

STACK EMISSIONS MONITORING REPORT



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Solutia UK Limited
Newport Steam Reforming Plant
Corporation Road
Newport
NP19 4XF

Permit:

EPR Permit: EPR/VP3736EF

Release Point:

A1 - Reformer Furnace Flue Gas Stack

Sampling Date(s):

18 January 2016

ESG Job Number:	LSO 160103
Report Date:	25th January 2016
Version:	2
Report By:	Owen May
MCERTS Number:	MM 10 1072
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Report Approved By:	David May
MCERTS Number:	MM 07 862
Business Title:	MCERTS Level 2 - Operations Manager
Technical Endorsements:	1, 2, 3 & 4
Signature:	



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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Solutia UK Limited operates a reformer furnace process at Newport Steam Reforming Plant which is subject to EPR Permit EPR/VP3736EF, under the Environmental Permitting Regulations 2010.

ESG were commissioned by The BOC Group 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 EPR Permit, EPR/VP3736EF.

Plant

A1 - Reformer Furnace Flue Gas Stack

Operator

Solutia UK Limited
Newport Steam Reforming Plant
Corporation Road
Newport
NP19 4XF

EPR Permit: EPR/VP3736EF

Stack Emissions Monitoring Test House

ESG - Cirencester Laboratory
Unit D
Bankside Trade Park
Cirencester
GL7 1YT
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.

This test report shall not be reproduced, except in full, without written approval of ESG.

This test report replaces and supersedes version 1 dated 25th January 2016. Please see APPENDIX 4 for the changes made.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	Units	Result	Calculated Uncertainty +/-	Limit	MCERTS accredited result
Oxides of Nitrogen (as NO ₂)	mg/m ³	114.9	10.7	140	✓
Oxides of Nitrogen (as NO ₂) Emission Rate	g/hr	154.9	14.4	-	
Carbon Monoxide	mg/m ³	11.8	4.7	25	✓
Carbon Monoxide Emission Rate	g/hr	15.9	6.3	-	
Carbon Dioxide	% v/v	7.05	0.3	-	✓
Oxygen	% v/v	12.5	0.3	-	✓
Moisture	%	8.9	0.50	-	✓
Stack Gas Temperature	°C	202	-	-	✓
Stack Gas Velocity	m/s	12.3	0.31	-	
Gas Volumetric Flow Rate (Actual)	m ³ /hr	5584	290	-	
Gas Volumetric Flow Rate (STP, Wet)	m ³ /hr	3147	164	-	
Gas Volumetric Flow Rate (STP, Dry)	m ³ /hr	2866	149	-	
Gas Volumetric Flow Rate at Reference Conditions	m ³ /hr	1349	70	-	

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, dry gas 3% Oxygen.

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	Sampling Date(s)	Sampling Times	Sampling Duration
Combustion Gases	18 January 2016	11:25 - 13:25	120 minutes
Preliminary Stack Traverse	18 January 2016	10:25	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Reformer Furnace
Continuous or batch	Continuous
Product Details	Reformed metals
Part of batch to be monitored (if applicable)	Any representative part
Normal load, throughput or continuous rating	32% load
Fuel used during monitoring	Hydrogen
Abatement	None
Plume Appearance	None visible from sample location

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by ESG 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 +/- %
NO _x	SRM - BS EN 14792	AE 102	1015	Yes	0.25 mg/m ³	9.31%
CO	SRM - BS EN 15058	AE 102	1015	Yes	0.22 mg/m ³	39.44%
CO ₂	SRM - ISO 12039	AE 102	1015	Yes	0.002 %	4.02%
O ₂	AM - BS EN 14789	AE 102	1015	Yes	0.01%	2.67%
H ₂ O	SRM - BS EN 14790	AE 105	1015	Yes	0.19%	5.64%
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	5 Pa	2.5 %

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
-	-	-	-	-	-	-	-

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	ESG - Cirencester	ESG - Cirencester	5 years
CO	Non Dispersive Infra Red	AE 102	1015	Yes	ESG - Cirencester	ESG - Cirencester	5 years
CO ₂	Non Dispersive Infra Red	AE 102	1015	Yes	ESG - Cirencester	ESG - Cirencester	5 years
O ₂	Zirconia Cell	AE 102	1015	Yes	ESG - Cirencester	ESG - Cirencester	5 years
H ₂ O	Gravimetric	AE 105	1015	Yes	ESG - Cirencester	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	Value	Units	Requirement	Compliant	Method
Lowest Differential Pressure	73	Pa	≥ 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	11.67	m/s	-	-	-
Highest Gas Velocity	13.28	m/s	-	-	-
Ratio of Gas Velocities	1.14	: 1	$< 3 : 1$	Yes	BS EN 15259
Mean Velocity	12.34	m/s	-	-	-
Maximum angle of flow with regard to duct axis	< 15	$^{\circ}$	$< 15^{\circ}$	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259

DUCT CHARACTERISTICS		
	Value	Units
Shape	Circular	-
Depth	0.40	m
Width	-	m
Area	0.13	m ²
Port Depth	170	mm

SAMPLING LINES & POINTS		
	Isokinetic	Non-Iso & Gases
Sample port size	-	3" flange to 2" port
Number of lines used	-	1
Number of points / line	-	1
Duct orientation	-	Vertical

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 = $\geq$ Stack depth / diameter + wall and port thickness + 1.5m	Yes

Sampling Platform Improvement Recommendations (if applicable)

The sampling location should meet all the requirements as specified in EA Guidance Note M1. Only one line is available the other has a narrow diameter valve fitting installed. For gases testing this is sufficient but should any isokinetic testing be needed in the future, a minimum for a 3" diameter port should be installed.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Flow traverse

Only one line is of sufficient diameter to allow insertion of a pitot, the SRM says that two lines should be available.

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APPENDIX 4 - Record of Report Amendments

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
NO _x	SRM - BS EN 14792	AE 102	1015	Yes	1
CO	SRM - BS EN 15058	AE 102	1015	Yes	1
CO ₂	SRM - ISO 12039	AE 102	1015	Yes	1
O ₂	AM - BS EN 14789	AE 102	1015	Yes	1
H ₂ O	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	-	Horiba PG-250 Analyser	P1892	Laboratory Balance	-
Box Thermocouples	-	FT-IR	-	Tape Measure	P2024
Meter In Thermocouple	-	FT-IR Oven Box	-	Stopwatch	P2370
Meter Out Thermocouple	-	Bernath 3006 FID	-	Protractor	-
Control Box Timer	-	Signal 3030 FID	-	Barometer	P1916
Oven Box	-	Servomex	-	Digital Micromanometer	P1915
Probe	-	JCT Heated Head Filter	-	Digital Temperature Meter	P1745
Probe Thermocouple	-	Thermo FID	-	Stack Thermocouple	P2319
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	P2037	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	P1952	Chiller (JCT/MAK 10)	P1969	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	P2548	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)	-
Wet Gas Meter	P497		-	20m Heated Line (1)	P2402
Inclinometer (Swirl Device)	P2096		-	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
Owen May	MM 10 1072	MCERTS Level 2	Sep-16	Sep-16	Jun-21	Feb-18	Mar-17	Jul-20
Daniel Camm	MM 16 1364	MCERTS Trainee	-	-	-	-	-	Jan-21

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GASES SUMMARY

Test	Sampling Time and Date	Concentration mg/m ³	LOD mg/m ³	Limit mg/m ³	Emission Rate g/hr
NO _x	11:25 - 13:25 18 January 2016	114.9	0.25	140	154.9
CO	11:25 - 13:25 18 January 2016	11.80	0.22	25	15.9

Test	Sampling Time and Date	Concentration %	LOD %
CO ₂	11:25 - 13:25 18 January 2016	7.05	0.002
O ₂	11:25 - 13:25 18 January 2016	12.5	0.01

Reference conditions are 273K, 101.3kPa, dry gas 3% Oxygen.

PRE-SAMPLING CALIBRATION DATA

Date	18 January 2016
Start Time	10:25
End Time	11:00

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	250	0	83.7	0	0.4	83	54	0.84
CO	200	0	85.2	-0.1	0.4	84.6	48	0.70
CO ₂	20	0	12.02	0.01	0.08	12	50	0.17
O ₂	25	0	10.07	0	0.09	10.02	51	0.50

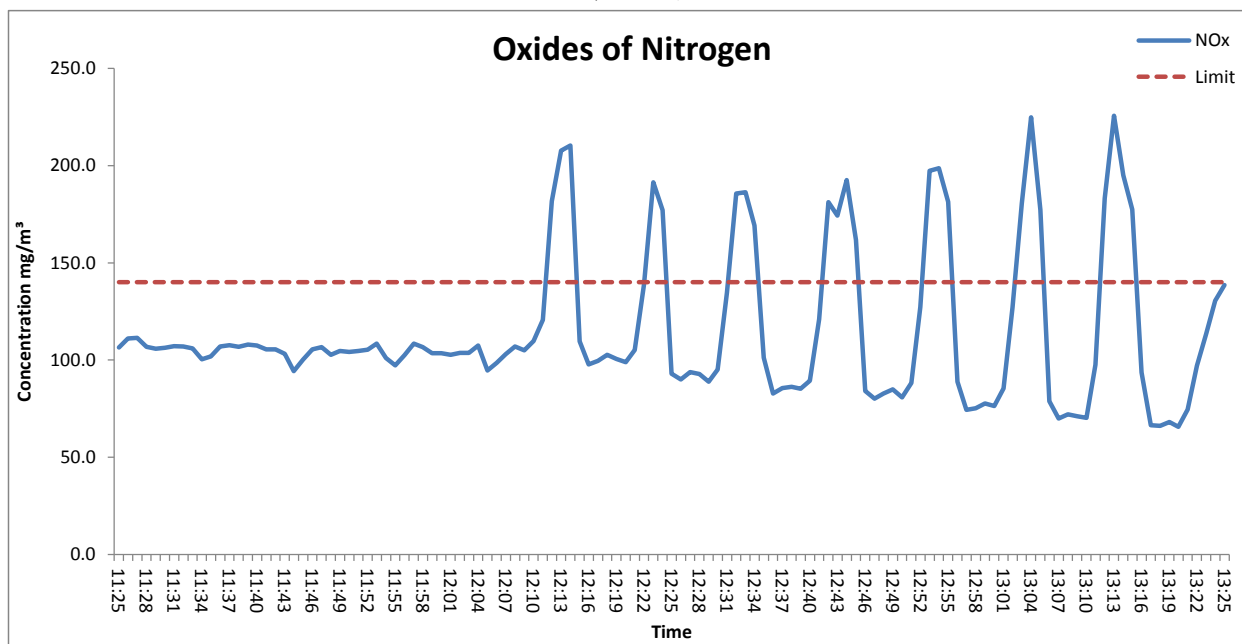
POST-SAMPLING CALIBRATION DATA

Date	18 January 2016
Start Time	15:28
End Time	15:37

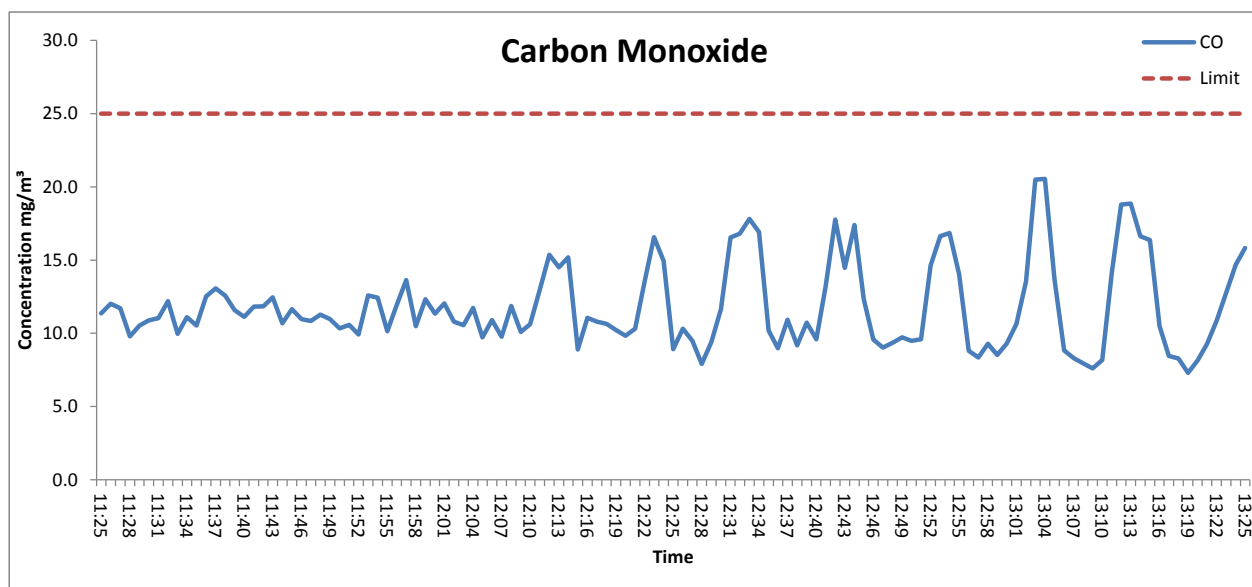
Chiller Temperature (°C)	2.6
Requirement	< 4°C
Compliant	Yes

Gas	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
NO	0.8	82.9	0.16	-0.20
CO	0.1	85	-0.15	0.35
CO ₂	0.09	12.09	0.05	0.40
O ₂	0.12	9.97	0.12	-0.32

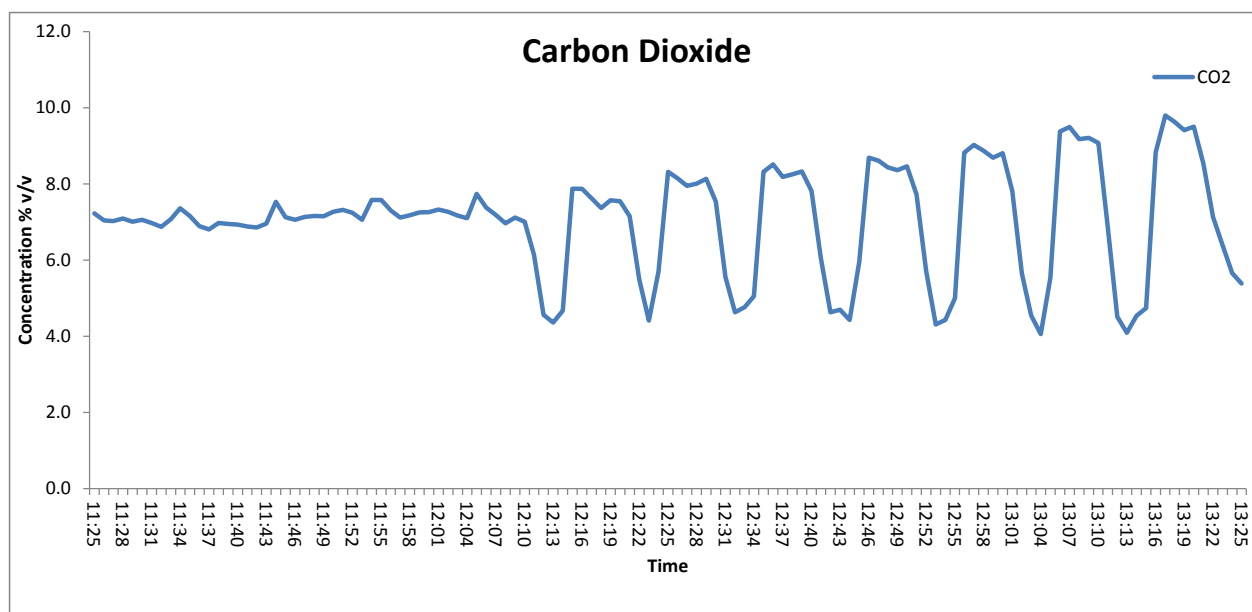
APPENDIX 2 - Summaries, Calculations, Raw Data and Charts
OXIDES OF NITROGEN (as NO₂) EMISSIONS CHART



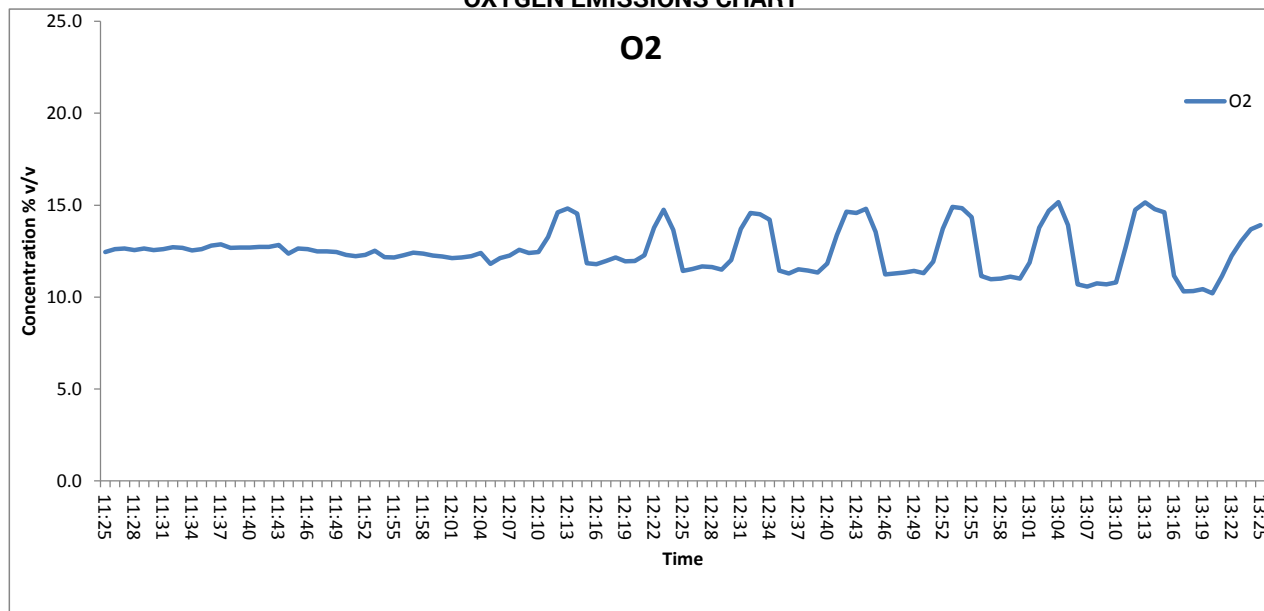
CARBON MONOXIDE EMISSIONS CHART



CARBON DIOXIDE EMISSIONS CHART



OXYGEN EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Non Isokinetic							
Test Number	Sampling Time and Date	Start Weight kg	End Weight kg	Total gain kg	Concentration %	LOD %	Uncertainty %
Run 1	12:25 - 13:25 18 January 2016	3.1688	3.1739	0.0051	8.9	0.19	5.6

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	65	1.1	0.000	0.000	0.022	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.40	m
Stack Width, W	-	m
Stack Area, A	0.13	m ²
Average stack gas temperature	202	°C
Stack static pressure	0.052	kPa
Barometric Pressure	99.3	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	7.051012	0.070510	0.138416	6.421778	0.064218	0.126063
O ₂	32	1.427679	12.529793	0.125298	0.178885	11.411630	0.114116	0.162921
N ₂	28	1.249219	80.419194	0.804192	1.004612	73.242557	0.732426	0.914960
H ₂ O	18	0.803070	-	-	-	8.924035	0.089240	0.071666

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3219	kg/m ³
Wet Density (STP), P_{STW}	1.2756	kg/m ³
Dry Density (Actual), P_{Actual}	0.7450	kg/m ³
Average Wet Density (Actual), $P_{ActualW}$	0.719	kg/m ³

Where:

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

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

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

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	18 January 2016
Time of Survey	10:25
Velocity Measurement Device:	S-Type Pitot

Sampling Line A								
Traverse Point	Distance into duct (m)	DP pt mmH ₂ O (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	0.01	9.8	96	200	13.28	1.67	-	<15
2	0.03	9.7	95	201	13.22	1.66	-	<15
3	0.06	8.8	86	202	12.61	1.58	-	<15
4	0.09	8.7	85	202	12.56	1.58	-	<15
5	0.14	8.3	81	202	12.24	1.54	-	<15
6	0.26	8.0	78	203	12.03	1.51	-	<15
7	0.31	7.6	74	203	11.73	1.47	-	<15
8	0.34	8.3	82	203	12.30	1.55	-	<15
9	0.37	7.5	74	203	11.67	1.47	-	<15
10	0.39	7.6	75	202	11.76	1.48	-	<15
Mean	-	8.4	82	202	12.34	1.55	-	

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt mmH ₂ O (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 mmH ₂ O	End Value mmH ₂ O	Difference %	Outcome	Start Value mmH ₂ O	End Value mmH ₂ O	Difference %	Outcome
Run 1	88	87	1.1	Pass	90	88	2.2	Pass

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

S-Type Pitot Stagnation Check				
Run	Stagnation (Pa)	Reference (Pa)	Difference (Pa)	Outcome (Permitted +/- 10 Pa)
Run 1	52	50	2.0	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	73.5	Pa	≥ 5 Pa	Yes
Lowest Gas Velocity	11.67	m/s	-	-
Highest Gas Velocity	13.28	m/s	-	-
Ratio of Gas Velocities	1.14	-	$< 3 : 1$	Yes
Maximum angle of flow with regard to duct axis	0	°	$< 15^\circ$	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, $V = K_{pt} \times (1-e) \times \sqrt{2 \times DP_{pt} / \rho_{ActualW}}$		
Where: K_{pt} = Pitot tube calibration coefficient $(1-e)$ = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, V_a	12.34	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	202	0	°C
Total Pressure	99.352	101.3	kPa
Oxygen	12.5	3	%
Moisture	8.92	0.00	%
Pitot tube calibration coefficient, K_{pt}	0.83		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (V_a)	12.34	m/s
Stack Area (A)	0.13	m ²
Gas Volumetric Flowrate (Actual), Q_{Actual}	5584	m ³ /hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	3147	m ³ /hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	2866	m ³ /hr
Gas Volumetric Flowrate (REF), Q_{Ref}	1349	m ³ /hr

Where:

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

$$Q_{STP} = Q_{Actual} \times (T_s / T_a) \times (P_a / P_s) \times 3600$$

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

$$Q_{Ref} = Q_{STP} \times ((100 - Ma) / (100 - Ms)) \times ((20.9 - O_{2a}) / (20.9 - O_{2s}))$$

Nomenclature:

T_s = Absolute Temperature, Standard Conditions, 273 K

P_s = Absolute Pressure, Standard Conditions, 101.3 kPa

T_a = Absolute Temperature, Actual Conditions, K

P_a = Absolute Pressure, Actual Conditions, kPa

Ma = Water vapour, Actual Conditions, % Vol

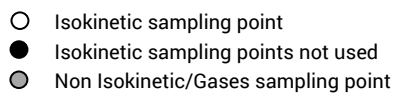
Ms = Water vapour, Reference Conditions, % Vol

O_{2a} = Oxygen, Actual Conditions, % Vol

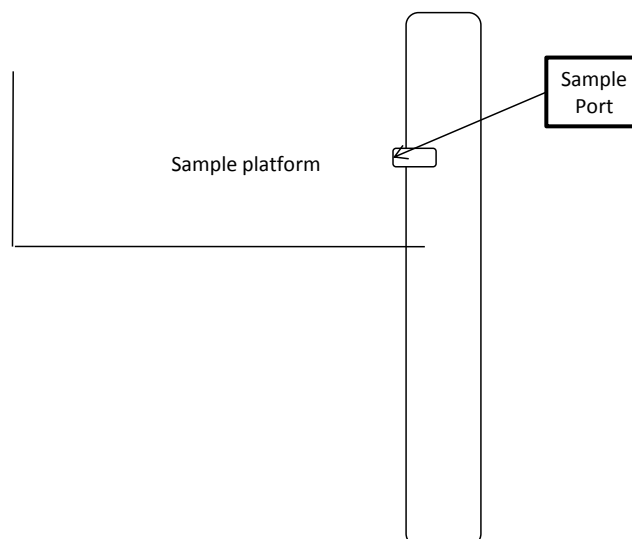
O_{2s} = Oxygen, Reference Conditions, % Vol

STACK DIAGRAM

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	40%	0.16	m

[illegible]

Not cameras allowed on site



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	0.000	2	0.5	1	0.1	-
as a %	0.03	0.42	0.50	1.00	0.80	0.00
compliant?	Yes	Yes	Yes	Yes	Yes	Yes

Run	Volume (STP) m ³	Mass Gained mg	O2 Correction -	Leak mg/m ³	Uncollected Mass mg	Combined uncertainty
Run 1	0.0	5100.0	2.13	0.0	57.7	-
MU as % v/v	0.12	0.19	0.22	0.00	0.11	0.33
MU as %	1.2	2.0	1.18	0.0	1.1	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.67	% v/v	5.64	%
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Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXIDES OF NITROGEN

Limit value	140	mg/m ³
Concentration @ Ref conditions	114.9	mg/m ³
Cal gas conc	171.585	mg/m ³
Analyser Full Scale	513	mg/m ³

Performance characteristics	Value	Units	specification	MU Met?
Response time	54	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	120	minutes	-	-
Number of readings in measurement	120	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	Yes
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.7	% of value	<2 % range	Yes
Zero drift	0.40	% full scale	<2% range / 24hr	Yes
Span drift	-0.50	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	0.02	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.8	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	0.01	% full scale/10K	<3% range / 10 K	Yes
dependence on voltage	0.1	% full scale/10V	< 0.1%vol / 10 volt	Yes
losses in the line (leak)	0.84	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	0.01
Standard deviation of repeatability at span level	urs	0.01
Lack of fit	ufit	2.07
Drift	u0dr	0.14
volume or pressure flow dependence	uspres	0.00
atmospheric pressure dependence	uapres	0.13
ambient temperature dependence	utemp	0.00
Dependence on voltage	uvolt	0.44
losses in the line (leak)	uleak	0.25
Uncertainty of calibration gas	ucalib	0.30
Uncertainty in factor	uf	1.01

Measurement uncertainty (Concentration Measured)	51.23	mg/m ³
Combined uncertainty	2.39	mg/m ³
Expanded at a 95% confidence interval	4.77	mg/m ³

Expanded uncertainty expressed with a level of confidence of 95%	3.41	% ELV
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Expanded uncertainty expressed with a level of confidence of 95%	4.77	mg/m ³
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Expanded uncertainty expressed with a level of confidence of 95%	9.31	% value
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON MONOXIDE

Limit value	25	mg/m ³
Concentration @ Ref conditions	11.8	mg/m ³
Cal gas conc	106.5	mg/m ³
Analyser Full Scale	250	mg/m ³

Performance characteristics	Value	Units	specification	MU Met?
Response time	48	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	120	minutes	-	-
Number of readings in measurement	120	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	Yes
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.7	% of value	<2 % range	Yes
Zero drift	-0.30	% full scale	<2% range / 24hr	Yes
Span drift	0.70	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	0.02	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.80	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	0.01	% full scale/10K	<3% range / 10 K	Yes
dependence on voltage	0.10	% full scale/10V	< 0.1%vol /10 volt	Yes
losses in the line (leak)	0.70	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	0.01
Standard deviation of repeatability at span level	urs	0.01
Lack of fit	ufit	1.01
Drift	u0dr	-0.15
volume or pressure flow dependence	uspres	0.00
atmospheric pressure dependence	uapres	0.06
ambient temperature dependence	utemp	0.00
Dependence on voltage	uvolt	0.22
losses in the line (leak)	uleak	0.02
Uncertainty of calibration gas	ucalib	0.03
Uncertainty in factor	uf	0.11

Measurement uncertainty (Concentration Measured)	5.3	mg/m ³
Combined uncertainty	1.1	mg/m ³
Expanded uncertainty	2.1	mg/m ³

Expanded uncertainty expressed with a level of confidence of 95%	8.42	% ELV
Expanded uncertainty expressed with a level of confidence of 95%	2.10	mg/m ³
Expanded uncertainty expressed with a level of confidence of 95%	39.44	% value

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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON DIOXIDE

Limit value	-	%vol
Reported Concentration	7.05	%vol
Calibration gas	12.02	%vol
Analyser Full Scale	20	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	50	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	120	minutes	-	-
Number of readings in measurement	120	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.01	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	0.08	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.56	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.17	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.00
Lack of fit	ufit	0.08
Drift	u0dr	0.03
volume or pressure flow dependence	uspres	0.00
atmospheric pressure dependence	uapres	0.01
ambient temperature dependence	utemp	0.00
Combined interference (from mcerts)	-	0.06
dependence on voltage	uvolt	0.086
losses in the line (leak)	uleak	0.01
Uncertainty of calibration gas	ucalib	0.04

Measurement uncertainty (Concentration Measured)	7.05	%vol
Combined uncertainty	0.14	%vol
% of value	2.01	%

Expanded uncertainty expressed with a level of confidence of 95%	4.02	% of value
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Expanded uncertainty expressed with a level of confidence of 95%	0.28	% vol
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

Reference	3	%vol
Reported Concentration	12.53	%vol
Calibration gas	10.07	%vol
Analyser Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	51	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	120	minutes	-	-
Number of readings in measurement	120	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.03	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.08	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.80	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.10	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.50	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.00	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.0013
Lack of fit	ufit	0.0751
Drift	u0dr	-0.0401
volume or pressure flow dependence	uspres	0.00003
atmospheric pressure dependence	uapres	0.0122
ambient temperature dependence	utemp	0.0005
Combined interference (from mcerts)	-	0.0808
dependence on voltage	uvolt	0.0862
losses in the line (leak)	uleak	0.0359
Uncertainty of calibration gas	ucalib	0.0723

Measurement uncertainty (Concentration Measured)	12.53	%vol
Combined uncertainty	0.17	%vol
% of value	1.33	%

Expanded uncertainty expressed with a level of confidence of 95%	2.67	% of value
Expanded uncertainty expressed with a level of confidence of 95%	0.334	% vol

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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	12.3	m/s
Measured Volumetric Flow rate at Actual Conditions	5584	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	-	0.36		
Factor loading, function of the number of measurements.	3 readings	0.591	minimum 3	Yes
Range of measurement device	pa	1000		
Resolution	pa	1.00		
Calibration uncertainty	pa	3.17	<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	0.00004		
Uncertainty of temperature measurement	K	2.42	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	507		
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	0.16
Expanded uncertainty at a 95% Confidence Interval	0.30

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	1.26
Expanded uncertainty at a 95% Confidence Interval	2.47

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	146.84
Expanded uncertainty at a 95% Confidence Interval	287.82

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	2.63
Expanded uncertainty at a 95% Confidence Interval	5.15

APPENDIX 4 - Record of Report Amendments

Version	Issue Date	Amendments
2	13th April 2017	Revised reference conditions from STP to STP, 3% Oxygen, dry

END OF REPORT