STACK EMISSIONS MONITORING REPORT

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Operator & Address:
CEMEX UK Materials Ltd Gilbey Road Grimsby DN31 2SJ

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

Release Point:
Coating Plant

Sampling Date(s):
9th April 2014

ESG Job Number:	LNO 11712
Report Date:	28th April 2014
Version:	1
Report By:	Lawrence Mason
MCERTS Number:	MM 07 849
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Report Approved By:	Andy Hegarty
MCERTS Number:	MM 03 397
Business Title:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Signature:	

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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

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

Environmental Scientifics Group Limited were commissioned by CEMEX UK Materials 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 Defra Process Guidance Note, PG 3/15 (12).

Plant

Coating Plant

Operator

CEMEX UK Materials Ltd
Gilbey Road
Grimsby
DN31 2SJ

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

Stack Emissions Monitoring Test House

Environmental Scientifics Group Limited - 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	16	0.62	50	✓
Particulate Emission Rate	g/hr	251	9.5	-	
Moisture	%	5.8	0.16	-	✓
Stack Gas Temperature	°C	64	-	-	✓
Stack Gas Velocity	m/s	18.5	-	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	18804	-	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	15175	-	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	14303	-	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	15175	-	-	

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	09 April 2014	08:33 - 09:05	32 minutes
Total Particulate Matter Run 2	09 April 2014	09:18 - 09:50	32 minutes
Stack Gas Flow Rate & Temperature Run 1	09 April 2014	08:20	-

EXECUTIVE SUMMARY

PROCESS DETAILS	
Parameter	**Process Details**
Description of process	Roadstone Coating
Continuous or batch	Batch
Product Details	Hardstone 6mm, 10mm & Base
Part of batch to be monitored (if applicable)	N/A
Normal load, throughput or continuous rating	55 t/hr
Fuel used during monitoring	Kerosene
Abatement	Bag Filter
Plume Appearance	Plume Visible

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by Environmental Scientifics Group Limited is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency Technical Guidance Note (Monitoring) M2. i.e. CEN, ISO, BS, US EPA etc.

MONITORING METHODS						
Species	**Method** Standard Reference Method / Alternative Method	**ESG Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Limit of Detection (LOD)**	**Calculated MU +/- %**
TPM	SRM - BS EN 13284-1	AE 104	1015	Yes	0.22 mg/m^3	3.8 %
H_2O	SRM - BS EN 14790	AE 105	1015	Yes	0.01%	2.7%
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	5 Pa	-

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 (ESG or Subcontract)**	**Sample Archive Location**	**Archive Period**
TPM	Gravimetric	AE 106	1015	Yes	ESG Stockport	ESG Stockport	3 months

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	ESG Stockport	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	255	Pa	>= 5 Pa	Yes	BS EN 13284-1
Lowest Gas Velocity	18.1	m/s	-	-	-
Highest Gas Velocity	18.9	m/s	-	-	-
Ratio of Gas Velocities	1.0	: 1	< 3 : 1	Yes	BS EN 13284-1
Mean Velocity	18.5	m/s	-	-	-
Maximum angle of flow with regard to duct axis	10	^{o}	< 15^{o}	Yes	BS EN 13284-1
No local negative flow	Yes	-	-	Yes	BS EN 13284-1

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 (CEN Methods)	**Isokinetic** (ISO Methods)	**Non-Iso & Gases**
Sample port size	4 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 the minimum duration for sampling has been met, the overall effect of not obtaining a third sample is seen as negligible and the result fully compliant.

One Sampling Line

Only one sampling line was available due to one port being stuck, the number of sampling points was doubled to meet the requirements of BS EN 13284-1.

APPENDICES

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APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	**Method** Standard Reference Method / Alternative Method	**ESG 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
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	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 13-03	Horiba PG-250 Analyser	-	Laboratory Balance	LNO 00-13, 00-12
Box Thermocouples	LNO 03-03	FT-IR	-	Tape Measure	LNO 24-LM
Meter In Thermocouple	LNO 03-03	FT-IR Oven Box	-	Stopwatch	-
Meter Out Thermocouple	LNO 03-03	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17-03	Signal 3030 FID	-	Barometer	LNO 08-LM
Oven Box	-	Servomex	-	Digital Micromanometer	-
Probe	LNO 11-27	JCT Heated Head Filter	-	Digital Temperature Meter	-
Probe Thermocouple	LNO 10-27	Thermo FID	-	Stack Thermocouple	-
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LNO 06-LM	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LNO 14-LM	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-LM	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	-
Inclinometer (Swirl Device)	LNO 23-LM		-	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.

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

STACK EMISSIONS MONITORING TEAM

Team Leader	Lawrence Mason MCERTS Level 2, Technical Endorsements 1, 2, 3 & 4 MM 07 849 MCERTS Expiry Date - Jun 2018 H&S Expiry Date - Jul 2017
Technician	Mark Derbyshire MCERTS Level 1, Technical Endorsement 1 MM 07 824 MCERTS Expiry Date - Dec 2017 H&S Expiry Date - Apr 2017

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	08:33 - 09:05 09 April 2014	17	0.63	50	264
Run 2	09:18 - 09:50 09 April 2014	15	0.60	50	237
Blank	-	0.31	-	-	-

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	G1342	0.10917	0.11827	0.00910	160.54090	160.54600	0.00510	0.01420
Run 2	G1343	0.11169	0.11945	0.00776	183.25690	183.26180	0.00490	0.01266

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	G1512	0.11012	0.11008	-0.00004	166.80010	166.80040	0.00030	0.00026

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	756.01
Stack static pressure, P_{static}	mm H_2O	12.24
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	756.91
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	38.5
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.047971
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.817
Gas meter correction factor, Y_d		1.0152
Mean dry gas meter temperature, T_m		15.125
Mean pressure drop across orifice, ΔH	mmH_2O	63.467
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		0.786
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.8341
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		21.0
% 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}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0575 5.75
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.85
Mean of velocity heads, ΔP_{avg}	mm H_2O	27.64
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.26
Mean stack gas temperature, T_s	°C	64
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	18.86

Molecular weight of dry gas, M_d		
CO_2	%	15.50
O_2	%	20.95
Total	%	36.45
N_2 (100 -Total)	%	63.55
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		31.32
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	30.55
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	320.1
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	243.4
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	258.22
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	5.84
Nozzle area, A_n	mm^2	26.74
Total sampling time, θ	min	32
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	106.7
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00910
Mass collected in probe, M_p	g	0.00510
Total mass collected, M_n	g	0.01420
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	17.024
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	18.062
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	No O2 Ref
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		263.75

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	756.01
Stack static pressure, P_{static}	mm H_2O	12.24
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	756.91
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		0.817
Gas meter correction factor, Y_d		1.0152
Mean dry gas meter temperature, T_m		19.750
Mean pressure drop across orifice, ΔH	mmH_2O	63.646
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		0.774
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.8209
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		20.95
% 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}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0575
	%	5.75
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.85
Mean of velocity heads, ΔP_{avg}	mm H_2O	27.60
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.25
Mean stack gas temperature, T_s	°C	68
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	18.96

Molecular weight of dry gas, M_d		
CO_2	%	15.50
O_2	%	20.95
Total	%	36.45
N_2 (100 -Total)	%	63.55
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		31.32
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	30.55
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	321.7
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	241.8
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	256.52
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	5.84
Nozzle area, A_n	mm^2	26.74
Total sampling time, θ	min	32
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	105.7
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00776
Mass collected in probe, M_p	g	0.00490
Total mass collected, M_n	g	0.01266
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	15.42
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	16.36
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	No O2 Ref
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		237.38

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	25.91	0.09	0.1	-381	0.52	Yes
Run 2	25.90	0.08	0.08	-406.4	0.52	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	106.74	Yes
Run 2	105.73	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	2.5	Yes
Run 2	0.22	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	0.31	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	GF	47	64	180	160
Run 2	GF	47	73	180	160

GF = Glass Fibre

QF = Quartz Fibre

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	08:33 - 09:05 09 April 2014	3.4738	3.5123	0.0385	5.8	0.01	2.7

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	834	26	0.09	0.10	0.52	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	64	^oC
Stack static pressure	0.12	kPa
Barometric Pressure	100.8	kPa
Pitot tube calibration coefficient, K_{pt}	0.85	-

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	15.500000	0.155000	0.304274	14.608601	0.146086	0.286775
O_2	32	1.427679	20.950000	0.209500	0.299099	19.745173	0.197452	0.281898
N_2	28	1.249219	63.550000	0.635500	0.793879	59.895263	0.598953	0.748223
H_2O	18	0.803070	-	-	-	5.750964	0.057510	0.046184

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3973	kg/m^3
Wet Density (STP), P_{STW}	1.3631	kg/m^3
Dry Density (Actual), P_{Actual}	1.1277	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	1.100	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	09 April 2014
Time of Survey	08:20
Velocity Measurement Device:	S Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.03	26.0	255	64	18.1	-	5
2	0.09	26.5	260	64	18.2	-	8
3	0.15	26.8	263	64	18.3	-	8
4	0.21	27.0	265	64	18.4	-	5
5	0.27	28.0	274	64	18.8	-	5
6	0.33	28.5	279	64	18.9	-	8
7	0.39	27.8	272	64	18.7	-	10
8	0.45	27.5	270	64	18.6	-	10
9	0.51	27.0	265	64	18.4	-	8
10	0.57	26.5	260	64	18.2	-	5
Mean	-	27.2	266	64	18.5	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	

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	255	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	18.1	m/s	-	-
Highest Gas Velocity	18.9	m/s	-	-
Ratio of Gas Velocities	1.0	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	10	^{o}	< 15^{o}	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, V = K_{pt} x (1-ε) * √(2 * ΔP_{pt} / $P_{ActualW}$)		
Where: K_{pt} = Pitot tube calibration coefficient (1-ε) = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, Va	**18.5**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	64	0	^{o}C
Total Pressure	100.92	101.3	kPa
Oxygen	21.0	21	%
Moisture	5.75	5.75	%

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	18.5	m/s
Stack Area (A)	0.28	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	18804	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	15175	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	14303	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	15175	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))

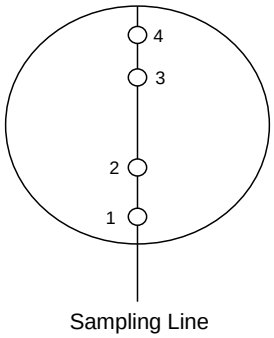
Nomenclature:
Ts = Absolute Temperature, Standard Conditions, 273 K
Ps = Absolute Pressure, Standard Conditions, 101.3 kPa
Ta = Absolute Temperature, Actual Conditions, K
Pa = Absolute Pressure, Actual Conditions, kPa
Ma = Water vapour, Actual Conditions, % Vol
Ms = Water vapour, Reference Conditions, % 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
-	-	-	-



Sampling Line

Isokinetic Sampling CEN Methods			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	8.3	0.05	8
2	25.0	0.15	8
3	75.0	0.45	10
4	91.7	0.55	8
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

○ 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	0.5	1	N/A	0.18	-	-
as a %	0.12	0.69	0.50	1.00	N/A	0.43	0.39	0.001
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**
Run 2	0.001	2	0.5	1.00	N/A	0.180	-	-
as a %	0.12	0.68	0.50	1.00	N/A	0.439	0.31	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	0.79	14.2000	1.00	0.038	0.0002	-
MU as mg/m^3	0.22	0.2158	-	0.038	0.0002	**0.31**
MU as %	1.32	1.2676	-	0.223	0.0011	-
Run 2	0.76	12.6600	1.00	0.027	0.0002	-
MU as mg/m^3	0.20	0.2193	-	0.027	0.0002	**0.30**
MU as %	1.3	1.4218	-	0.178	0.0012	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.63**	**mg/m^3**	**3.7**	**%**

R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.60**	**mg/m^3**	**3.9**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Leak
	m^3	K	kPa	% by volume	% by volume	%
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 2%**
Run 1	0.001	2	0.5	1	N/A	-
as a %	0.12	0.69	0.50	1.00	N/A	0.39
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP)	Mass Gained	O_2 Correction	Leak	Uncollected Mass	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	0.79	38500.00	1.00	102.86	57.74	-
MU as % v/v	0.08	0.02	-	0.01	0.009	**0.08**
MU as %	1.32	0.26	-	0.22	0.15	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.16**	**% v/v**	**2.7**	**%**

END OF REPORT