STACK EMISSIONS MONITORING REPORT

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

Release Point:
Coating Plant

Sampling Date(s):
7th April 2015

ESG Job Number:	LNO 12331
Report Date:	16th April 2015
Version:	1
Report By: MCERTS Number: MCERTS Level: Technical Endorsements:	Andy Hegarty MM 03 397 MCERTS Level 2 - Team Leader 1, 2, 3 & 4
Report Approved By: MCERTS Number: Business Title: Technical Endorsements: Signature:	Dave Armitage MM 04 516 MCERTS Level 2 - Team Leader 1, 2, 3 & 4

UKAS TESTING 1015

CONTENTS

EXECUTIVE SUMMARY

MONITORING OBJECTIVES

CEMEX UK Materials Ltd operates an 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
Grimsby Coated Stone
Gilbey Road
Pyewipe
Grimsby
Lincolnshire
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	26	1.3	50	✓
Particulate Emission Rate	g/hr	679	35	-	
Moisture	%	10.7	0.29	-	✓
Stack Gas Temperature	°C	48	-	-	
Stack Gas Velocity	m/s	16.9	0.54	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	30598	1377	-	✓
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	26639	1199	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	23792	1071	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	26639	1199	-	

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	07 April 2015	07:41 - 08:14	32 minutes
Total Particulate Matter Run 2	07 April 2015	08:22 - 08:45	32 minutes
Total Particulate Matter Run 3	07 April 2015	09:03 - 09:36	32 minutes
Stack Gas Flow Rate & Temperature Run 1	07 April 2015	07:12	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Roadstone Coating
Continuous or batch	Batch
Product Details	20mm Limestone
Part of batch to be monitored (if applicable)	N/A
Normal load, throughput or continuous rating	30 t/hr
Fuel used during monitoring	Kerosene
Abatement	Bag Filter
Plume Appearance	Steam 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	0.54 mg/m³	5.2 %
H_2O	SRM - BS EN 14790	AE 105	1015	Yes	0.02%	2.7%
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	5 Pa	3.2 %

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	226	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	16.7	m/s	-	-	-
Highest Gas Velocity	17.1	m/s	-	-	-
Ratio of Gas Velocities	1.0	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	16.9	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^{o}	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259
Highly homogeneous flow stream / gas velocity	Yes	-	-	Yes	BS EN 15259

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Circular	-
Depth	0.60	m
Width	-	m
Area	0.50	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	Horizontal	-	-
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

Sampling Lines

Only one sampling line was available due to one port being rusted shut, to meet the requirements of the standard the number of points sampled were doubled.

Nozzle Size

Due to high flow in the duct, a nozzle of less than 6mm was used.

APPENDICES

CONTENTS

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	3
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 13-01	Horiba PG-250 Analyser	-	Laboratory Balance	LNO 0013/0014
Box Thermocouples	LNO 03-01	FT-IR	-	Tape Measure	LNO 18-AH
Meter In Thermocouple	LNO 03-01	FT-IR Oven Box	-	Stopwatch	LNO 17-AH
Meter Out Thermocouple	LNO 03-01	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 03-01	Signal 3030 FID	-	Barometer	LNO 08-AH
Oven Box	LNO 09-11	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.

STACK EMISSIONS MONITORING TEAM

MONITORING TEAM							
Personnel	**MCERTS Number**	**MCERTS Qualification**	**TE / H&S Qualifications and Expiry Date**				
			TE1	**TE2**	**TE3**	**TE4**	**H&S**
Andy Hegarty	MM 03 397	MCERTS Level 2 - Team Leader	Oct-19	Dec-15	Aug-16	Dec-19	Jan-19
Ryan Murphy	MM 07 826	MCERTS Level 1 - Technician	-	-	-	-	Apr-17

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	07:41 - 08:14 07 April 2015	28	1.3	50	757
Run 2	08:22 - 08:45 07 April 2015	29	1.4	50	735
Run 3	09:03 - 09:36 07 April 2015	20	1.2	50	545
Blank	-	1.0	-	-	-

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	G3027	0.10899	0.11213	0.00314	188.66100	188.67450	0.01350	0.01664
Run 2	G3070	0.10896	0.11767	0.00871	182.94880	182.95650	0.00770	0.01641
Run 3	G3071	0.10869	0.11477	0.00608	185.47410	185.48020	0.00610	0.01218

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	G3026	0.11042	0.11033	-0.00009	159.87320	159.87390	0.00070	0.00061

If total mass gained is less than the LOD then the LOD is reported

ISOKINETIC SAMPLING EQUATIONS - RUN 1 — TPM

Absolute pressure of stack gas, P_S			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	777.01	CO_2	%	0.03
Stack static pressure, P_{static}	mm H_2O	10.20	O_2	%	20.95
$P_s = P_b + (P_{static}) / 13.6$	mm Hg	777.76	Total	%	20.98
			N_2 (100 -Total)	%	79.02
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.84
Moisture trap weight increase,Vlc	g	51.3	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.0639198	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.68
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		0.643	Area of stack, A_s	m^2	0.50
Gas meter correction factor, Y_d		0.84747	$Q_a = (60)(A_s)(V_s)$	m^3/min	522.4
Mean dry gas meter temperature, T_m		12.813	**Total flow of stack gas, Q**		
Mean pressure drop across orifice, ΔH	mmH_2O	36.058	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = (0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d) / (T_m + 273)$		0.534	$Q_{std} = (Q_a)P_s(0.3592)(1-B_{wo}) / (T_s) +273$	Dry	404.8
Volume of gas metered wet, V_{mstw}			$Q_{stdO2} = (Q_a)P_s(0.3592)(1-B_{wo})(O_2REF) / (T_s) +273$	@O_2ref	No O2 Ref
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.5980	$Q_{stw} = (Q_a)P_s(0.3592) / (T_s) +273$	Wet	453.23
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	**Percent isokinetic, %I**		
			Nozzle diameter, D_n	mm	4.89
% oxygen measured in gas stream, act%O_2		21.0	Nozzle area, A_n	mm^2	18.78
% oxygen reference condition		21	Total sampling time, θ	min	32
O_2 Reference Factor O_2 Ref = 21.0 - act%O_2 / 21.0 - ref%O_2		No O2 Ref	$\%I = (4.6398E6)(T_s+273)(V_{mstd}) / (P_s)(V_s)(A_n)(\theta)(1-B_{wo})$	%	110.4
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	No O2 Ref	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			**Particulate Concentration, C**		
$B_{wo} = V_{wstd} / (V_{mstd} + V_{wstd})$		0.1069	Mass collected on filter, M_f	g	0.00314
	%	10.69	Mass collected in probe, M_p	g	0.01350
Moisture by FTIR	%	-	Total mass collected, M_n	g	0.01664
Velocity of stack gas, V_s			$C_{wet} = M_n / V_{mstw}$	mg/m^3	27.825
Pitot tube velocity constant, K_p		34.97	$C_{dry} = M_n / V_{mstd}$	mg/m^3	31.155
Velocity pressure coefficient, C_p		0.831	$C_{dry@X\%O2} = M_n / V_{mstd@X\%oxygen}$	mg/m^3	No O2 Ref
Mean of velocity heads, ΔP_{avg}	mm H_2O	23.75			
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.87			
Mean stack gas temperature, T_s	°C	49			
$V_s = (K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)}) / (M_s)(P_s)$	m/s	17.32	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		756.67

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 2 — TPM

Absolute pressure of stack gas, P_S			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	777.01	CO_2	%	0.03
Stack static pressure, P_{static}	mm H_2O	10.20	O_2	%	20.95
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	777.76	Total	%	20.98
			N_2 (100 -Total)	%	79.02
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.84
Moisture trap weight increase,Vlc	g	-	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.68
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		0.615	Area of stack, A_s	m^2	0.50
Gas meter correction factor, Y_d		0.84747	$Q_a = (60)(A_s)(V_s)$	m^3/min	506.0
Mean dry gas meter temperature, T_m		12.813	**Total flow of stack gas, Q**		
Mean pressure drop across orifice, ΔH	mmH_2O	32.044	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		0.511	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	381.6
Volume of gas metered wet, V_{mstw}			$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	No O2 Ref
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.5720	$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	427.26
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Percent isokinetic, %I**		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Nozzle diameter, D_n	mm	4.89
% oxygen measured in gas stream, act%O_2		20.95	Nozzle area, A_n	mm^2	18.78
% oxygen reference condition		21	Total sampling time, θ	min	32
O_2 Reference Factor O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		No O2 Ref	$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	112.0
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	No O2 Ref	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			**Particulate Concentration, C**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1069	Mass collected on filter, M_f	g	0.00871
	%	10.69	Mass collected in probe, M_p	g	0.00770
Moisture by FTIR	%	-	Total mass collected, M_n	g	0.01641
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	28.69
Pitot tube velocity constant, K_p		34.97	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	32.12
Velocity pressure coefficient, C_p		0.831	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	No O2 Ref
Mean of velocity heads, ΔP_{avg}	mm H_2O	21.69	**Particulate Emission Rates, E**		
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.66	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		735.50
Mean stack gas temperature, T_s	°C	58			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	16.78			

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 3 — TPM

Absolute pressure of stack gas, P_S			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	777.01	CO_2	%	0.03
Stack static pressure, P_{static}	mm H_2O	10.20	O_2	%	20.95
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	777.76	Total	%	20.98
			N_2 (100 -Total)	%	79.02
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.84
Moisture trap weight increase,Vlc	g	-	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.68
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		0.642	Area of stack, A_s	m^2	0.50
Gas meter correction factor, Y_d		0.84747	$Q_a = (60)(A_s)(V_s)$	m^3/min	523.9
Mean dry gas meter temperature, T_m		12.813	**Total flow of stack gas, Q**		
Mean pressure drop across orifice, ΔH	mmH_2O	34.734	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		0.533	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	397.3
Volume of gas metered wet, V_{mstw}			$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	$@O_2$ref	No O2 Ref
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.5964	$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	444.83
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Percent isokinetic, %I**		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Nozzle diameter, D_n	mm	4.89
% oxygen measured in gas stream, act%O_2		20.95	Nozzle area, A_n	mm^2	18.78
% oxygen reference condition		21	Total sampling time, θ	min	32
O_2 Reference Factor O_2 Ref $= \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		No O2 Ref	$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	112.1
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	No O2 Ref	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			**Particulate Concentration, C**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1069	Mass collected on filter, M_f	g	0.00608
	%	10.69	Mass collected in probe, M_p	g	0.00610
Moisture by FTIR	%	-	Total mass collected, M_n	g	0.0122
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	20.42
Pitot tube velocity constant, K_p		34.97	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	22.87
Velocity pressure coefficient, C_p		0.831	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	No O2 Ref
Mean of velocity heads, ΔP_{avg}	mm H_2O	23.38	**Particulate Emission Rates, E**		
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.83	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		545.10
Mean stack gas temperature, T_s	°C	56			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	17.37			

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	17.0	0.03	0.06	-228.6	0.34	Yes
Run 2	16.3	0.03	0.05	-228.6	0.33	Yes
Run 3	17.0	0.04	0.1	-228.6	0.34	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	110.4	Yes
Run 2	112.0	Yes
Run 3	112.1	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m³	5% ELV mg/m³	LOD < 5% ELV
Run 1	0.54	2.5	Yes
Run 2	0.58	2.5	Yes
Run 3	0.55	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	1.04	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	50	180	160
Run 2	GF	47	58	180	160
Run 3	GF	47	56	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	07:41 - 08:14 07 April 2015	3.5232	3.5745	0.0513	10.7	0.021	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	598	17.0	0.03	0.06	0.34	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.60	m
Stack Width, W	-	m
Stack Area, A	0.50	m^2
Average stack gas temperature	48	^oC
Stack static pressure	0.1	kPa
Barometric Pressure	103.6	kPa
Pitot tube calibration coefficient, K_{pt}	0.83	-

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	0.030000	0.000300	0.000589	0.026793	0.000268	0.000526
O_2	32	1.427679	20.950000	0.209500	0.299099	18.710779	0.187108	0.267130
N_2	28	1.249219	79.020000	0.790200	0.987133	70.574020	0.705740	0.881624
H_2O	18	0.803070	-	-	-	10.688408	0.106884	0.085835

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2868	kg/m^3
Wet Density (STP), P_{STW}	1.2351	kg/m^3
Dry Density (Actual), P_{Actual}	1.1203	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	1.075	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	07 April 2015
Time of Survey	07:12
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O (average of 3)	ΔP pt Pa (average of 3)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
1	0.02	-	-	-	-	-	-	-
2	0.05	23.8	234	48	16.97	8.53	-	<15
3	0.09	-	-	-	-	-	-	-
4	0.14	24.1	236	48	17.06	8.58	-	<15
5	0.21	-	-	-	-	-	-	-
6	0.39	-	-	-	-	-	-	-
7	0.46	23.5	230	48	16.86	8.47	-	<15
8	0.51	-	-	-	-	-	-	-
9	0.55	23.2	227	48	16.74	8.41	-	<15
10	0.58	-	-	-	-	-	-	-
Mean	-	23.6	232	48	16.91	8.50	-	

Sampling Line B

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

PRELIMINARY STACK SURVEY QUALITY ASSURANCE CHECKLIST

PITOT LEAK CHECK

Run	Pre Traverse Leak Rate				Post Traverse Leak Rate			
	Start Value mmH O	End Value mmH O	Difference %	Outcome	Start Value mmH O	End Value mmH O	Difference %	Outcome
Run 1	97	94	3.1	Pass	116	113	2.6	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	95	100	-5.0	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	227	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	16.7	m/s	-	-
Highest Gas Velocity	17.1	m/s	-	-
Ratio of Gas Velocities	1.0	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	0	^{o}	< 15^{o}	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, $V = K_{pt} \times (1-\varepsilon) * \sqrt{(2 * \Delta P_{pt} / P_{ActualW})}$		
Where: K_{pt} = Pitot tube calibration coefficient $(1-\varepsilon)$ = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, Va	**16.9**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	48	0	^{o}C
Total Pressure	103.7	101.3	kPa
Oxygen	21.0	21	%
Moisture	10.69	10.69	%

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	16.91	m/s
Stack Area (A)	0.50	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	30598	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	26639	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	23792	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	26639	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

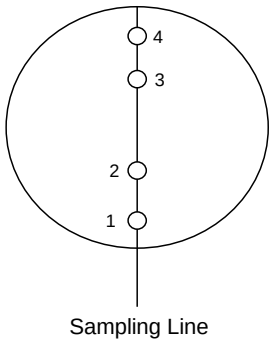
O_2s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK DIAGRAM

	Value	Units
Stack Depth	0.60	m
Stack Width	-	m
Area	0.50	m^2

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



Isokinetic Sampling CEN Methods			
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	0.5	1	N/A	0.3200	-	-
as a %	0.17	0.70	0.48	1.00	N/A	1.07018	0.35	0.001
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**
Run 2	0.001	2	0.5	1.00	N/A	0.330	-	-
as a %	0.17	0.70	0.48	1.00	N/A	1.154	0.31	0.001
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**
Run 3	0.001	2	0.5	1	N/A	0.3300	-	-
as a %	0.17	0.70	0.48	1.00	N/A	1.10669	0.59	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	0.58	16.6400	1.00	0.057	0.0004	-
MU as mg/m^3	0.37	0.5351	-	0.057	0.0006	**0.65**
MU as %	1.32	1.9231	-	0.203	0.0021	-
Run 2	0.56	16.4100	1.00	0.051	0.0004	-
MU as mg/m^3	0.38	0.5770	-	0.051	0.0006	**0.69**
MU as %	1.3	2.0110	-	0.177	0.0021	-
Run 3	0.58	12.1800	1.00	0.069	0.0004	-
MU as mg/m^3	0.27	0.5533	-	0.069	0.0006	**0.62**
MU as %	1.32	2.7094	-	0.340	0.0029	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**1.30**	**mg/m^3**	**4.69**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**1.39**	**mg/m^3**	**4.83**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**1.24**	**mg/m^3**	**6.07**	**%**

(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 %	0.17	0.70	0.48	1.00	N/A	0.35
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	0.58	51300.00	1.00	174.45	57.74	-
MU as % v/v	0.14	0.02	-	0.02	0.012	**0.15**
MU as %	1.32	0.19	-	0.20	0.11	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.29**	**% v/v**	**2.72**	**%**

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	16.9	m/s
Measured Volumetric Flow rate at Actual Conditions	30598	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	-	0.42		
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	5.37	<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	1.64	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	529		
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	-	0.0003		

Measurement Uncertainty - Velocity	m/s
Combined uncertainty	0.09
Expanded uncertainty at a 95% Confidence Interval	0.18

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 Concentration	1.62
Expanded uncertainty at a 95% Confidence Interval	3.17

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	706.63
Expanded uncertainty at a 95% Confidence Interval	1384.99

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 Concentration	2.31
Expanded uncertainty at a 95% Confidence Interval	4.53

END OF REPORT