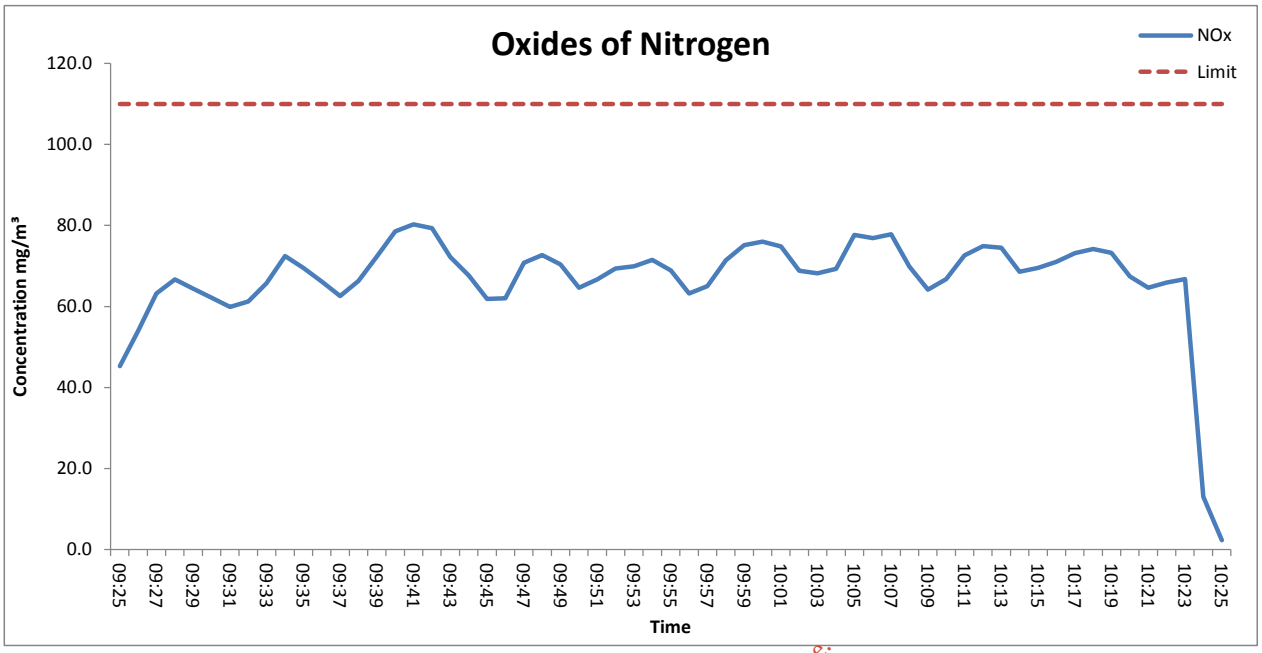
Date	11 January 2018
Start Time	01:26
End Time	12:11

Chiller Temperature (°C)	2.5
Requirement	< 4°C
Compliant	Yes

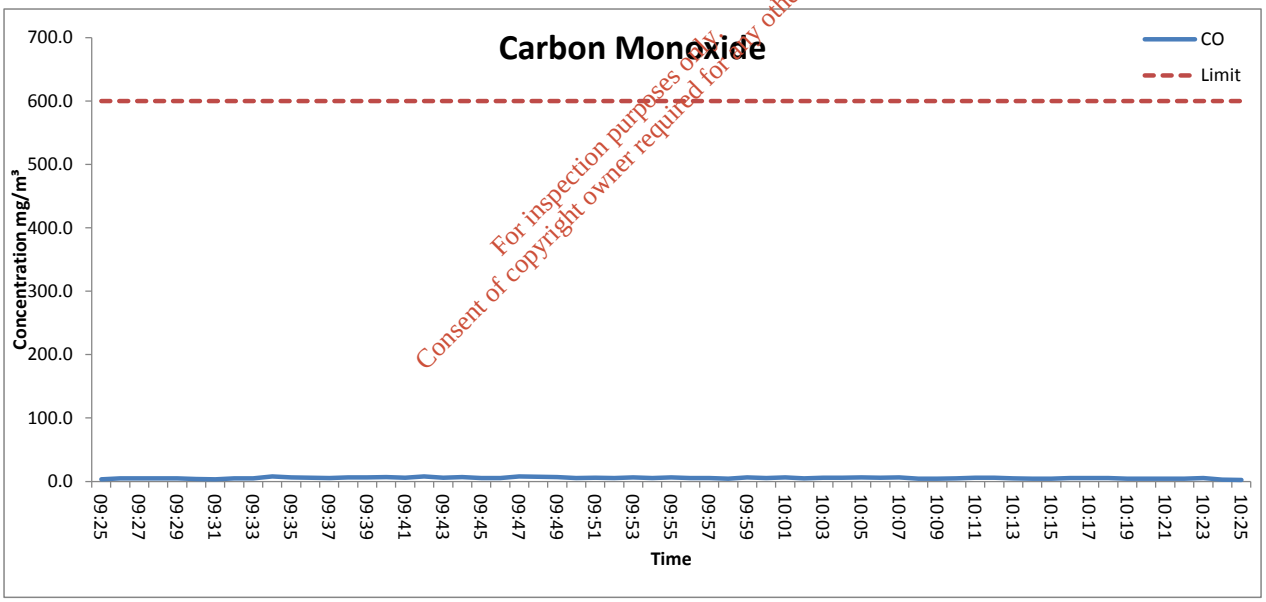
Gas	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
NO	0.20	199.9	-0.16	0.26
CO	1.00	165.0	0.04	0.32
O_2	0.10	20.90	0.00	-0.12

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

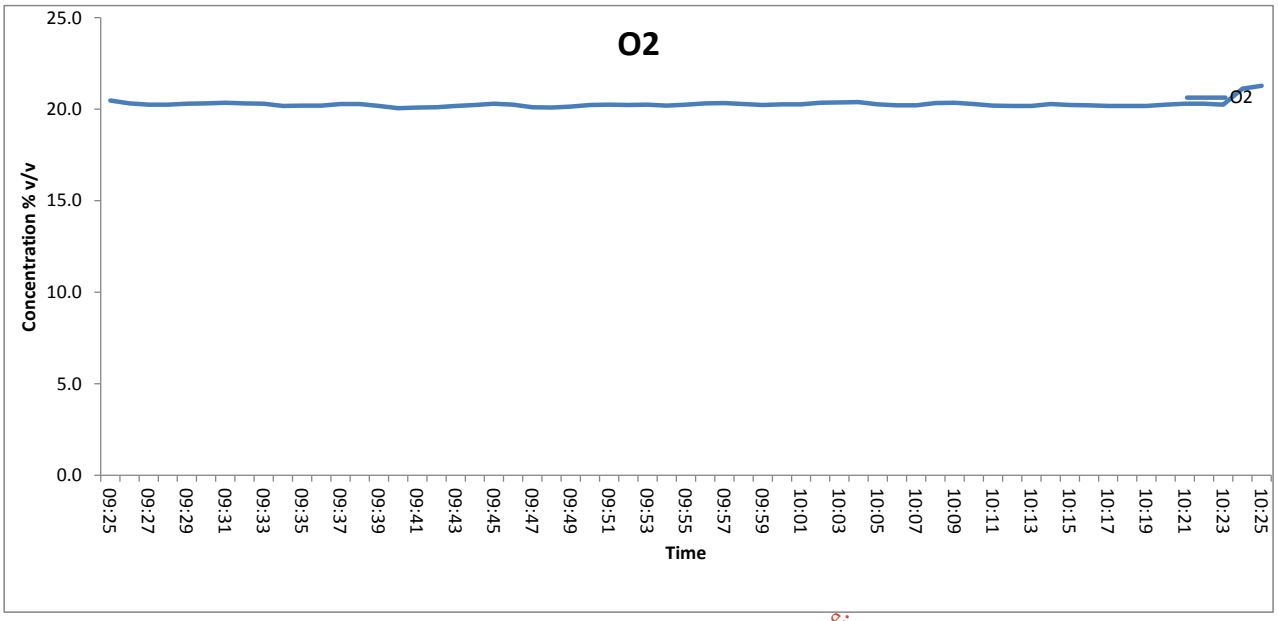
OXIDES OF NITROGEN (as NO_2) EMISSIONS CHART



CARBON MONOXIDE EMISSIONS CHART



OXYGEN EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Isokinetic							
Test Number	Sampling Time and Date	Start Weight kg	End Weight kg	Total gain kg	Concentration %	LOD %	Uncertainty %
Run 1	09:22 - 10:22 11 January 2018	3.6574	3.7804	0.1230	16.4	0.0	2.6

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	935	13.2	0.01	0.01	0.264	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	2.30	m
Stack Width, W	-	m
Stack Area, A	4.16	m^2
Average stack gas temperature	60	°C
Stack static pressure	0.6	kPa
Barometric Pressure	100.3	kPa

Stack Gas Composition & Molecular Weights								
Component	Molar Mass M	Density kg/m³ p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m³ pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m³ pi
CO_2	44	1.963059	1.760000	0.017600	0.034550	1.471410	0.014714	0.028885
O_2	32	1.427679	20.278497	0.202785	0.289512	16.953396	0.169534	0.242040
N_2	28	1.249219	77.961503	0.779615	0.973910	65.178016	0.651780	0.814216
H_2O	18	0.803070	-	-	-	16.397179	0.163972	0.131681

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2980	kg/m^3
Wet Density (STP), P_{STW}	1.2168	kg/m^3
Dry Density (Actual), P_{Actual}	1.0599	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.994	kg/m^3

Where:

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

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

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

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	11 January 2018
Time of Survey	08:49
Velocity Measurement Device:	S-Type Pitot

Sampling Line A								
Traverse Point	Distance into duct (m)	DP pt mmH_2O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
1	0.05	53.0	519	60	27.8	115.4	-	NM
2	0.10	55.0	539	60	28.3	117.6	-	NM
3	0.15	58.0	568	60	29.1	120.8	-	NM
4	0.20	56.0	549	60	28.6	118.7	-	NM
5	0.26	55.0	539	60	28.3	117.6	-	NM
6	0.31	56.0	549	60	28.6	118.7	-	NM
7	0.36	55.0	539	60	28.3	117.6	-	NM
8	0.41	53.0	519	60	27.8	115.4	-	NM
9	0.46	18.0	176	60	16.2	67.3	-	NM
10	0.51	11.0	108	60	12.7	52.6	-	NM
11	0.56	15.0	147	60	14.8	61.4	-	NM
12	0.61	2.0	20	60	5.4	22.4	-	NM
13	0.66	2.0	20	60	5.4	22.4	-	NM
14	0.71	5.0	49	60	8.5	35.5	-	NM
15	0.77	6.0	59	60	9.3	38.8	-	NM
16	0.82	9.0	88	60	11.4	47.6	-	NM
17	0.87	9.0	88	60	11.4	47.6	-	NM
18	0.92	9.0	88	60	11.4	47.6	-	NM
19	0.97	12.0	118	60	13.2	54.9	-	NM
20	1.02	0.1	1	60	1.2	5.0	-	NM
21	1.07	0.1	1	60	1.2	5.0	-	NM
22	1.12	0.1	1	60	1.2	5.0	-	NM
23	1.17	0.1	1	60	1.2	5.0	-	NM
24	1.22	20.0	196	60	17.1	70.9	-	NM
25	1.28	32.0	314	60	21.6	89.7	-	NM
26	1.33	17.0	167	60	15.7	65.4	-	NM
27	1.38	51.0	500	60	27.3	113.2	-	NM
28	1.43	30.0	294	60	20.9	86.8	-	NM
29	1.48	33.0	323	60	21.9	91.1	-	NM
30	1.53	34.0	333	60	22.3	92.5	-	NM
31	1.58	54.0	529	60	28.0	116.5	-	NM
32	1.63	53.0	519	60	27.8	115.4	-	NM
33	1.68	55.0	539	60	28.3	117.6	-	NM
34	1.73	44.0	431	60	25.3	105.2	-	NM
35	1.79	41.0	402	60	24.4	101.5	-	NM
36	1.84	32.0	314	60	21.6	89.7	-	NM
37	1.89	29.0	284	60	20.5	85.4	-	NM
38	1.94	34.0	333	60	22.3	92.5	-	NM
39	1.99	39.0	382	60	23.8	99.0	-	NM
40	2.04	0.1	1	60	1.2	5.0	-	NM
41	2.09	40.0	392	60	24.1	100.3	-	NM
42	2.14	73.0	715	60	32.6	135.5	-	NM
43	2.19	77.0	755	60	33.5	139.1	-	NM
44	2.24	82.0	804	60	34.6	143.6	-	NM
45	2.30	83.0	813	60	34.8	144.5	-	NM
Mean	-	33.2	325	60	19.6	81.3	-	-

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt mmH_2O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
1	0.05	0.1	1	60	1.2	5.0	-	NM
2	0.10	52.0	510	60	27.5	114.3	-	NM
3	0.15	55.0	539	60	28.3	117.6	-	NM
4	0.20	56.0	549	60	28.6	118.7	-	NM
5	0.26	0.1	1	60	1.2	5.0	-	NM
6	0.31	50.0	490	60	27.0	112.1	-	NM
7	0.36	56.0	549	60	28.6	118.7	-	NM
8	0.41	55.0	539	60	28.3	117.6	-	NM
9	0.46	0.1	1	60	1.2	5.0	-	NM
10	0.51	18.0	176	60	16.2	67.3	-	NM
11	0.56	12.0	118	60	13.2	54.9	-	NM
12	0.61	55.0	539	60	28.3	117.6	-	NM
13	0.66	16.0	157	60	15.3	63.4	-	NM
14	0.71	24.0	235	60	18.7	77.7	-	NM
15	0.77	37.0	363	60	23.2	96.5	-	NM
16	0.82	55.0	539	60	28.3	117.6	-	NM
17	0.87	19.0	186	60	16.6	69.1	-	NM
18	0.92	0.1	1	60	1.2	5.0	-	NM
19	0.97	0.1	1	60	1.2	5.0	-	NM
20	1.02	0.1	1	60	1.2	5.0	-	NM
21	1.07	0.1	1	60	1.2	5.0	-	NM
22	1.12	0.1	1	60	1.2	5.0	-	NM
23	1.17	0.1	1	60	1.2	5.0	-	NM
24	1.22	0.1	1	60	1.2	5.0	-	NM
25	1.28	0.1	1	60	1.2	5.0	-	NM
26	1.33	0.1	1	60	1.2	5.0	-	NM
27	1.38	0.1	1	60	1.2	5.0	-	NM
28	1.43	10.0	98	60	12.1	50.1	-	NM
29	1.48	2.0	20	60	5.4	22.4	-	NM
30	1.53	9.0	88	60	11.4	47.6	-	NM
31	1.58	14.0	137	60	14.3	59.3	-	NM
32	1.63	34.0	333	60	22.3	92.5	-	NM
33	1.68	52.0	510	60	27.5	114.3	-	NM
34	1.73	64.0	627	60	30.5	126.9	-	NM
35	1.79	0.1	1	60	1.2	5.0	-	NM
36	1.84	71.0	696	60	32.2	133.6	-	NM
37	1.89	0.1	1	60	1.2	5.0	-	NM
38	1.94	73.0	715	60	32.6	135.5	-	NM
39	1.99	0.1	1	60	1.2	5.0	-	NM
40	2.04	0.1	1	60	1.2	5.0	-	NM
41	2.09	0.1	1	60	1.2	5.0	-	NM
42	2.14	0.1	1	60	1.2	5.0	-	NM
43	2.19	0.1	1	60	1.2	5.0	-	NM
44	2.24	0.1	1	60	1.2	5.0	-	NM
45	2.30	0.1	1	60	1.2	5.0	-	NM
Mean	-	19.8	194	60	12.1	50.1	-	-

PRELIMINARY STACK SURVEY QUALITY ASSURANCE CHECKLIST

PITOT LEAK CHECK								
Run	Pre Traverse Leak Rate				Post Traverse Leak Rate			
	Start Value Pa	End Value Pa	Difference %	Outcome	Start Value Pa	End Value Pa	Difference %	Outcome
Run 1	90	90	0.0	Pass	103	102	1.0	Pass

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

S-Type Pitot Stagnation Check				
Run	Stagnation (Pa)	Reference (Pa)	Difference (Pa)	Outcome (Permitted +/- 10 Pa)
Run 1	102	101	1.0	Pass

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

Sampling Plane Validation Criteria				
EA Technical Guidance Note (Monitoring) M1	Result	Units	Requirement	Compliant
Lowest Differential Pressure	1	Pa	>= 5 Pa	No
Lowest Gas Velocity	1.2	m/s	-	-
Highest Gas Velocity	34.8	m/s	-	-
Ratio of Gas Velocities	28.8	-	< 3 : 1	No
Maximum angle of flow with regard to duct axis	NM	°	< 15°	-
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	**15.8**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	60	0	°C
Total Pressure	100.9	101.3	kPa
Oxygen	17.6	21	%
Moisture	16.40	16.40	%
Pitot tube calibration coefficient, K_{pt}	0.89		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	15.82	m/s
Stack Area (A)	4.16	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	236634	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	193231	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	161547	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	193231	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 (($20.9 - O_2a$) / ($20.9 - O_2s$))

Nomenclature:

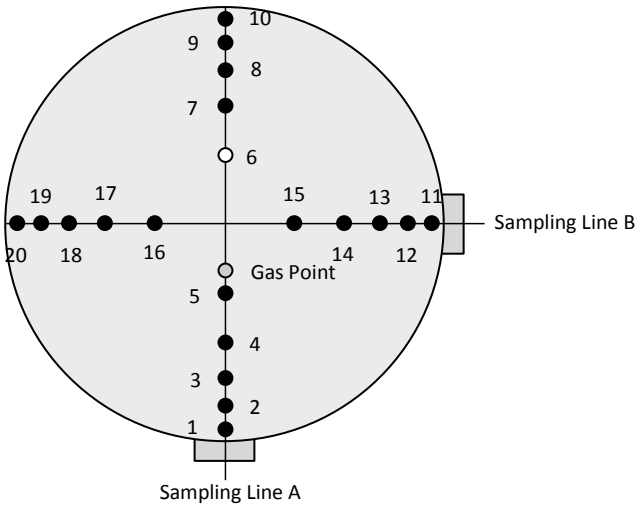
Ts = Absolute Temperature, Standard Conditions, 273 K
Ps = Absolute Pressure, Standard Conditions, 101.3 kPa
Ta = Absolute Temperature, Actual Conditions, K
Pa = Absolute Pressure, Actual Conditions, kPa
Ma = Water vapour, Actual Conditions, % Vol
Ms = Water vapour, Reference Conditions, % Vol
O_2a = Oxygen, Actual Conditions, % Vol
O_2s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK DIAGRAM

	Value	Units
Stack Depth	2.30	m
Stack Width	-	m
Area	4.16	m^2

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	33	0.76	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 °
Point Not Used	2.6	0.06	-
Point Not Used	8.2	0.19	-
Point Not Used	14.6	0.34	-
Point Not Used	22.6	0.52	-
Point Not Used	34.2	0.79	-
6	65.8	1.51	-
Point Not Used	77.4	1.78	-
Point Not Used	85.4	1.96	-
Point Not Used	91.8	2.11	-
Point Not Used	97.4	2.24	-
Point Not Used	2.6	0.06	-
Point Not Used	8.2	0.19	-
Point Not Used	14.6	0.34	-
Point Not Used	22.6	0.52	-
Point Not Used	34.2	0.79	-
Point Not Used	65.8	1.51	-
Point Not Used	77.4	1.78	-
Point Not Used	85.4	1.96	-
Point Not Used	91.8	2.11	-
Point Not Used	97.4	2.24	-

SAMPLING LOCATION

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	0.001	2.0	0.50	1.0	N/A	0.2100	-	-
as a %	0.13	0.61	0.48	1.0	N/A	1.12340	0.08	0.001
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**

Run	Volume (STP)	Mass of particulate	O_2 Correction	Leak	Uncollected Mass	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	0.67	7.5900	1.0	0.004	0.0001	-
MU as mg/m^3	0.10	0.2247	-	0.004	0.0001	**0.25**
MU as %	1.27	2.7668	-	0.044	0.0016	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.49**	**mg/m^3**	**6.09**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

MEASUREMENT UNCERTAINTY BUDGET - ISOKINETIC FORMALDEHYDE

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Limit of Detection	Leak
	m³	K	kPa	% by volume	% by volume	% by mass	%
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**≤ 5% of ELV**	**<=2%**
Run 1	0.934660773	283.75	109.84	1.0	-	0.97665	-
as a %	0.11	0.70	0.46	1.0	-	0.06	0.08
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**

Run	Volume (STP)	Mass of Formaldehyde	O2 Correction	Leak	Lab Uncertainty	Combined uncertainty
	m³	mg	-	mg/m³	mg	
Run 1	0.9751	0.9767	-	0.0002	-	-
MU as mg/m³	0.0057	0.0116	-	0.0002	0.0197	**0.0236**
MU as %	1.3094	2.6403	-	0.0438	4.5	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.05**	**mg/m³**	**10.76**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Leak
	m³	K	kPa	% by volume	% by volume	%
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 2%**
Run 1	0.001	2.0	0.50	1.0	N/A	-
as a %	0.13	0.61	0.48	1.0	N/A	0.08
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP)	Mass Gained	O_2 Correction	Leak	Uncollected Mass	Combined uncertainty
	m³	mg	-	mg/m³	mg	
Run 1	0.67	123000	1.0	68.89	58	-
MU as % v/v	0.25	0.02	-	0.01	0.009	**0.25**
MU as %	1.27	0.08	-	0.04	0.05	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.51**	**% v/v**	**2.55**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXIDES OF NITROGEN

Limit value	110	mg/m^3
Concentration @ Ref conditions	66.8	mg/m^3
Cal gas conc	412	mg/m^3
Analyser Full Scale	1025	mg/m^3

	Value	Units	specification	MU Met?
Response time	66	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	-0.16	% full scale	<2% range / 24hr	Yes
Span drift	0.26	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	0.5	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.50	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence zero / span	0.50	% full scale/10K	<3% range / 10 K	Yes
Combined interference	3.00	% range	<4% of Range	Yes
dependence on voltage	0.32	% 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)	0.32	% 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	$U_{d,z}$	-0.092
short term span drift	$U_{d,s}$	0.150
influence of Ambient Temp at Zero	$U_{t,z}$	0.100
influence of Ambient Temp at Span	$U_{t,s}$	1.800
influence of sample gas pressure	U_p	0.000
influence of sample gas flow	U_{fit}	0.346
influence of supply voltage	U_v	0.000
Combined Interfence	U_i	0.004
Uncertainty of Cal gas	U_{adj}	2.009

Measurement uncertainty (Concentration Measured)	66.81	mg/m^3
Combined uncertainty	2.74	mg/m^3
Expanded at a 95% confidence interval	5.47	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**4.98**	**% ELV**

Expanded uncertainty expressed with a level of confidence of 95%	**5.47**	**mg/m^3**

Expanded uncertainty expressed with a level of confidence of 95%	**8.19**	**% value**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON MONOXIDE

Limit value	600	mg/m^3
Concentration @ Ref conditions	5.4	mg/m^3
Cal gas conc	205.0	mg/m^3
Analyser Full Scale	625	mg/m^3

Performance characteristics	Value	Units	specification	MU Met?
Response time	45	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	60	minutes	-	-
Number of readings in measurement	60	-	-	-
Repeatability at zero	0.1	% 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	0.04	% full scale	<2% range / 24hr	Yes
Span drift	0.32	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	0.5	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	1.1	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence zero / span	2.5	0.9	<3% range / 10 K	Yes
Combined interference	0.03	% of Range	<4% of Range	Yes
dependence on voltage	-1.75	% 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)	0.02	% 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	$U_{d,s}$	0.02
influence of Ambient Temp zero	$U_{t,z}$	0.10
influence of Ambient Temp span	$U_{t,s}$	0.18
influence of sample gas pressure	U_p	-5.77
influence of sample gas flow	U_{fit}	0.35
influence of supply voltage	U_v	0.00
Combined Interfence	U_i	3.77
Uncertainty of Cal gas	U_{adj}	0.82

Measurement uncertainty (Concentration Measured)	6.4	mg/m^3
Combined uncertainty	7.0	mg/m^3
Expanded uncertainty	13.9	mg/m^3

Expanded uncertainty expressed with a level of confidence of 95%	**2.32**	**% ELV**
Expanded uncertainty expressed with a level of confidence of 95%	**13.9**	**mg/m^3**
Expanded uncertainty expressed with a level of confidence of 95%	**217**	**% value**

Developed for the STA by R Robinson, NPL

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

Reference	N/A	%vol
Reported Concentration	20.28	%vol
Calibration gas	20.95	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	37	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	0.00	% full scale	<2% range / 24hr	Yes
Span drift	-0.12	% 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	9	<3% range / 10 K	Yes
Combined interference	0.14	% range	<4% of Range	Yes
dependence on voltage	0.01	% 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	$U_{d,z}$	0.0000
short term span drift	$U_{d,s}$	-0.0693
influence of Ambient Temp at Zero	$U_{t,z}$	0.0000
influence of Ambient Temp at Span	$U_{t,s}$	0.0540
influence of sample gas pressure	U_p	0.0000
influence of sample gas flow	U_{fit}	0.0173
influence of supply voltage	U_v	0.0006
Combined Interfence	U_i	0.0485
Uncertainty of Cal gas	U_{adj}	0.1048

Measurement uncertainty (Concentration Measured)	20.28	%
Combined uncertainty	0.16	%
Expanded uncertainty	0.32	%

Expanded uncertainty expressed with a level of confidence of 95%	**0.32**	**%**
Expanded uncertainty expressed with a level of confidence of 95%	**0.07**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	15.8	m/s
Measured Volumetric Flow rate at Actual Conditions	236634	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	-	0.43		
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	5.78	<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	1.70	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	515		
Uncertainty associated with the estimate of density	-	0.008		
Uncertainty associated with the measurement of local velocity	-	0.0001		
Uncertainty associated with the measurement of mean velocity	-	0.0002		

Measurement Uncertainty - Velocity	m/s
Combined uncertainty	0.21
Expanded uncertainty at a 95% Confidence Interval	0.40

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	1.30
Expanded uncertainty at a 95% Confidence Interval	2.54

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	6268
Expanded uncertainty at a 95% Confidence Interval	12286

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	2.65
Expanded uncertainty at a 95% Confidence Interval	5.19

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

END OF REPORT

Thank you for choosing SOCOTEC UK 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