STACK EMISSIONS MONITORING REPORT

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Permit Reference:
DEFRA Process Guidance Note: PG 3/15 (12)

Release Point:
Coating Plant

Sampling Date(s):
19th October 2018

SOCOTEC UK Job Number:	LNO 14547
Report Date:	5th November 2018
Version:	1
Report By: MCERTS Number: MCERTS Level: Technical Endorsements:	Andy Hegarty MM 03 397 MCERTS Level 2 - Team Leader 1, 2, 3 & 4
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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

CEMEX UK Materials Limited operates a roadstone coating process at Gromsby which is subject to DEFRA Process Guidance Note PG 3/15 (12), under the Environmental Permitting Regulations 2010.

SOCOTEC UK LTD were commissioned by CEMEX UK Materials Limited 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 DEFRA Process Guidance Note, PG 3/15 (12).

Plant

Coating Plant

Operator

CEMEX UK Materials Limited
Grimsby Coated Stone
Gilbey Road
Pyewipe
Grimsby
Lincolnshire
DN31 2SJ

DEFRA Process Guidance Note: PG 3/15 (12)

Stack Emissions Monitoring Test House

SOCOTEC UK - 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.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Limit**	**MCERTS accredited result**
Total Particulate Matter	mg/m³	30	1.2	50	✓
Particulate Emission Rate	g/hr	463	18.5	-	
Moisture	%	2.6	0.09	-	✓
Stack Gas Temperature	°C	78	-	-	✓
Stack Gas Velocity	m/s	19.3	0.49	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	19667	1019	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	15524	804	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	15120	783	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	15524	804	-	

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	19 October 2018	08:29 - 09:01	32 minutes
Total Particulate Matter Run 2	19 October 2018	09:15 - 09:47	32 minutes
Preliminary Stack Traverse	19 October 2018	08:12	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Roadstone Coating
Continuous or batch	Continuous
Product Details	6mm, 10mm & 20mm
Part of batch to be monitored (if applicable)	When mixing
Normal load, throughput or continuous rating	30 - 40t/hr
Fuel used during monitoring	Kerosine
Abatement	Bag Filter
Plume Appearance	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 Agency Technical Guidance Note (Monitoring) M2.

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 - BS EN 13284-1	AE 104	1015	Yes	0.46 mg/m³	4%
H_2O	SRM - BS EN 14790	AE 105	1015	Yes	0.02%	3.4%
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	5 Pa	2.5%
Volumetric Flow Rate	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	-	5.2%

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

EXECUTIVE SUMMARY

Analytical Methods

The following tables list the analytical methods employed together with the custody 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 (Stockport)	SOCOTEC UK (Stockport)	8 Weeks

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	MCERTS Accredited Analysis	Laboratory	Data Archive Location	Archive Period
H_2O	Gravimetric	AE 105	1015	Yes	SOCOTEC UK (Stockport)	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	275	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	18.8	m/s	-	-	-
Highest Gas Velocity	20.1	m/s	-	-	-
Ratio of Gas Velocities	1.1	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	19.3	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	0.60	m
Width	-	m
Area	0.28	m^2
Port Depth	90	mm

SAMPLING LINES & POINTS		
	Isokinetic	**Non-Iso & Gases**
Sample port size	3.75 inch BSP	-
Number of lines used	1	-
Number of points / line	4	-
Duct orientation	Vertical	-
Filtration for TPM	In Stack	-

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

M1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	Yes
Platform has 2 levels of handrails (approximately 0.5 m & 1.0 m high)	Yes
Platform has vertical base boards (approximately 0.25 m high)	Yes
Platform has removable chains / self closing gates at the top of ladders	Yes
Handrail / obstructions do not hamper insertion of sampling equipment	Yes
Depth of Platform = >Stack depth / diameter + wall and port thickness + 1.5m	Yes

Sampling Platform Improvement Recommendations (if applicable)

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

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

CEMEX Deviation

Due to limited production on the day of the emissions monitoring, sampling was only possible over 2 sampling periods as opposed to the 3 sampling runs the process guidance note outlines as an ideal. BS EN 13284-1 stipulates a minimum sampling duration of 30mins, in order to obtain a compliant result this minimum duration for sampling has been met, the overall effect of not obtaining a third sample (or second, change as appropriate) is seen as negligible and the result fully compliant.

Sample Points

The sampling point requirements of EN 13284-1 could not be met as one of the sample ports is siezed. As required in MID 13284-1 for such situations the number of sampling points has been doubled.

Nozzle Size

Due to the high stack velocity a nozzle less than 6mm was used.

APPENDICES

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APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

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 UK Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Number of Samples**
TPM	SRM - BS EN 13284-1	AE 104	1015	Yes	2
H_2O	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 13-17	Horiba PG-250 Analyser	-	Laboratory Balance	LNO 0013/0014
Box Thermocouples	LNO 03-17	FT-IR Gasmet	-	Tape Measure	LNO 18-AH
Meter In Thermocouple	LNO 03-17	FT-IR Oven Box	-	Stopwatch	LNO 17-AH
Meter Out Thermocouple	LNO 03-17	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 03-17	Signal 3030 FID	-	Barometer	LNO 08-AH
Oven Box	-	Servomex	-	Digital Micromanometer	-
Probe	LNO 11-08	JCT Heated Head Filter	-	Digital Temperature Meter	-
Probe Thermocouple	LNO 10-08	Thermo FID	-	Stack Thermocouple	-
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LNO 06-AH	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LNO 14-AH	Chiller (JCT/MAK 10)	-	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	-	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	LNO 31-AH	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	-
Inclinometer (Swirl Device)	LNO 23-AH		-	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 +/- %
-	-	-	-	-	-

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
Andy Hegarty	MM 03 397	MCERTS Level 2	Jan-19	Oct-19	Dec-20	Aug-21	Dec-19	Jan-19
Lindsay Adams	MM 14 1275	MCERTS Level 2	May-21	May-20	Jul-20	Nov-20	Feb-21	Mar-19

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	08:29 - 09:01 19 October 2018	29	1.2	50	447
Run 2	09:15 - 09:47 19 October 2018	31	1.2	50	479
Blank	-	3.7	-	-	-

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	G8960	0.10735	0.11722	0.00987	190.84590	190.85120	0.00530	0.01517
Run 2	G8961	0.10702	0.11900	0.01198	199.98130	199.98580	0.00450	0.01648

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	G8991	0.10649	0.10647	-0.00002	168.35700	168.35900	0.00200	0.00198

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	769.51
Stack static pressure, P_{static}	mm H_2O	6.12
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	769.96
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	11.0
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.013706
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.534
Gas meter correction factor, Y_d		0.981
Mean dry gas meter temperature, T_m	°	10.500
Mean pressure drop across orifice, DH	mmH_2O	36.558
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$	m^3	0.513
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.5262
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		20.9
% oxygen reference condition		21
O_2 Reference Factor O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		No O2 Ref
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	No O2 Ref
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0260
	%	2.60
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.81
Mean of velocity heads, DP_{avg}	mm H_2O	29.50
Mean square root of velocity heads, ÖDP		5.43
Mean stack gas temperature, T_s	°C	81
$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	19.53

Molecular weight of dry gas, M_d		
CO_2	%	0.08
O_2	%	20.90
Total	%	20.98
N_2 (100 -Total)	%	79.02
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.85
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.57
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.28
$Q_a = (60)(A_s)(V_s)$	m³/min	331.3
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	251.9
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	258.59
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	4.88
Nozzle area, A_n	mm^2	18.73
Total sampling time, q	min	32
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	96.0
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00987
Mass collected in probe, M_p	g	0.00530
Total mass collected, M_n	g	0.01517
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	28.827
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	29.598
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	No O2 Ref
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		447.26

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 2 — TPM

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	769.51
Stack static pressure, P_{static}	mm H_2O	6.12
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	769.96
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.550
Gas meter correction factor, Y_d		0.981
Mean dry gas meter temperature, T_m		12.500
Mean pressure drop across orifice, DH	mmH_2O	37.452
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$	m^3	0.524
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.5383
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		20.9
% oxygen reference condition		21
O_2 Reference Factor O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		No O2 Ref
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	No O2 Ref
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0260
	%	2.60
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.81
Mean of velocity heads, DP_{avg}	mm H_2O	30.00
Mean square root of velocity heads, ÖDP		5.48
Mean stack gas temperature, T_s	°C	81
$V_s = \frac{(K_p)(C_p)(ÖDP)(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	19.69

Molecular weight of dry gas, M_d		
CO_2	%	0.08
O_2	%	20.90
Total	%	20.98
N_2 (100 -Total)	%	79.02
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.85
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.57
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.28
$Q_a = (60)(A_s)(V_s)$	m^3/min	334.1
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	254.0
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	260.82
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	4.88
Nozzle area, A_n	mm^2	18.73
Total sampling time, q	min	32
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	97.4
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.01198
Mass collected in probe, M_p	g	0.00450
Total mass collected, M_n	g	0.01648
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	30.62
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	31.44
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	No O2 Ref
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		479.13

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER QUALITY ASSURANCE CHECKLIST

LEAK RATE						
Run	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable?
Run 1	16.37	0.00	0.10	-228.6	0.33	Yes
Run 2	16.86	0.10	0.00	-254	0.34	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	96.00	Yes
Run 2	97.36	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m³	5% ELV mg/m³	LOD < 5% ELV
Run 1	0.46	2.5	Yes
Run 2	0.45	2.5	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	3.74	50	5.0	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	83	180	160
Run 2	Glass Fibre	47	83	180	160

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	08:29 - 09:01 19 October 2018	3.5460	3.5570	0.0110	2.6	0.02	3.4

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	32	526	16.4	0.00	0.10	0.33	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.60	m
Stack Width, W	-	m
Stack Area, A	0.28	m^2
Average stack gas temperature	78	^oC
Stack static pressure	0.06	kPa
Barometric Pressure	102.6	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	0.075238	0.000752	0.001477	0.073279	0.000733	0.001439
O_2	32	1.427679	20.900000	0.209000	0.298385	20.355654	0.203557	0.290613
N_2	28	1.249219	79.024762	0.790248	0.987193	76.966542	0.769665	0.961481
H_2O	18	0.803070	-	-	-	2.604525	0.026045	0.020916

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2871	kg/m^3
Wet Density (STP), P_{STW}	1.2744	kg/m^3
Dry Density (Actual), P_{Actual}	1.0159	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	1.006	kg/m^3

Where:

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

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

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

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	19 October 2018
Time of Survey	08:12
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	28.0	274	77	18.8	5.3	-	<15
2	0.15	32.0	314	77	20.1	5.7	-	<15
3	0.45	30.0	294	78	19.5	5.5	-	<15
4	0.55	28.0	274	78	18.8	5.3	-	<15
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	29.5	289	78	19.3	5.5	-	-

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 °
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	-	-

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	96	96	0.0	Pass	102	102	0.0	Pass

To complete a compliant pitot leak check a pressure of over 80 mmH O (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	60	60	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	274	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	18.8	m/s	-	-
Highest Gas Velocity	20.1	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} 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	**19.3**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	78	0	°C
Total Pressure	102.66	101.3	kPa
Oxygen	20.9	21	%
Moisture	2.60	2.60	%
Pitot tube calibration coefficient, K_{pt}	0.81		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	19.32	m/s
Stack Area (A)	0.28	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	19667	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	15524	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	15120	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	15524	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))

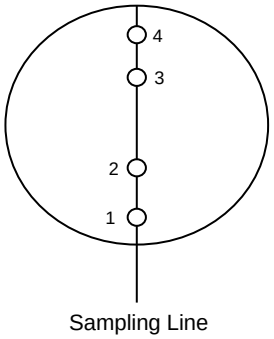
Nomenclature:
Ts = Absolute Temperature, Standard Conditions, 273 K
Ps = Absolute Pressure, Standard Conditions, 101.3 kPa
Ta = Absolute Temperature, Actual Conditions, K
Pa = Absolute Pressure, Actual Conditions, kPa
Ma = Water vapour, Actual Conditions, % Vol
Ms = Water vapour, Reference Conditions, % 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	0.60	m
Stack Width	-	m
Area	0.28	m^2

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



Isokinetic Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	8.3	0.05	< 15
2	25.0	0.15	< 15
3	75.0	0.45	< 15
4	91.7	0.55	< 15
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

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

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	0.2400	-	-
as a %	0.20	0.56	0.49	1.0	N/A	0.91213	0.61	0.004
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**
Run 2	0.0011	2.0	0.50	1.0	N/A	0.240	-	-
as a %	0.20	0.70	0.49	1.0	N/A	0.892	0.00000	0.004
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	0.40	15.1700	1.0	0.102	0.0011	-
MU as mg/m^3	0.37	0.4561	-	0.102	0.0022	**0.59**
MU as %	1.27	1.5821	-	0.353	0.0075	-
Run 2	0.52	16.4800	1.0	0.000	0.0011	-
MU as mg/m^3	0.41	0.4459	-	0.00000	0.0021	**0.60**
MU as %	1.3	1.4563	-	0.00000	0.0069	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**1.19**	**mg/m^3**	**4.12**	**%**

R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**1.21**	**mg/m^3**	**3.95**	**%**

(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 - 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 %	0.20	0.56	0.49	1.0	N/A	0.61
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	0.40	11000	1.0	75.69	58	-
MU as % v/v	0.03	0.02	-	0.01	0.014	**0.05**
MU as %	1.27	0.91	-	0.35	0.52	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.09**	**% v/v**	**3.37**	**%**

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	19.3	m/s
Measured Volumetric Flow rate at Actual Conditions	19667	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	-	0.45		
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	6.21	<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	1.79	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	524		
Uncertainty associated with the estimate of density	-	0.007		
Uncertainty associated with the measurement of local velocity	-	0.0002		
Uncertainty associated with the measurement of mean velocity	-	0.0002		

Measurement Uncertainty - Velocity	m/s
Combined uncertainty	0.25
Expanded uncertainty at a 95% Confidence Interval	0.49

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	1.3
Expanded uncertainty at a 95% Confidence Interval	2.5

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	520
Expanded uncertainty at a 95% Confidence Interval	1019

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	5.2

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