

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):

02nd December 2016

ESG Job Number:	LSO 161216
Report Date:	20th December 2016
Version:	2
Report By:	Steve Huntley
MCERTS Number:	MM 02 081
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
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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
Units C & 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 20th December 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	126.7	7.8	140	✓
Oxides of Nitrogen (as NO ₂) Emission Rate	g/hr	246	15.1	-	✓
Carbon Monoxide	mg/m ³	6.7	3.2	25	✓
Carbon Monoxide Emission Rate	g/hr	13.1	6.3	-	✓
Carbon Dioxide	% v/v	9.68	0.3	-	✓
Oxygen	% v/v	9.22	0.3	-	✓
Moisture	%	8.4	0.58	-	✓
Stack Gas Temperature	°C	160	-	-	✓
Stack Gas Velocity	m/s	11.3	0.28	-	
Gas Volumetric Flow Rate (Actual)	m ³ /hr	5097	265	-	
Gas Volumetric Flow Rate (STP, Wet)	m ³ /hr	3238	168	-	
Gas Volumetric Flow Rate (STP, Dry)	m ³ /hr	2965	154	-	
Gas Volumetric Flow Rate at Reference Conditions	m ³ /hr	1940	101	-	

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	02 December 2016	11:17 - 13:17	120 minutes
Preliminary Stack Traverse	02 December 2016	11:40	-

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	30% 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	0.79 mg/m ³	6.2%
CO	SRM - BS EN 15058	AE 102	1015	Yes	0.42 mg/m ³	48.1%
CO ₂	SRM - ISO 12039	AE 102	1015	Yes	0.002 %	3.0%
O ₂	AM - BS EN 14789	AE 102	1015	Yes	0.01%	3.7%
H ₂ O	SRM - BS EN 14790	AE 105	1015	Yes	0.25%	6.94%
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%

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	74	Pa	≥ 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	10.7	m/s	-	-	-
Highest Gas Velocity	12.0	m/s	-	-	-
Ratio of Gas Velocities	1.1	: 1	$< 3 : 1$	Yes	BS EN 15259
Mean Velocity	11.3	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 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	P1988	Laboratory Balance	P1906
Box Thermocouples	-	FT-IR Gasmet	-	Tape Measure	P2044
Meter In Thermocouple	-	FT-IR Oven Box	-	Stopwatch	-
Meter Out Thermocouple	-	Bernath 3006 FID	-	Protractor	-
Control Box Timer	-	Signal 3030 FID	-	Barometer	P1408
Oven Box	-	Servomex	-	Digital Micromanometer	P2053
Probe	-	JCT Heated Head Filter	-	Digital Temperature Meter	P1475
Probe Thermocouple	-	Thermo FID	-	Stack Thermocouple	P2268
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	P1919	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	P1906	Chiller (JCT/MAK 10)	P2562	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	P2575	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	P499		-	20m Heated Line (1)	P2546
Inclinometer (Swirl Device)	P2954		-	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 +/- %
Oxygen	CG 10	BOC	-	9.78	2.0
Nitric Oxide	SC 13	BOC	80.5	-	2.0
Carbon Monoxide	CG 10	BOC	83.3	-	2.0
Carbon Dioxide	CG 10	BOC	-	11.83	2.0

STACK EMISSIONS MONITORING TEAM

MONITORING TEAM								
Personnel	MCERTS Number	MCERTS		TE / H&S Qualifications and Expiry Date				
		Level	Expiry	TE1	TE2	TE3	TE4	H&S
Steve Huntley	MM 02 081	MCERTS Level 2	Mar-17	Mar-17	Mar-17	Mar-17	Nov-18	Sep-17
Alistair Holmes	MM 13 1218	MCERTS Level 1	Mar-18	Jan-19	-	-	-	Mar-18

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	11:17 - 13:17 02 December 2016	126.7	0.79	140	245.7
CO	11:17 - 13:17 02 December 2016	6.73	0.42	25	13.06

Test	Sampling Time and Date	Concentration %	LOD %
CO ₂	11:17 - 13:17 02 December 2016	9.68	0.002
O ₂	11:17 - 13:17 02 December 2016	9.22	0.01

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

PRE-SAMPLING CALIBRATION DATA

Date	02 December 2016
Start Time	10:45
End Time	11:10

Chiller Temperature (°C)	2.7
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	0.00	80.5	0.30	0.20	81.2	36	-0.87
CO	200	0.00	83.3	0.40	0.40	82.7	42	0.72
CO ₂	20	0.00	11.83	0.02	0.02	11.79	48	0.34
O ₂	25	0.00	9.78	0.03	0.04	9.85	47	-0.72

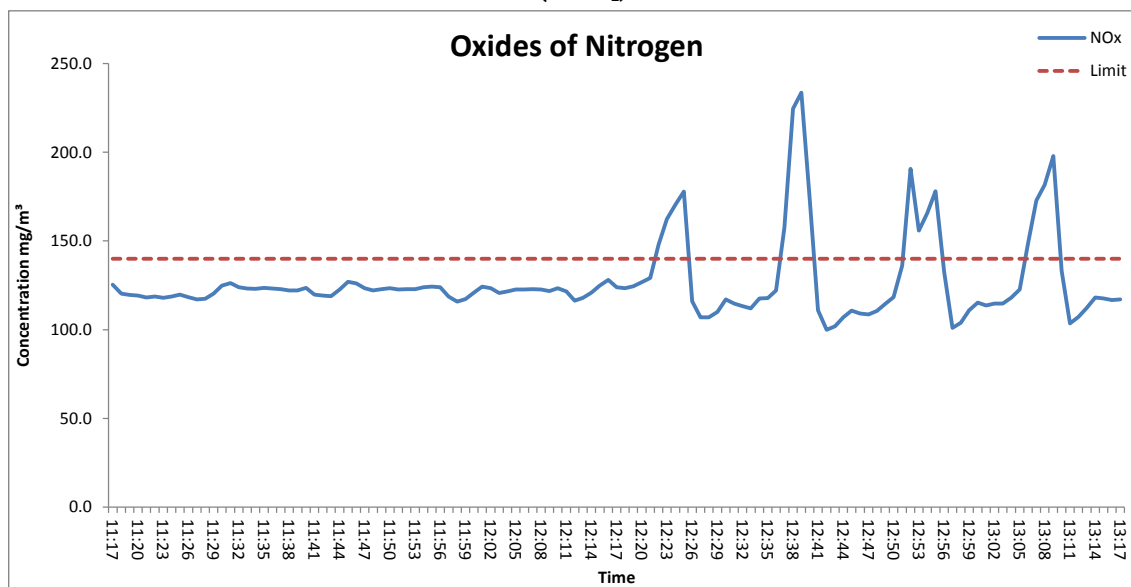
POST-SAMPLING CALIBRATION DATA

Date	02 December 2016
Start Time	13:20
End Time	13:35

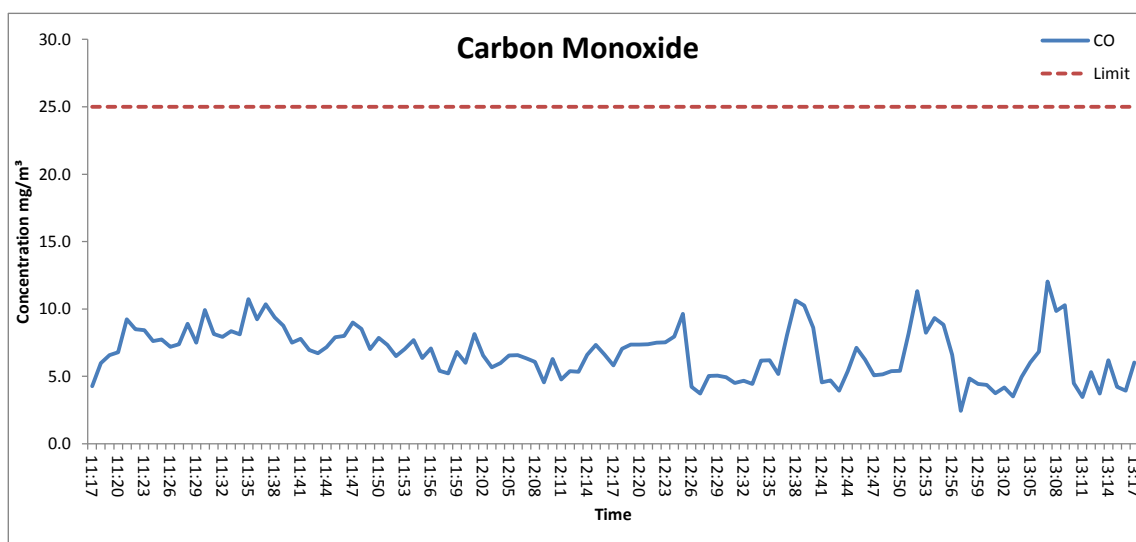
Chiller Temperature (°C)	2.5
Requirement	< 4°C
Compliant	Yes

Gas	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
NO	0.50	82.0	0.12	0.20
CO	0.30	82.1	-0.05	-0.25
CO ₂	0.07	11.80	0.25	-0.20
O ₂	0.06	9.72	0.08	-0.60

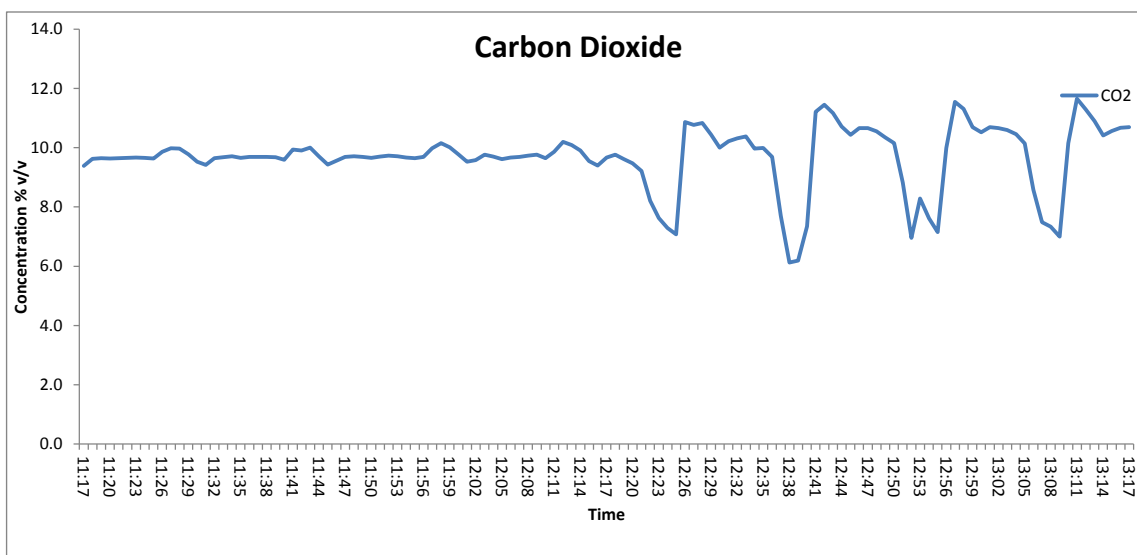
APPENDIX 2 - Summaries, Calculations, Raw Data and Charts
OXIDES OF NITROGEN (as NO₂) EMISSIONS CHART



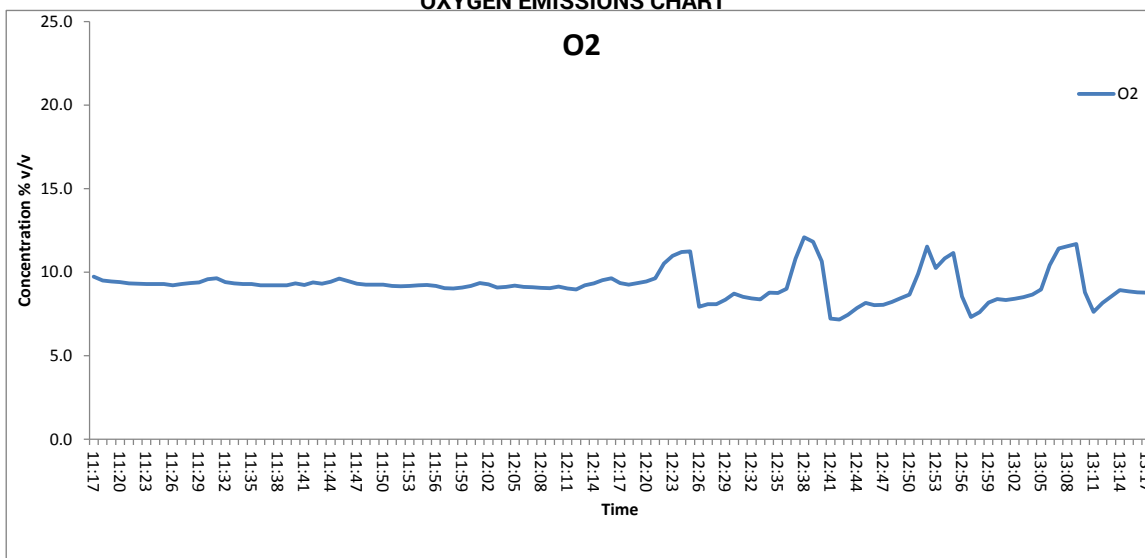
CARBON MONOXIDE EMISSIONS CHART



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	End Weight	Total gain	Concentration	LOD	Uncertainty
		kg	kg	kg	%	%	%
Run 1	11:36-12:06 02 December 2016	2.9724	2.9761	0.0037	8.4	0.25	6.9

Moisture Quality Assurance							
Test Number	Sampling Duration	Total Volume Sampled	Sampling Rate	Start Leak Rate	End Leak Rate	Acceptable Leak Rate	Leak Tests Acceptable?
	mins	l	l/min	l/min	l/min	l/min	
Run 1	30	50	1.7	0.010	0.010	0.033	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	160	°C
Stack static pressure	0.055	kPa
Barometric Pressure	102	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	9.681687	0.096817	0.190057	8.866076	0.088661	0.174046
O ₂	32	1.427679	9.222059	0.092221	0.131661	8.445168	0.084452	0.120570
N ₂	28	1.249219	81.096253	0.810963	1.013070	74.264484	0.742645	0.927726
H ₂ O	18	0.803070	-	-	-	8.424273	0.084243	0.067653

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3348	kg/m ³
Wet Density (STP), P_{STW}	1.2900	kg/m ³
Dry Density (Actual), P_{Actual}	0.8478	kg/m ³
Average Wet Density (Actual), $P_{ActualW}$	0.819	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	02 December 2016
Time of Survey	11:40
Velocity Measurement Device:	S- Type

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) m³/s	O₂ % Vol	Angle of Swirl °
1	0.05	9.5	93	160	12.0	1.5	-	<15
2	0.10	8.8	87	160	11.6	1.5	-	<15
3	0.30	7.6	74	160	10.7	1.3	-	<15
4	0.35	7.6	74	160	10.7	1.3	-	<15
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	8.4	82	160	11.3	1.4	-	-
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) m³/s	O₂ % 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	90	88	2.2	Pass	87	85	2.3	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 Stagnation Check				
Run	Stagnation (Pa)	Reference (Pa)	Difference (Pa)	Outcome (Permitted +/- 10 Pa)
Run 1	55	53	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	74	Pa	≥ 5 Pa	Yes
Lowest Gas Velocity	10.7	m/s	-	-
Highest Gas Velocity	12.0	m/s	-	-
Ratio of Gas Velocities	1.1	-	$< 3 : 1$	Yes
Maximum angle of flow with regard to duct axis	< 15	$^{\circ}$	$< 15^{\circ}$	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, $V = K_{pt} \times (1-e) \times \sqrt{2 \times DP_{pt} / \rho_{Actual}}$		
Where: K_{pt} = Pitot tube calibration coefficient $(1-e)$ = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, V_a	11.3	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	160	0	$^{\circ}\text{C}$
Total Pressure	102.055	101.3	kPa
Oxygen	9.2	3	%
Moisture	8.42	0.00	%
Pitot tube calibration coefficient, K_{pt}	0.81		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (V_a)	11.27	m/s
Stack Area (A)	0.13	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	5097	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	3238	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	2965	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	1940	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

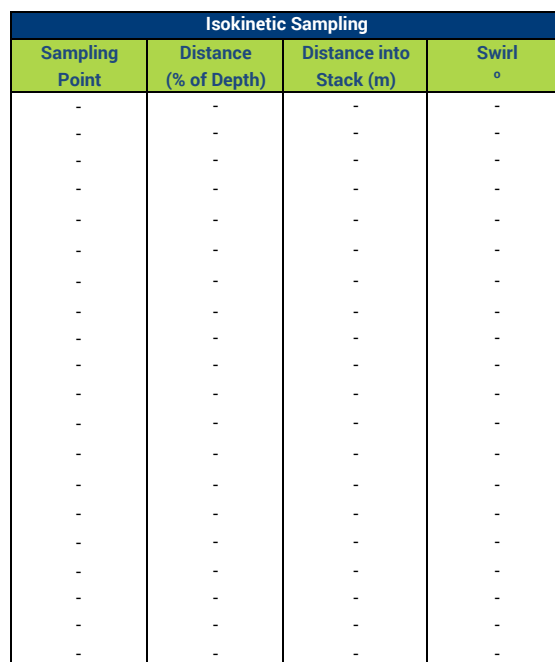
Ms = Water vapour, Reference Conditions, % Vol

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



- ### SAMPLING LOCATION

A schematic diagram showing a vertical rectangular structure. A horizontal line extends from the left side of the structure, labeled "Sample platform". A small rectangular port is located on the right side of the structure, labeled "Sample Port". A line connects the "Sample Port" label to the port.

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	0.50	1.0	0.1	-
as a %	0.07	0.46	0.49	1.0	1.08	0.60
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	3700	1.5	255.2	58	-
MU as % v/v	0.11	0.25	0.24	0.03	0.14	0.39
MU as %	1.2	2.7	0.85	0.3	1.6	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.79	% v/v	6.94	%
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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	126.7	mg/m ³
Cal gas conc	165.025	mg/m ³
Analyser Full Scale	513	mg/m ³

Performance characteristics	Value	Units	specification	MU Met?
Response time	36	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	0.70	% of value	<2 % range	Yes
Zero drift	0.12	% full scale	<2% range / 24hr	Yes
Span drift	0.20	% 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)	-0.87	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.0	% 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	0.13
volume or pressure flow dependence	uspres	0.002
atmospheric pressure dependence	uapres	0.13
ambient temperature dependence	utemp	0.00001
Dependence on voltage	uvolt	0.44
losses in the line (leak)	uleak	-0.41
Uncertainty of calibration gas	ucalib	0.47
Uncertainty in factor	uf	1.18

Measurement uncertainty (Concentration Measured)	81.57	mg/m ³
Combined uncertainty	2.51	mg/m ³
Expanded at a 95% confidence interval	5.02	mg/m ³

Expanded uncertainty expressed with a level of confidence of 95%	3.6	% ELV
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Expanded uncertainty expressed with a level of confidence of 95%	5.0	mg/m ³
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Expanded uncertainty expressed with a level of confidence of 95%	6.2	% 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	6.7	mg/m ³
Cal gas conc	104.125	mg/m ³
Analyser Full Scale	250	mg/m ³

Performance characteristics	Value	Units	specification	MU Met?
Response time	42	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	0.70	% of value	<2 % range	Yes
Zero drift	-0.05	% full scale	<2% range / 24hr	Yes
Span drift	-0.25	% 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)	0.72	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.0	% 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	-0.01
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.06
ambient temperature dependence	utemp	0.00001
Dependence on voltage	uvolt	0.22
losses in the line (leak)	uleak	0.02
Uncertainty of calibration gas	ucalib	0.02
Uncertainty in factor	uf	0.06

Measurement uncertainty (Concentration Measured)	4.3	mg/m ³
Combined uncertainty	1.0	mg/m ³
Expanded uncertainty	2.1	mg/m ³

Expanded uncertainty expressed with a level of confidence of 95%	8.3	% ELV
Expanded uncertainty expressed with a level of confidence of 95%	2.1	mg/m ³
Expanded uncertainty expressed with a level of confidence of 95%	48.1	% value

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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON DIOXIDE

Limit value	-	%vol
Reported Concentration	9.68	%vol
Calibration gas	11.83	%vol
Analyser Full Scale	20	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	48	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)	0.05	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.04	% 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)	0.34	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.0	% 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	0.01
volume or pressure flow dependence	uspres	0.00
atmospheric pressure dependence	uapres	0.010
ambient temperature dependence	utemp	0.0005
Combined interference (from mcerts)	-	0.06
dependence on voltage	uvolt	0.086
losses in the line (leak)	uleak	0.02
Uncertainty of calibration gas	ucalib	0.06

Measurement uncertainty (Concentration Measured)	9.68	%vol
Combined uncertainty	0.14	%vol
% of value	1.49	%

Expanded uncertainty expressed with a level of confidence of 95%	2.99	% of value
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Expanded uncertainty expressed with a level of confidence of 95%	0.29	% vol
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

Reference	3	%vol
Reported Concentration	9.22	%vol
Calibration gas	9.78	%vol
Analyser Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	47	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)	0.02	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.15	% 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)	-0.72	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.0	% 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	0.08
Drift	u0dr	-0.0701
volume or pressure flow dependence	uspres	0.00003
atmospheric pressure dependence	uapres	0.01
ambient temperature dependence	utemp	0.0005
Combined interference (from mcerts)	-	0.08
dependence on voltage	uvolt	0.09
losses in the line (leak)	uleak	-0.04
Uncertainty of calibration gas	ucalib	0.05

Measurement uncertainty (Concentration Measured)	9.22	%vol
Combined uncertainty	0.17	%vol
% of value	1.85	%

Expanded uncertainty expressed with a level of confidence of 95%	3.7	% of value
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Expanded uncertainty expressed with a level of confidence of 95%	0.34	% vol
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	11.3	m/s
Measured Volumetric Flow rate at Actual Conditions	5097	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	0.00005		
Uncertainty of temperature measurement	K	2.21	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	521		
Uncertainty associated with the estimate of density	-	0.008		
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	0.15
Expanded uncertainty at a 95% Confidence Interval	0.28

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	1.3
Expanded uncertainty at a 95% Confidence Interval	2.5

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	135
Expanded uncertainty at a 95% Confidence Interval	264

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	2.6
Expanded uncertainty at a 95% Confidence Interval	5.2

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