



Test Report



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OXIDES OF NITROGEN (AS NO₂) AND CARBON MONOXIDE COMPLIANCE TESTING AT SOUTH HOOK LNG TERMINAL ON BEHALF OF INTERTEK LIMITED

Permit Number: **XP3538LD**

Operator Name: **South Hook LNG (on behalf of Intertek Limited)**

Installation Name: **South Hook LNG Terminal**

Dates of Monitoring Visit: **18th - 22nd November 2019**

Contract Reference: **E08040221**

Client Contact: **Adrian Walsh**

Client Organisation: **Intertek Limited**

Address: **Unit 14 - Waterston Trading Estate
Main Road, Waterston
Milford Haven
SA73 3SL**

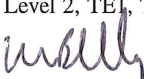
Monitoring Organisation: **National Physical Laboratory**


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Date of Report: **20th December 2019**

Report Author: **Matthew Ellison**

Reference: XP3538LD/INTERTEK/SHLNG/NOV2019/SCV/PPC/Q4/V1

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Signature: 

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1.1 Monitoring Objectives

NPL were awarded a contract by Intertek Limited to carry out emissions compliance testing at South Hook LNG plant near Milford Haven, Pembrokeshire. The scope of work includes carrying out emissions monitoring on the SCV flue stacks phases one and two.

There are a total of fifteen SCV units on the South Hook site that require monitoring, eight on phase one and seven on phase two. Three units were measured for oxides of nitrogen and carbon monoxide.

In addition, oxygen measurements were taken to allow a correction to reference conditions. Water vapour and flow measurements were also taken to determine the moisture content and velocity of the flue gas.

NPL carried out the monitoring visit between the 18th and 22nd November 2019. The report documents the results obtained.

1.2.1 SCV G (Phase One) Monitoring Results

Client: Intertek
Site: South Hook LNG
Emission Point: SCV G (Phase One)

Field	Units	Oxides of Nitrogen (as NO ₂)	Carbon Monoxide	Oxygen	Moisture
Emission Limit Value	mg/m ³ , Reference Conditions	107	N/A	N/A	N/A
Periodic Monitoring Result	Reference Conditions	52.3	571	12.0	1.3
Uncertainty (95% Confidence Level)	Reference Conditions	5.9	50.7	0.4	N/A
	Units	mg/m ³	mg/m ³	%Vol/Vol	%Vol/Vol
Average Stack Flow	m ³ /s at Reference Conditions	4.7			
Reference Conditions		273K, 101.3 kPa, 3% Oxygen on a dry gas basis			
Date	dd/mm/yyyy	22/11/2019			
Sample Period	From hh:mm	10:00			
	To hh:mm	11:00			
Monitoring Method		BS EN 14792:2017	BS EN 15058:2017	BS EN 14789:2017	BS EN 14790:2017
Accreditation		UKAS & MCERTS	UKAS & MCERTS	UKAS & MCERTS	UKAS & MCERTS
Process Status	Load (Tonnes/Hour)	100			
Process Status	Burner Demand (%)	22.3			

1.2.2 SCV E (Phase Two) Monitoring Results

Client: Intertek
Site: South Hook LNG
Emission Point: SCV E (Phase Two)

Field	Units	Oxides of Nitrogen (as NO ₂)	Carbon Monoxide	Oxygen	Moisture
Emission Limit Value	mg/m ³ , Reference Conditions	107	N/A	N/A	N/A
Periodic Monitoring Result	Reference Conditions	53.9	308	10.7	1.8
Uncertainty (95% Confidence Level)	Reference Conditions	5.7	23.0	0.4	N/A
	Units	mg/m ³	mg/m ³	%Vol/Vol	%Vol/Vol
Average Stack Flow	m ³ /s at Reference Conditions	6.5			
Reference Conditions		273K, 101.3 kPa, 3% Oxygen on a dry gas basis			
Date	dd/mm/yyyy	18/11/2019			
Sample Period	From hh:mm	15:30			
	To hh:mm	16:30			
Monitoring Method		BS EN 14792:2017	BS EN 15058:2017	BS EN 14789:2017	BS EN 14790:2017
Accreditation		UKAS & MCERTS	UKAS & MCERTS	UKAS & MCERTS	UKAS & MCERTS
Process Status	Load (Tonnes/Hour)	150			
Process Status	Burner Demand (%)	45.1			

1.2.3 SCV F (Phase Two) Monitoring Results

Client: Intertek
Site: South Hook LNG
Emission Point: SCV F (Phase Two)

Field	Units	Oxides of Nitrogen (as NO ₂)	Carbon Monoxide	Oxygen	Moisture
Emission Limit Value	mg/m ³ , Reference Conditions	107	N/A	N/A	N/A
Periodic Monitoring Result	Reference Conditions	55.5	68.9	9.2	7.5
Uncertainty (95% Confidence Level)	Reference Conditions	5.3	5.6	0.4	N/A
	Units	mg/m ³	mg/m ³	%Vol/Vol	%Vol/Vol
Average Stack Flow	m ³ /s at Reference Conditions	7.5			
Reference Conditions		273K, 101.3 kPa, 3% Oxygen on a dry gas basis			
Date	dd/mm/yyyy	18/11/2019			
Sample Period	From hh:mm	13:00			
	To hh:mm	14:00			
Monitoring Method		BS EN 14792:2017	BS EN 15058:2017	BS EN 14789:2017	BS EN 14790:2017
Accreditation		UKAS & MCERTS	UKAS & MCERTS	UKAS & MCERTS	UKAS & MCERTS
Process Status	Load (Tonnes/Hour)	150			
Process Status	Burner Demand (%)	47.0			

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1.3 Operating Information

South Hook LNG Terminal, situated in Pembrokeshire South West Wales, is a regasification plant for natural gas. The LNG is transported in specially designed vessels to Milford Haven where it is then transferred into storage tanks, where it awaits reheating and distribution into the UK National Grid.

A total of fifteen SCVs have been built across two phases. Each one has at least two five inch ports installed, as set out in BS EN 15259. The ports are located approximately thirteen metres from the base of the stack and can be accessed by ladders that lead to a permanent platform. The sampling platform has lighting, toe boards and handrails. There is sufficient parking on the roadway at the base of the stacks for the mobile laboratory and provision of 240v 16A power supply outlets.

Continuous or Batch Process?	Each SCV operates on a batch process. The number of SCVs operating and the load at which they are set depend upon the required site output.		
What part of the batch process was sampled? (If applicable)	The periodic monitoring is carried out once an SCV has been brought online to the operators required load and has stabilised. This loading remains constant through the one hour test.		
What fuel was used during monitoring? (If applicable)	A small amount of LNG is used as fuel to heat a volume of water. This heat exchange warms up the LNG allowing it to be passed out into the National Grid system.		
What feedstock was used during monitoring? (If applicable)	N/A		
What was the load during monitoring?	Emission Point	Load (Ton/hr)	Burner Demand (%)
	SCV 1G	100	22.3
	SCV 2E	150	45.1
	SCV 2F	150	47.0
What abatement systems are present? Were they in operation?	Each SCV uses water injection to abate NOx emissions. The system was in operation during the periodic monitoring of each SCV.		
Periodic monitoring results and corresponding CEM values	There are no CEMs installed on the SCVs monitored.		

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1.4 Monitoring Deviations

Were all substances in the monitoring objectives monitored? If not why?	All substances set out in the objective were monitored.
Were all substances monitored in accordance to the relevant method? If not why?	All substances set out in the monitoring objectives were measured in accordance to the relevant standards.
Were there any other issues relevant to the monitoring results?	No.

1.5 Conclusions

NPL carried out the emissions monitoring at South Hook LNG over a period of one week. Three SCVs were monitored for the required determinands.

The client is aware of BS EN 15259 and the requirement to carry out homogeneity testing. These tests were carried out on SCVs 1H and 2A, both units passed.

Reference - XP3538LD/INTERTEK/SHLNG/JULY2011/SCV/HOMOGENEITY.

1.6 References

1. STA – Risk Assessment Guide: Industrial-emission monitoring.
2. Environment Agency - Manual Stack emission monitoring performance standard for Organisations.
3. Environment Agency – M1 Technical Guidance Note – Sampling requirements for stack emission monitoring.
4. Environment Agency – M2 Technical Guidance Note – Monitoring of stack emissions to air.
5. Environment Agency - MID 15259 - Stationary source emissions - Requirements for the measurement sections and sites and for the measurement objective, plan and report.
6. Guidance on Assessing Measurement Uncertainty in Stack Emissions Monitoring, by Pullen J and Robinson R, Source Testing Association, Quality Guidance Note QGN1.

APPENDIX ONE

2.1.1 Emissions Testing Personnel Details

Name	Role	MCERTS Number	Certification Level & Expiry Dates					
			Level 1	Level 2	TE1	TE2	TE3	TE4
Matthew Ellison	Team Leader	MM-05-682	N/A	Apr-2023	Sep-2023	Sep-2023	Dec-2023	Sep-2023
Jonny Guy	Site Assistant	MM-16-1388	Sep-2021	N/A	N/A	N/A	N/A	N/A

2.1.2 Emissions Testing Procedures

	Instrumental Methods			Manual Methods		
	NOx	CO	O ₂	H ₂ O	Stack Flow	Temperature
SRM Standard	BS EN 14792:2017	BS EN 15058:2017	BS EN 14789:2017	BS EN 14790:2017	BS EN ISO 16911:2013	BS ISO 16911:2013
Instrument	Horiba PG-250	Horiba PG-250	Horiba PG-250	N/A	Pitot	Type K Thermocouple
Instrument Serial No.	AS0208	AS0208	AS0208	N/A	AS0638	AS0638
Principle	Chemiluminescence	NDIR	Zirconia	Saturation Chart	Flow	Temperature
Operational Range	0 - 250 ppm	0 - 500 ppm	0 - 25%	N/A	N/A	N/A
Certified Range	0 - 125 mg/m ³	0 - 95 mg/m ³	0 - 25%	N/A	N/A	N/A
Uncertainty	10%	6%	6%	20%	10%	1%
NPL Procedure	QPAS B 538	QPAS B 538	QPAS B 538	QPAS B 540	QPAS B 567	QPAS B 567
UKAS Accreditation	YES	YES	YES	YES	YES	YES

The sample gas was extracted from the stack via a chemically inert heated line and drawn through a conditioning unit. All moisture in the gas sample was removed and cooled down to 4°C before it was pumped down another line to the NPL Mobile Source Emissions Laboratory and analysed using a Horiba PG-250. The entire sampling system had been leak tested before testing was carried out to ensure no dilution of the sample gas.

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The conventional analyser zero and span settings were checked before and after each test run using zero grade nitrogen (ex BOC), a suitable gas mixture (BOC beta gas standard), traceable to national reference standards and a gas dilution system. The certified accuracies of the gas standards are listed below: -

Component	Sample Location	Cylinder ID	Certified Amount	Certified Uncertainty
Carbon Monoxide	Phase 1 & 2 SCVs	146655SG	152.1 ppm	1%
Nitrogen Oxide		146655SG	78.3 ppm	1%
Oxygen		253223SG	15.30%	1%

These measurement uncertainties are expressed at a 95% level of confidence.

The ranges of the Horiba PG-250 analyser used for the testing and the values used to calibrate the instrument before and after the testing are listed below: -

Gaseous Components	Horiba Ranges	Calibrated Values
Carbon Monoxide	0 - 200 ppm	152.1 ppm
Oxides of Nitrogen (as NO ₂)	0 - 100 ppm	78.3 ppm
Oxygen	0 - 25%	15.30%

A leak test was conducted before testing to confirm hydraulic integrity of the gaseous sampling system. This was conducted by blocking the inlet of the sampling probe and checking the flow rate at the analyser.

The electrical volt/millivolt outputs from the PG-250 gas analyser was collected by data logger software on a PC and downloaded to digital media at the end of each day. Under the program used during the tests, the software records and stores individual readings either every 1 or 10 seconds. From this data, the logger can perform a series of calculations to output 1 minute averaged measurement on a volume/volume or mass/volume basis. After each 1 minute average has been established the data buffer is reset and the process repeats.

2.1.3 Equipment Checklist Reference

See workfile INTK47NOV19/Equipment Checklist.

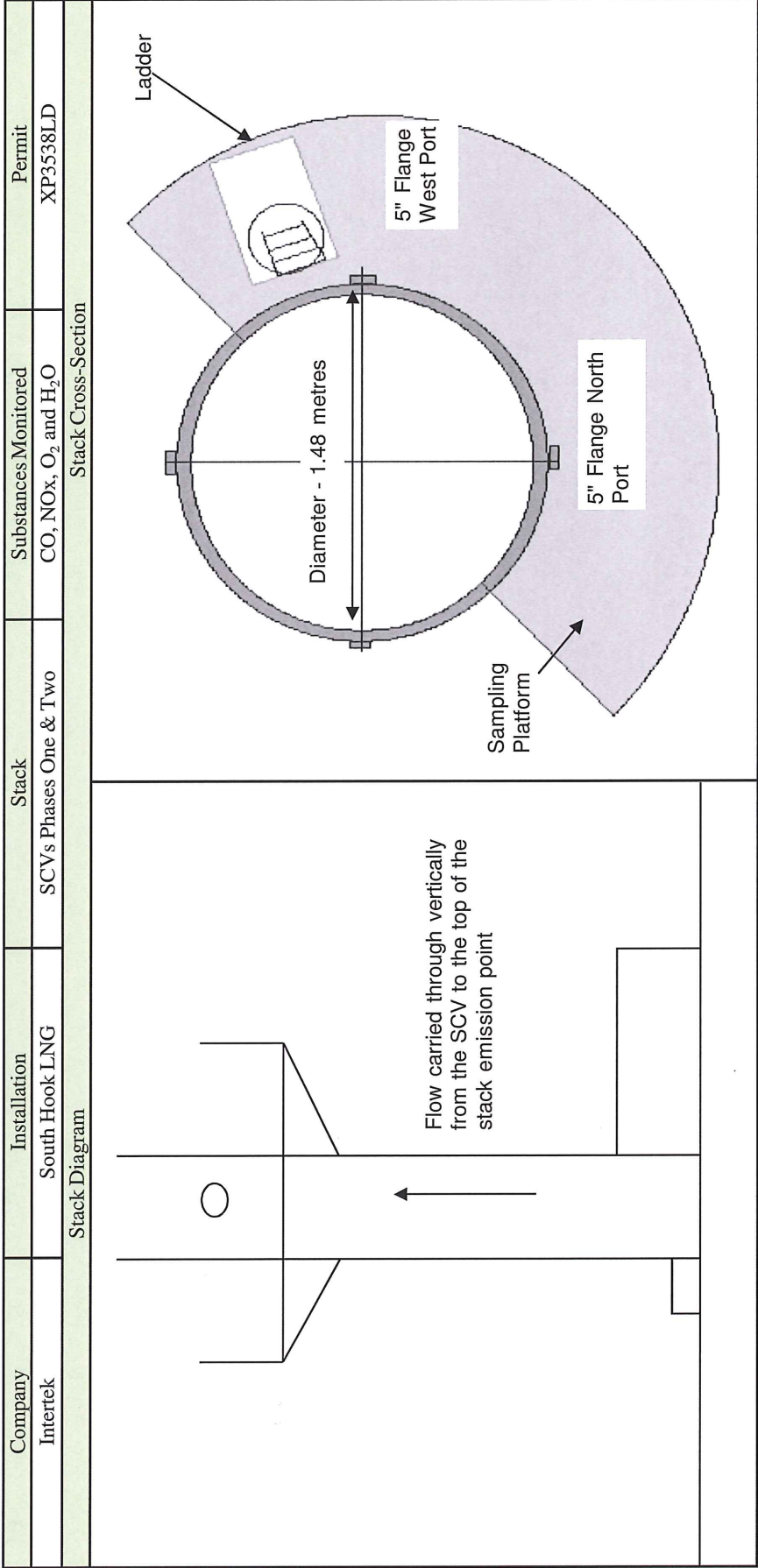
2.1.4 Data Capture Location Reference

All data collected using the NPL computer system on site is backed up at the end of each day onto a memory stick. When the team returns to site this information is then uploaded onto the NPL servers and stored in the relevant location for that job. The link below is where the South Hook emissions data is stored:

P:\Stack Emissions Team\South Hook LNG - Intertek\INTK47NOV19\7. Monitoring Record Sheets

APPENDIX TWO

2.2.1 - Stack Diagram



Position	1	2	3	4	5	6	7	8	9	10
% of Diameter	3.2	8.2	14.6	22.6	34.2	65.8	77.4	85.4	91.8	96.8
Insertion, m	0.05	0.12	0.22	0.33	0.51	0.97	1.15	1.26	1.36	1.43
Insertion plus offset, m	0.15	0.22	0.32	0.43	0.61	1.07	1.25	1.36	1.46	1.53

Notes - The circular stack diameter was measured as 1.48 metres, whilst the port offset (distance between the edge of the stack to the end of the port) was measured as 23 centimetres. Access to the top of the stack was by a series of three ladders. Each one had a resting platform in-between with a self closing gate installed. The main platform itself is a permanent structure with toe boards, railings and self closing gate.

2.2.2 - Flow Criteria Measurements

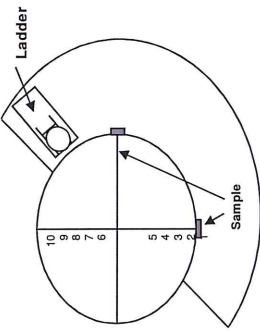
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A diagram of a circular sample. A vertical line passes through the center of the circle. A horizontal line also passes through the center, with the left half labeled 10, 9, 8, 7, 6 and the right half labeled 5, 4, 3, 2, 1. A small rectangular label with the word "Sample" is attached to the right side of the circle. A ladder is shown on the left side of the circle, with a line pointing to it labeled "Ladder".

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SAMPLING LINE: North										
Traverse Point	Distance into duct (m)	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Average mm H2O	Δp Pa	Stack Temp Ts °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	√Δp
1	1.42	3.10	3.10	3.10	3.10	30.39	11.5	5.82	7	1.76
2	1.26	3.40	3.40	3.40	3.40	33.33	11.4	6.09	7	1.84
3	1.04	3.40	3.40	3.40	3.40	33.33	11.4	6.09	6	1.84
4	0.44	3.60	3.60	3.60	3.60	35.29	11.3	6.27	7	1.90
5	0.22	3.20	3.20	3.20	3.20	31.37	11.2	5.91	5	1.79
6	0.06	3.60	3.60	3.60	3.60	35.29	11.2	6.27	6	1.90
SAMPLING LINE: West										
Traverse Point	Distance into duct (m)	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Average mm H2O	Δp Pa	Stack Temp Ts °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	√Δp
1	1.42	2.20	2.20	2.20	2.20	21.57	11.4	4.90	6	1.48
2	1.26	2.30	2.30	2.30	2.30	22.55	11.3	5.01	7	1.52
3	1.04	2.70	2.70	2.70	2.70	26.47	11.3	5.43	7	1.64
4	0.44	3.10	3.10	3.10	3.10	30.39	11.3	5.82	5	1.76
5	0.22	3.50	3.50	3.50	3.50	34.31	11.4	6.18	6	1.87
6	0.06	3.50	3.50	3.50	3.50	34.31	11.4	6.18	7	1.87
Average values		3.1	3.1	3.1	3.1	30.7	11.3	5.8	6.3	1.8
Duct / Stack Flow Characteristics:										
					Average	Flow Criteria Measurements				
Stack Velocity at stack gas T & P and a wet gas basis					5.83	Is the Flow Ratio 3:1 or less?				
Stack flow @ STP, O ₂ (ref) and on a dry gas basis					4.72	m ³ s ⁻¹				
Stack flow @ stack gas T & P and on a wet gas basis					10.03	m ³ s ⁻¹				
Stack flow @ stack gas T & P and on a dry gas basis					9.89	m ³ s ⁻¹				
Stack flow @ STP and on a wet gas basis					9.63	m ³ s ⁻¹				
Stack flow @ STP, O ₂ (ref) and on a wet gas basis					4.79	m ³ s ⁻¹				

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Monitoring Objective	Traverse	18/11/2019	Site:	South Hook LNG	Stack ID:	SCV 2E		
Date	AS0589	AS0589	Site Team:	MRE/JG	Time of Survey:	15:00		
Tape Measure ID	N/A	Diagram of Sample Location:						
Laser Measurement Device ID	AS0687							
Traverse Pitot Tube ID	AS0687							
Prior Assembly Visual Inspection	Pass							
Pre Test Leak Check <2.5 mm H2O	Pass							
Traverse Manometer Type	Digital							
Traverse Manometer ID	AS0638							
Traverse Manometer Range	240							
Traverse Temp. Readout ID	AS0638							
Traverse Thermocouple ID	AS0451a							
Static Pressure	Δp (mmH2O)	21.50						
Swirl Test Conducted	Pass							
Protractor ID	AS0626							
Post-Test Blockage Test (L-Type only)	Pass							
Post Test Leak Check <2.5 mm H2O	Pass							
Prior Assembly Visual Inspection	Pass							
Conditions	Value	Units	Duct Dimensions					
Stack pressure	759.48	mmHg	Port ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Port Depth
Ref O ₂ Value	3	%	A					
Moisture Content	1.79	%	B					
CO	100	ppm	C					
CO ₂	6	%	D					
N ₂	83.59	%	Circular Duct					
O ₂	10.40	%	Line ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Diameter
Dry Molecular wt	29.38		A					
Stack Molecular wt	29.17		B					
Duct Diameter	1.48	m	Rectangular Duct					
Duct Depth		m	Line ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Depth
Duct Width		m	A					
Area of stack	1.72	m ²	B					
Pbar	1010.2	mbar	C					
Pbar	758	mmHg	D					
Pitot tube coeff	0.834		Outside Side Division					
Reference Temp	273	K	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Width	
Reference Pressure	760	mmHg	Static Measurement					
Ambient Temperature	7	°C	Measurement Line					
			Reading 1 Reading 2(107)					
			Enter manually from previous visit					
			Circular Duct	Rectangular Duct	A B C D			
			Duct Diameter (m)	1.48	21.50 21.60 21.40			
			Duct Depth (m)					
			Duct Width (m)					
			Post-test Blockage Test 4	Traverse Point	Δp Reading (mm H ₂ O)	Δp Reading (mm H ₂ O)	Δp Average (mm H ₂ O)	
			Reading 1					
			Reading 2					

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SAMPLING LINE: North										
Traverse Point	Distance into duct (m)	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Average mm H2O	Δp Pa	Stack Temp Ts °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	√Δp
1	1.42	3.90	3.90	3.90	3.90	38.23	16.5	6.58	7	1.97
2	1.26	2.50	2.50	2.50	2.50	24.51	16.5	5.27	7	1.58
3	1.04	5.00	5.00	5.00	5.00	49.02	16.7	7.46	7	2.24
4	0.44	5.20	5.20	5.20	5.20	50.98	17.5	7.62	6	2.28
5	0.22	4.30	4.30	4.30	4.30	42.15	17.8	6.93	5	2.07
6	0.06	4.00	4.00	4.00	4.00	39.21	18.0	6.68	6	2.00
SAMPLING LINE: West										
Traverse Point	Distance into duct (m)	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Average mm H2O	Δp Pa	Stack Temp Ts °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	√Δp
1	1.42	3.40	3.40	3.40	3.40	33.33	13.8	6.12	7	1.84
2	1.26	4.00	4.00	4.00	4.00	39.21	13.9	6.64	6	2.00
3	1.04	4.30	4.30	4.30	4.30	42.15	14.1	6.88	7	2.07
4	0.44	5.20	5.20	5.20	5.20	50.98	14.8	7.58	6	2.28
5	0.22	5.20	5.20	5.20	5.20	50.98	15.4	7.59	7	2.28
6	0.06	5.70	5.70	5.70	5.70	55.88	16.0	7.95	7	2.39
Average values		4.4	4.4	4.4	4.4	43.1	15.9	6.9	6.5	2.1
Duct / Stack Flow Characteristics:										
Flow Criteria Measurements					Average		Units			
Stack Velocity at stack gas T & P and a wet gas basis					6.94		ms ⁻¹		Is the Flow Ratio 3:1 or less?	
Stack flow @ STP, O ₂ (ref) and on a dry gas basis					6.49		m ³ s ⁻¹			
Stack flow @ stack gas T & P and on a wet gas basis					11.94		m ³ s ⁻¹		Any local negative flow?	
Stack flow @ stack gas T & P and on a dry gas basis					11.72		m ³ s ⁻¹		Flow <15° of duct axis?	
Stack flow @ STP and on a wet gas basis					11.27		m ³ s ⁻¹			
Stack flow @ STP, O ₂ (ref) and on a wet gas basis					6.61		m ³ s ⁻¹		Minimum Δp detected > 0.5 mmH2O	
									YES	

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A diagram showing a circular area divided into 10 radial segments, numbered 1 to 10. A ladder is positioned at the top left, and a sample point is marked on the right side. An arrow points from the text 'Sample' to the sample point.

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SAMPLING LINE: North										
Traverse Point	Distance into duct (m)	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Average mm H2O	Δp Pa	Stack Temp Ts °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	√Δp
1	1.42	4.40	4.40	4.40	4.40	43.13	13.2	6.94	6	2.10
2	1.26	5.50	5.50	5.50	5.50	53.92	13.4	7.77	5	2.35
3	1.04	5.20	5.20	5.20	5.20	50.98	13.3	7.55	5	2.28
4	0.44	4.40	4.40	4.40	4.40	43.13	13.1	6.94	6	2.10
5	0.22	4.80	4.80	4.80	4.80	47.05	12.9	7.25	6	2.19
6	0.06	4.70	4.70	4.70	4.70	46.07	12.9	7.17	7	2.17
SAMPLING LINE: West										
Traverse Point	Distance into duct (m)	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Spot Reading mm H2O	Ap Average mm H2O	Δp Pa	Stack Temp Ts °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	√Δp
1	1.42	3.80	3.80	3.80	3.80	37.25	13.3	6.45	6	1.95
2	1.26	3.80	3.80	3.80	3.80	37.25	13.2	6.45	7	1.95
3	1.04	4.10	4.10	4.10	4.10	40.19	13.1	6.70	7	2.02
4	0.44	5.10	5.10	5.10	5.10	50.00	13.0	7.47	6	2.26
5	0.22	6.40	6.40	6.40	6.40	62.74	13.0	8.37	8	2.53
6	0.06	5.90	5.90	5.90	5.90	57.84	13.5	8.04	7	2.43
Average values		4.8	4.8	4.8	4.8	47.5	13.2	7.3	6.3	2.2
Duct / Stack Flow Characteristics:										
Stack Velocity at stack gas T & P and a wet gas basis					Average		Flow Criteria Measurements			
Stack flow @ STP, O ₂ (ref) and on a dry gas basis					7.26		Is the Flow Ratio 3:1 or less?			
Stack flow @ stack gas T & P and on a wet gas basis					7.47		Any local negative flow?			
Stack flow @ stack gas T & P and on a dry gas basis					12.48		Flow <15° of duct axis?			
Stack flow @ STP and on a wet gas basis					12.30		Minimum Δp detected > 0.5 mmH2O			
Stack flow @ STP, O ₂ (ref) and on a wet gas basis					11.90					
					7.59					

2.2.3 - One Minute Averaged Gaseous Emissions Data

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

Minute Averaged Gaseous Data from South Hook LNG 22nd November 2019			
SCV G - Phase One			
Referenced to 273K, 101.3kPa and 3% Oxygen on a Dry Basis			
Time (hh:mm)	Carbon Monoxide (mg/Nm ³)	Oxides of Nitrogen (mg/Nm ³)	Oxygen (%)
10:00	579	51.7	12.1
10:01	572	52.4	12.0
10:02	570	52.1	11.9
10:03	570	51.5	12.0
10:04	573	52.2	11.9
10:05	562	52.1	11.9
10:06	559	51.7	11.9
10:07	567	51.8	12.0
10:08	568	51.9	12.1
10:09	570	52.3	12.0
10:10	582	52.0	12.1
10:11	579	51.6	12.1
10:12	578	51.8	12.1
10:13	573	52.2	12.1
10:14	559	52.5	12.0
10:15	564	52.6	12.1
10:16	577	52.9	12.1
10:17	579	52.8	12.0
10:18	570	52.9	12.1
10:19	578	53.0	12.1
10:20	589	52.4	12.1
10:21	581	52.9	12.1
10:22	577	52.9	12.1
10:23	572	53.3	12.0
10:24	569	52.9	11.9
10:25	557	52.7	11.9
10:26	567	52.4	11.9
10:27	568	52.0	12.0
10:28	554	52.1	12.0
10:29	560	51.9	12.1
10:30	558	52.2	12.1
10:31	554	52.5	12.1
10:32	581	52.2	12.1
10:33	575	52.2	12.1
10:34	560	52.6	12.0
10:35	559	52.4	12.0
10:36	566	52.2	12.0
10:37	562	52.4	12.1
10:38	571	52.5	12.1
10:39	576	52.7	12.1
10:40	570	53.3	12.0
10:41	582	52.7	12.1
10:42	576	53.0	12.1
10:43	582	52.9	12.1
10:44	586	53.0	12.1
10:45	582	52.9	12.0
10:46	568	52.9	12.0
10:47	563	52.3	12.0
10:48	551	51.8	12.0
10:49	547	51.7	12.0
10:50	551	51.8	12.0
10:51	570	51.3	12.0
10:52	567	51.5	12.1
10:53	574	51.5	12.1
10:54	580	51.4	12.1
10:55	579	51.9	12.1
10:56	577	52.2	12.1
10:57	587	52.1	12.1
10:58	589	52.1	12.1
10:59	589	52.1	12.1
11:00	591	51.9	12.1
Min Value	547	51.3	11.9
Max Value	591	53.3	12.1
Average	571	52.3	12.0

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

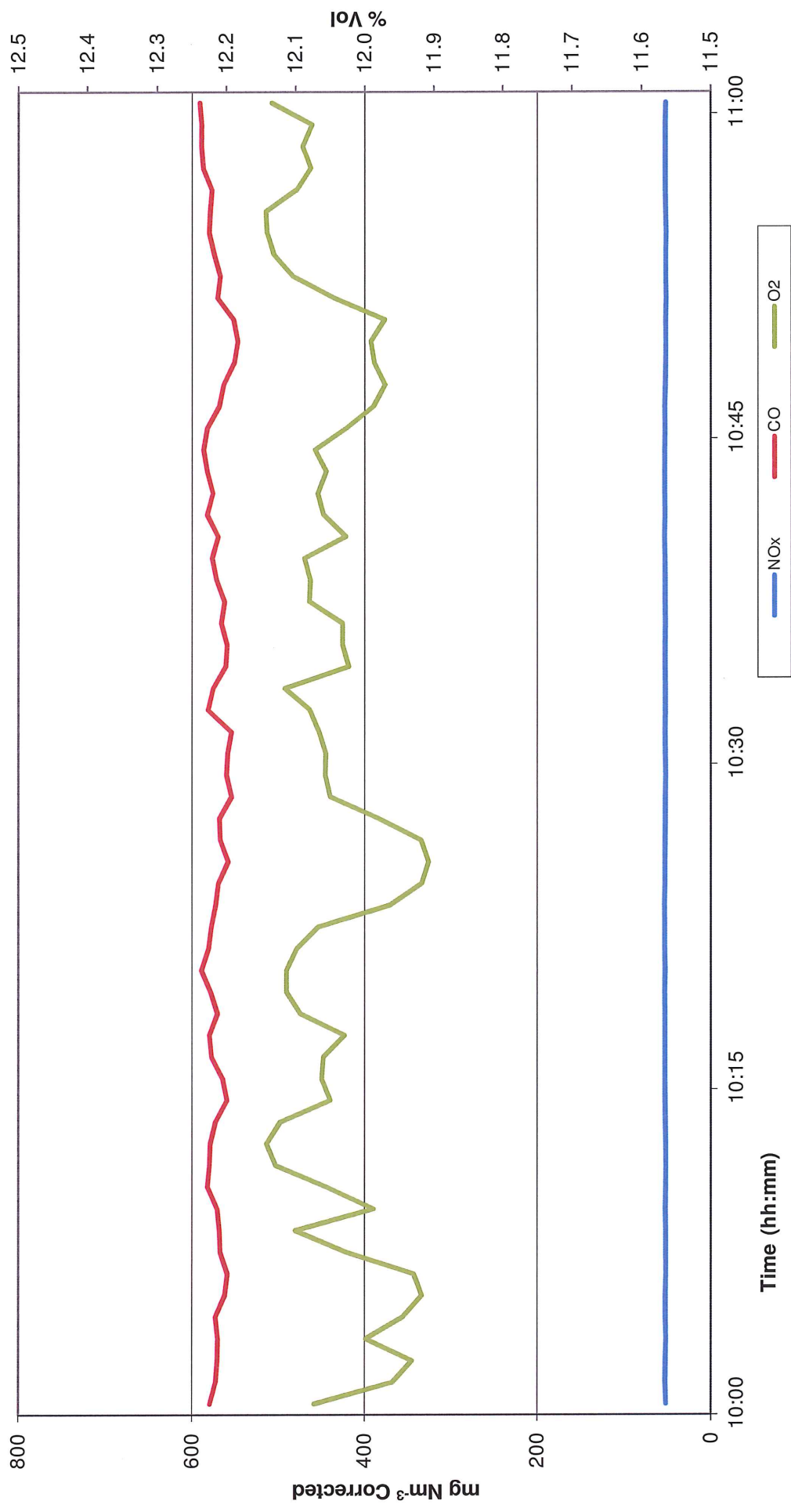
Minute Averaged Gaseous Data from South Hook LNG 18th November 2019			
SCV E - Phase Two			
Referenced to 273K, 101.3kPa and 3% Oxygen on a Dry Basis			
Time (hh:mm)	Carbon Monoxide (mg/Nm ³)	Oxides of Nitrogen (mg/Nm ³)	Oxygen (%)
15:30	240	53.8	10.4
15:31	390	51.5	11.2
15:32	464	50.3	11.7
15:33	480	50.2	11.8
15:34	484	51.4	12.0
15:35	497	50.9	12.0
15:36	464	52.0	11.8
15:37	345	53.3	11.1
15:38	238	55.1	10.4
15:39	173	56.0	9.8
15:40	150	56.0	9.5
15:41	136	56.3	9.4
15:42	140	56.3	9.4
15:43	149	56.1	9.4
15:44	192	56.0	10.0
15:45	297	54.1	10.8
15:46	425	51.8	11.4
15:47	463	51.2	11.9
15:48	481	50.8	12.0
15:49	459	51.9	12.0
15:50	480	52.0	12.0
15:51	423	52.7	11.6
15:52	315	54.4	10.9
15:53	216	55.9	10.2
15:54	166	56.5	9.7
15:55	152	56.5	9.5
15:56	147	56.3	9.4
15:57	147	56.5	9.4
15:58	152	56.6	9.5
15:59	213	56.0	10.2
16:00	328	54.1	10.9
16:01	436	51.9	11.5
16:02	494	50.5	11.9
16:03	484	50.6	12.0
16:04	497	50.7	12.0
16:05	481	51.2	11.9
16:06	378	52.8	11.3
16:07	260	55.1	10.6
16:08	193	56.1	10.0
16:09	158	56.3	9.6
16:10	149	56.3	9.4
16:11	147	56.3	9.4
16:12	145	56.2	9.4
16:13	181	56.1	9.8
16:14	266	54.7	10.5
16:15	389	52.4	11.3
16:16	467	51.0	11.8
16:17	486	50.8	12.0
16:18	483	51.0	12.1
16:19	501	50.7	12.1
16:20	477	51.3	11.8
16:21	338	53.8	11.1
16:22	232	55.7	10.4
16:23	177	56.3	9.8
16:24	148	56.5	9.4
16:25	143	56.4	9.3
16:26	139	56.3	9.4
16:27	153	56.0	9.4
16:28	208	55.5	10.0
16:29	325	53.3	10.8
16:30	460	50.6	11.5
Min Value	136	50.2	9.3
Max Value	501	56.6	12.1
Average	308	53.9	10.7

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

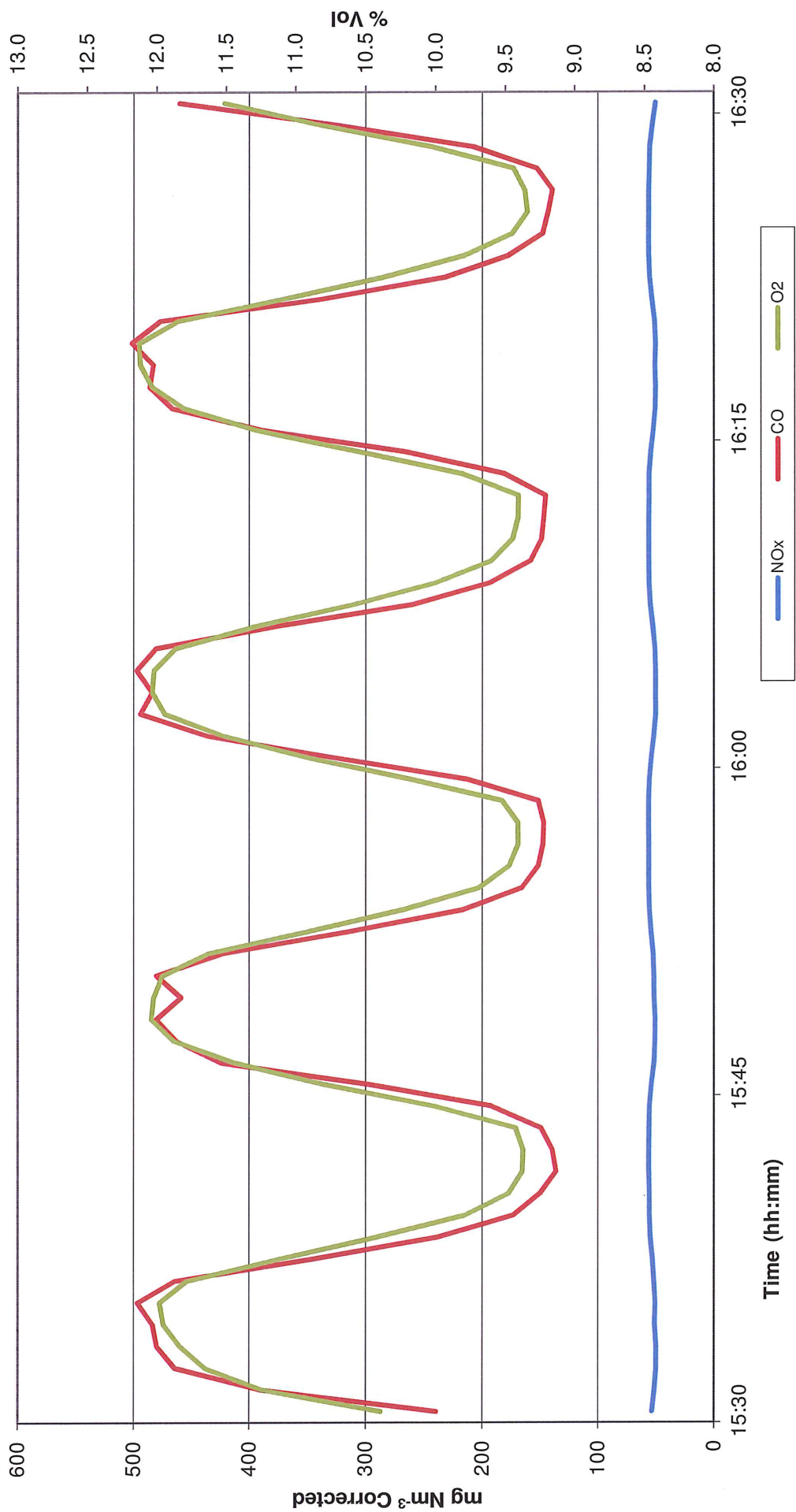
Minute Averaged Gaseous Data from South Hook LNG 18th November 2019			
SCV F - Phase Two			
Referenced to 273K, 101.3kPa and 3% Oxygen on a Dry Basis			
Time (hh:mm)	Carbon Monoxide (mg/Nm ³)	Oxides of Nitrogen (mg/Nm ³)	Oxygen (%)
13:00	84.4	56.2	9.5
13:01	80.8	56.0	9.5
13:02	76.2	55.8	9.4
13:03	65.0	55.5	9.1
13:04	59.4	55.3	9.0
13:05	57.5	55.0	9.0
13:06	55.8	55.1	8.9
13:07	52.0	55.0	8.8
13:08	50.3	54.8	8.8
13:09	53.0	54.7	8.8
13:10	56.9	55.1	9.0
13:11	58.9	55.8	9.1
13:12	66.7	55.9	9.2
13:13	76.7	55.9	9.4
13:14	82.6	56.1	9.5
13:15	82.6	56.1	9.5
13:16	86.4	56.1	9.6
13:17	82.8	56.1	9.5
13:18	82.6	56.2	9.5
13:19	78.8	56.0	9.4
13:20	75.1	56.3	9.4
13:21	73.4	56.0	9.3
13:22	65.9	56.0	9.2
13:23	61.9	56.0	9.1
13:24	59.1	56.0	9.1
13:25	56.4	55.6	9.0
13:26	51.3	55.6	8.9
13:27	48.0	55.3	8.8
13:28	49.7	55.1	8.8
13:29	55.6	55.0	8.9
13:30	59.8	55.3	9.0
13:31	67.6	55.5	9.2
13:32	74.9	55.5	9.3
13:33	76.1	55.5	9.3
13:34	79.2	55.5	9.4
13:35	83.0	55.5	9.5
13:36	83.4	55.9	9.5
13:37	81.0	55.6	9.5
13:38	82.9	55.6	9.4
13:39	82.4	55.3	9.4
13:40	79.3	55.3	9.4
13:41	70.9	55.6	9.3
13:42	66.6	55.4	9.2
13:43	61.4	55.4	9.1
13:44	56.6	55.1	9.0
13:45	56.0	55.0	9.0
13:46	55.0	54.7	8.9
13:47	52.2	54.6	8.9
13:48	49.5	54.7	8.8
13:49	48.7	55.0	8.8
13:50	58.0	55.0	8.9
13:51	66.6	55.5	9.1
13:52	70.6	55.5	9.2
13:53	80.9	55.6	9.4
13:54	84.0	55.9	9.5
13:55	82.2	56.3	9.5
13:56	84.9	55.9	9.5
13:57	84.7	56.0	9.5
13:58	82.9	55.9	9.5
13:59	82.7	55.8	9.5
14:00	71.1	55.5	9.3
Min Value	48.0	54.6	8.8
Max Value	86.4	56.3	9.6
Average	68.9	55.5	9.2

2.2.4 - Gaseous Emissions Graphical Data

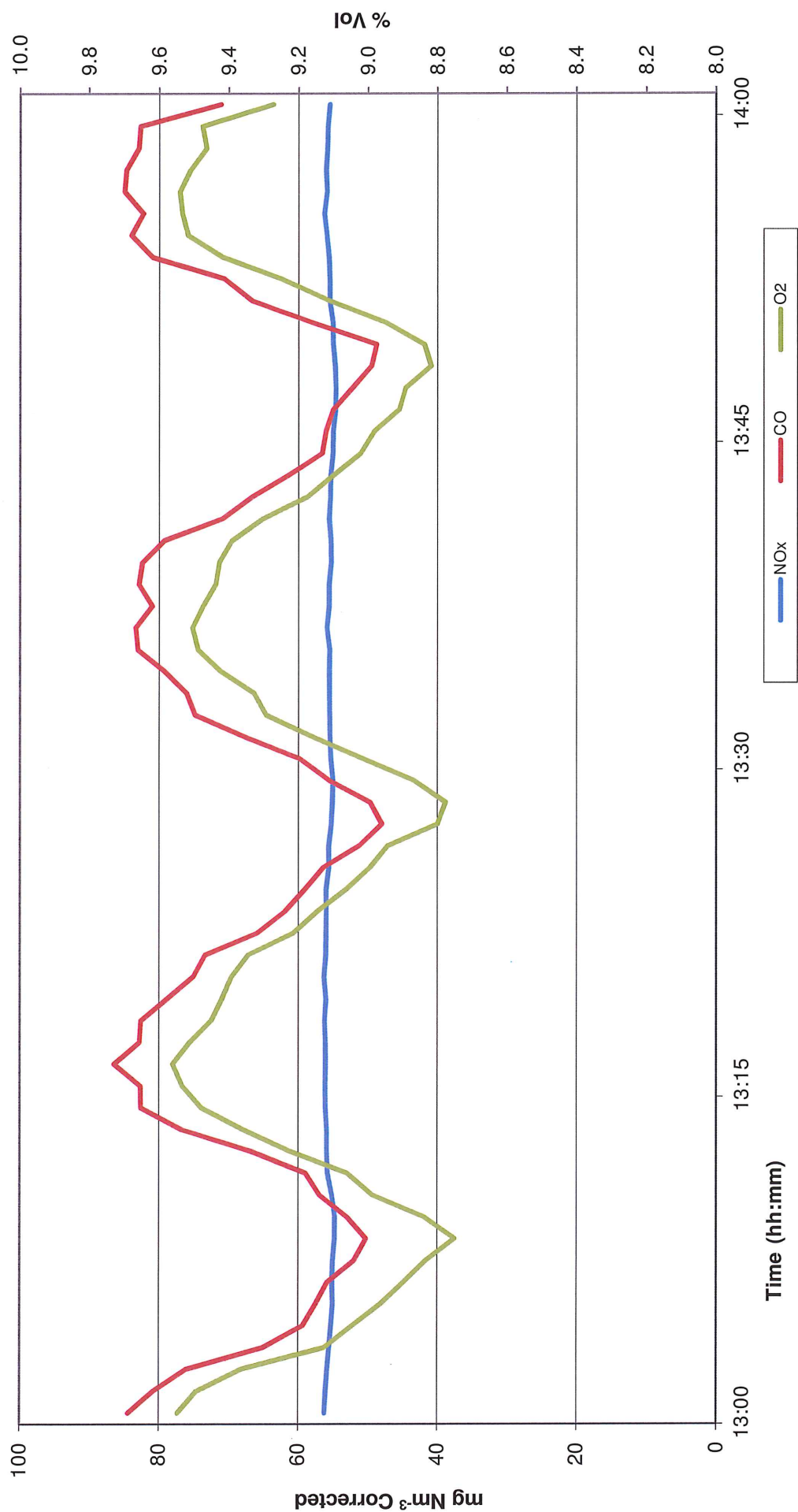
SCV 1G One Minute Averaged Gaseous Emissions Data - 22nd November 2019
(273.15K, 101.325kPa, 3% O₂, on a Dry Gas basis) using the NPL Conventional Analysis Package



SCV 2E One Minute Averaged Gaseous Emissions Data - 18th November 2019
(273.15K, 101.325kPa, 3% O₂, on a Dry Gas basis) using the NPL Conventional Analysis Package



SCV 2F One Minute Averaged Gaseous Emissions Data - 18th November 2019
(273.15K, 101.325kPa, 3% O₂, on a Dry Gas basis) using the NPL Conventional Analysis Package



2.2.5 - Gas Calibration Log

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

GAS CALIBRATION MEASUREMENTS

Client:	Intertek Ltd	Date:	18/11/2019	SO ₂ (ppm)		CO (ppm)		NONOX (ppm)		N ₂ O (ppm)	
Site:	South Hook LNG	Job Number:	INTK47NOV19	CBISS auto ranges		0-200		0-100		0-15	
Stack ID:	SCVs	Initial N ₂ pressure bar:	180	0-700		0-400		0-400 (only NO)			
Reference oxygen %	3	Leak check method	Flow method	0-5000		0-10000		0-3000 (only NO)			
GAS CALIBRATION LOG - ANALYSER ADJUSTMENT											
Gas Cylinder ID:		CO	NO	O ₂		CO ₂		VOCs		N ₂ O	
Initial Reg. Pressure bar		146655SG	146655SG	253223SG		253223SG					
Analyser type / Analyser ID		PG250 AS0208	PG250 AS0208	PG250 AS0208		PG250 AS0208					
Cylinder Concentration:		152.1 ppm	78.3 ppm	15.30 % Vol		15.24 % Vol		ppm C ₂ H ₄		ppm	
Span Value:		152.1 ppm	78.3 ppm	15.30 % Vol		15.24 % Vol		ppm C ₂ H ₄		ppm	
Analyser Range: 0 -		200 ppm	100 ppm	25 % Vol		20 % Vol		ppm C ₂ H ₄		ppm	
Check Zero		Time	12:30	ppm		-0.13 % Vol		ppm C ₂ H ₄		ppm	
Initial Gain		0	0	-15		-2					
Adjust Zero		Time	12:31	ppm		0.00 % Vol		ppm C ₂ H ₄		ppm	
Final Gain		0	0	-17		-3					
Check Span		Time	12:46	ppm		12:37		ppm C ₂ H ₄		ppm	
Initial Gain		147.4 ppm	72.4 ppm	15.36 % Vol		16.75 % Vol		ppm C ₂ H ₄		ppm	
Time		1.419	1.011	0.990		1.009					
Adjust Span		Time	12:47	ppm		12:38		ppm C ₂ H ₄		ppm	
Final Gain		152.1 ppm	78.3 ppm	15.30 % Vol		15.24 % Vol		ppm C ₂ H ₄		ppm	
Time		1.463	1.090	0.980		0.965					
Check Zero		Time	12:52	ppm		0.01 % Vol		ppm C ₂ H ₄		ppm	
Reading		1.0 ppm	0.3 ppm	0.01 % Vol		0.0 % Vol		ppm C ₂ H ₄		ppm	
Zero Drift		0.0 ppm	0.0 ppm	Accept <2% of range		Accept <2% of range		0.0 ppm C ₂ H ₄		0.0 ppm	
Acceptance		Accept <2% of range									
GAS CALIBRATION LOG - SAMPLING SYSTEM CHECK - FLOW METHOD											
Expected Flow:		CO	NO	O ₂							
Time		0.40 l/min	0.40 l/min	0.40 l/min		12:54					
Leak check		0.0 l/min	0.0 l/min	0.0 l/min		PASS					
Pass/fail		PASS	PASS	PASS		PASS					
GAS CALIBRATION LOG - DRIFT CHECK											
Span Value:		CO	NO	O ₂		CO ₂		VOCs		N ₂ O	
Time		152.1 ppm	78.3 ppm	15.30 % Vol		15.24 % Vol		0.0 ppm C ₂ H ₄		0.0 ppm	
Check Zero		Time	16:43	ppm		0.04 % Vol		ppm C ₂ H ₄		ppm	
Reading		0.6 ppm	0.0 ppm	16:54		16:54		ppm C ₂ H ₄		ppm	
Check Span		Time	16:47	ppm		15.23 % Vol		ppm C ₂ H ₄		ppm	
Reading		145.7 ppm	76.3 ppm	0.1		0.3		ppm C ₂ H ₄		ppm	
Zero Drift (%)		0.4	0.0	0.5		1.0		ppm C ₂ H ₄		ppm	
Span Drift (%)		4.2	2.6	Accept		Accept		ppm C ₂ H ₄		ppm	
Acceptance zero		Correct for drift	Correct for drift	Correct for drift		Correct for drift		ppm C ₂ H ₄		ppm	
Acceptance span		Correct for drift	Correct for drift	Correct for drift		Correct for drift		ppm C ₂ H ₄		ppm	

CALIBRATION TO BE CARRIED OUT BY OR UNDER THE SUPERVISION OF MCERTS QUALIFIED PERSONNEL WITH LEVEL TWO AND TE4

Name:	Matthew Ellison	MRE/IG
MCERTS ID:	MM-05-682	

Continuation Sheet

GAS CALIBRATION MEASUREMENTS

[illegible]

CALIBRATION TO BE CARRIED OUT BY OR UNDER THE SUPERVISION OF MCERT'S QUALIFIED PERSONNEL WITH LEVEL TWO AND TE4

Name:	Matthew Ellison
MCERTS ID:	MM-05-682
Personnel Present:	MRE/G

2.2.6 - Uncertainty Calculations

SCV 1G Uncertainty Calculations

Uncertainty calculation for gaseous measurement of NOx BS EN 14792:2017 - PG-250 AS0208
v3.7
Sep-19

Limit value	107 mg/m ³ (corrected)	Cal gas conc	180.75 mg·m ⁻³
Measured concentration	26.02 mg/m ³ (101.3kPa, 273K)	Full Scale	205.30 mg/m ³
Measured concentration	52.29 mg/m ³ (Corrected)		
NO/NO2 ratio	100.00	Gas	NO
		Full Scale	100 ppm
		Cal gas conc	76.3 ppm
		Conversion	2.05

Performance characteristics	Value	Specification
Response time	70 seconds	≤200 seconds
Logger sampling interval	60 seconds	
Measurement period	61 minutes	
Number of readings in measurement	61	
Standard deviation of repeatability at zero	0.03	≤±2% range
Standard deviation of repeatability at span level	0.15	≤±2% range
Standard deviation of reproducibility	0	≤±3.3% range
Deviation from linearity(lack of fit)	0.35	≤±2 % range
Zero drift	0.21	≤5% span value
Span drift	0	≤5% span value
Influence of sample gas flow	2	≤±2% range
Influence of atmospheric pressure	2	≤±2% range
Influence of ambient temperature	0.18	≤±5% range
CO (mg/m3)	300	
HCl (mg/m3)	50	
SO2 (mg/m3)	1000	
N2O (mg/m3)	20	
Influence of voltage	0.8	≤±4% range (Total)
Influence from vibration	0	
Losses in the line (leak)	0	
Converter efficiency	95.5	≤±2% range
Uncertainty of calibration gas	1	≤±5% of value
		≤± 2% of value

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	U ₀	mg/m3
Standard deviation of repeatability at span level	U _s	0.00
Standard deviation of reproducibility	U _p	0.04
Lack of fit	U _{li}	0.00
Drift	U _{dr}	0.41
Influence of sample gas flow	U _{gfs}	0.12
Influence of atmospheric pressure	U _{gpr}	0.00
Influence of ambient temperature	U _{gtr}	0.42
CO (mg/m3)	U _{temp}	0.03
HCl (mg/m3)	U _{unert}	0.28
SO2 (mg/m3)	U _{unert}	0.00
N2O (mg/m3)	U _{unert}	0.00
Influence of voltage	U _{unert}	0.05
Influence from vibration	U _{un}	0.00
Losses in the line (leak)	U _{un}	0.00
Converter efficiency	U _{unsk}	0.68
Uncertainty of calibration gas	U _{unv}	0.13
Uncertainty in factor	U _{unf}	2.18

Measurement uncertainty		
Combined uncertainty	k = 2	0.97 mg/m ³
Expanded uncertainty		1.95 mg/m ³
Uncertainty corrected to std conds		5.85 mg/m ³
Expanded uncertainty expressed with a level of confidence of 95%		5.85 mg·m ⁻³
Expanded uncertainty expressed with a level of confidence of 95%		11.19 % value
Expanded uncertainty expressed with a level of confidence of 95%		1.82 % ELV

Correction for reference conditions				
	ref	O2, %	Moisture, %	Pressure, kPa
	measured	12.04	3.00	101.30
	Uncert	0.37	0.00	101.30
Factors		2.01	1.00	0.00
Uncertainty in factor		0.08	0.01	1.00
Correction Factor		2.01	0.08	0.00

Effect of drift	0.21 mg/m3
-----------------	------------

	ranges	min	max	value at calib
flow		0.40	0.4	0.4 l/min
pressure		101.0	102	101.6 kPa
temp		280	283	280 K
CO range		100	300	0 mg/m3
HCl range		0	5	0 mg/m3
SO2 range		0	5	0 mg/m3
N2O range		0	2	0 mg/m3
Voltage		110	110	110 V

Use largest of sum of all positive or all negative influences		
Criteria	0.33 all +ves	0.00 all -ves
sum <4% range	0.33 largest	0.16 %
Value to use for interference uncertainty		
U _{int}	0.33	0.33

Uncertainty calculation for gaseous measurement of CO BS EN 15058:2017 - PG-250 AS0208
v4.3
Sep-18

Limit value	None	mg/m ³ (corrected)	Cal gas conc	190.13 mg/m ³
Measured concentration	284.22 mg/m ³ (101.3kPa, 273K)	Full Scale		250.00 mg/m ³
Measured concentration	571.22 mg/m ³ (Corrected)			
		Gas	CO	
		Full Scale	200 ppm	
		Cal gas conc	152.1 ppm	
		Conversion		1.25

Performance characteristics	Value	Specification
Response time	60 seconds	≤200
Logger sampling interval	60 seconds	
Measurement period	61 minutes	
Number of readings in measurement	61	
Standard deviation of repeatability	0.04 % full scale	≤±2% range
Standard deviation of repeatability at zero	0.1 % full scale	≤±2% range
Standard deviation of reproducibility	0 % full scale	≤±3 3% range
Deviation from linearity(lack of fit)	0.2 % full scale	≤±2 % range
Zero drift	2.01 mg/m ³	≤5% span value
Span drift	3.35 mg/m ³	≤5% span value
Influence of sample gas flow	2 % full scale/10l	≤±2% range
Influence of atmospheric pressure	2 % full scale/3kPa	≤±2% range
Influence of ambient temperature	0.05 % full scale/20K	≤±5% range
NO2 (mg/m ³)	30 mg/m ³	
N2O (mg/m ³)	20 mg/m ³	
CO2 (% vol)	15 % vol	≤±4% range (Total)
SO2 (mg/m ³)	200 mg/m ³	
Influence of voltage	-1.3 % full scale/10V	≤±2% range/10V
Influence from vibration	0 % full scale	≤±2% range
Losses in the line (leak)	0 % value	≤± 5% of value
Uncertainty of calibration gas	1 % value	≤± 2% of value

Performance characteristic	Uncertainty	Value of uncertainty quantity	mg/m3
Standard deviation of repeatability at zero	U ₀		0.00
Standard deviation of repeatability at span level	U _s		0.03
Standard deviation of reproducibility	U _{sp}		0.00
Lack of fit	U _{li}		0.23
Drift	U _{dr}		4.05
Influence of sample gas flow	U _{pres}		0.00
Influence of atmospheric pressure	U _{temp}		0.00
Influence of ambient temperature	U _{temp}		0.51
NO2 (mg/m ³)	U _{interf}		0.01
N2O (mg/m ³)	U _{interf}		0.04
CO2 (% vol)	U _{interf}		0.06
SO2 (mg/m ³)	U _{interf}		0.42
Influence of voltage	U _{interf}		-0.02
Influence from vibration	U _{vib}		0.00
Losses in the line (leak)	U _{leak}		0.00
Uncertainty of calibration gas	U _{cal}		1.42
Uncertainty in factor	uf		23.77

Measurement uncertainty			
Combined uncertainty		4.36	mg/m ³
Expanded uncertainty	k = 2	8.73	mg/m ³
Uncertainty corrected to std conds		50.67	mg/m ³
Expanded uncertainty expressed with a level of confidence of 95%		50.67 mg.m ³	
Expanded uncertainty expressed with a level of confidence of 95%		8.87 % value	

Correction for reference conditions				
	ref	O2, %	Moisture, %	Pressure, kPa
	measured	12.04	0.00	101.30
	Uncert	0.37	1.00	0.00
Factors		2.01	1.00	1.00
Uncertainty in factor		0.08	0.01	0.00
Correction Factor		2.01	uf	0.08

Effect of drift
7.02 mg/m ³

	ranges	min	max	value at calib
flow pressure		0.40	0.4	0.4 l/min
temp		101.0	102	101.6 kPa
NO2 range		280	283	280 K
N2O range		0	4	0 mg/m ³
CO2 range		0	2	0 mg/m ³
SO2 range		10	15	0 % vol
Voltage		0	5	0 mg/m ³
		110	110	110 V

Use largest of sum of all positive or all negative influences	
Criteria	0.52 all +ves
sum <4% range	0.02 all -ves
	0.52 largest
Value to use for interference uncertainty	
U _{int}	0.52

Uncertainty calculation for gaseous measurement of O₂ BS EN 14789:2017 - PG-250 AS0208

v3.1

Sep-18

Limit value	N/A	Cal gas conc	15.01 % vol
Measured concentration	12.04 % vol	Full Scale	25.00 % vol

Performance characteristics	Value		specification
Response time	65	seconds	≤200
Logger sampling interval	60	seconds	
Measurement period	61	minutes	
Number of readings in measurement	61		
Standard deviation of repeatability at zero	0.05	% vol	<0.2 % vol
Standard deviation of repeatability at span level	0.1	% vol	<0.2 % vol
Standard deviation of reproducibility	0.15	% vol	<0.2 % vol
Deviation from linearity(lack of fit)	0.26	% vol	<0.3 % vol
Zero drift	0.01	% vol	<0.2 % vol
Span drift	0.04	% vol	<0.2 % vol
Influence of sample gas flow	0.2	% vol/10l/h	<0.2 % vol
Influence of atmospheric pressure	0.2	% vol/3kPa	<0.2 % vol
Influence of ambient temperature	-0.07	% vol/20K	<0.5 % vol
Gross sensitivity	0.14	% vol	<0.4 % vol
Influence of voltage	0	% vol/10V	<0.2 % vol
Influence from vibration	0	% vol	<0.2 % vol
Losses in the line (leak)	0	% value	≤± 2% of value
Uncertainty of calibration gas	1	% value	≤± 2% of value

Effect of drift	0.04 % vol
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	ranges	max	value at calib
	min		
flow	0.40	0.4	0.4 l/min
pressure	101.0	102	101.6 kPa
temp	280	283	280 K
Voltage	110	110	110 V

Performance characteristic	Uncertainty	Value of uncertainty quantity	% vol
Standard deviation of repeatability at zero	U ₁₀		0.00
Standard deviation of repeatability at span level	U ₁₅		0.00
Standard deviation of reproducibility	U _{1p}		0.02
Lack of fit	U _{1ft}		0.15
Drift	U _{1dr}		0.02
Influence of sample gas flow	U _{1spres}		0.000
Influence of atmospheric pressure	U _{1apres}		0.02
Influence of ambient temperature	U _{1temp}		-0.01
Gross sensitivity	U _{1interf}		0.08
Influence of voltage	U _{1vol}		0.00
Influence from vibration	U _{1vb}		0.00
Losses in the line (leak)	U _{1leak}		0.00
Uncertainty of calibration gas	U _{1cal}		0.06

Measurement uncertainty			
Combined uncertainty		0.18	% vol
Expanded uncertainty	k = 2	0.37	% vol
Expanded uncertainty	expressed with a level of confidence of 95%	0.37 % vol	
Expanded uncertainty	expressed with a level of confidence of 95%	3.07 % value	

Uncertainty calculation for Velocity and Volume Flow Rate Measurement by Pitot tube EN ISO 16911-1

v1.3

Jan-16

Enter data in orange cells only

Constants		Gas constant	8.314 J/(K.mol)
Velocity meas. during calibration		3 m/s	
Air density meas. during calibration		1.23 kg/m ³	
DP meas. during calibration		7.9 Pa	
Uncertainty of velocity meas. at calibration		2.2 %	
Uncertainty of air density meas. at calibration		0.075 %	
Uncertainty of DP meas. at calibration		3.95 %	
Pitot coefficient, K		0.834	
Expanded uncertainty (95%, k=2) as % of value		9.0 %	
Expanded uncertainty (95%, k=2)		0.08	

Characteristics of pressure sensor used for Delta P		Enter uncertainties as (95%, k=2) where relevant
Repeatability of Delta P transducer		1 % of value
Range of Delta P transducer		2451 Pa
Resolution of Delta P transducer		1.96 Pa
Drift of Delta P transducer		0.1 % of range between calibrations
Lack of fit of measurement system		0.1 % of range
Uncertainty in Delta P transducer		10.0 Pa
Enter uncertainties as (95%, k=2) where relevant		
Uncertainty in temperature readout system		1 °C
Uncertainty in atmospheric pressure transducer		170 Pa
Uncertainty in duct area measurement		0.8 %

Uncertainty in stack gas composition		Enter uncertainties as (95%, k=2) where relevant
Water vapour measurement		20 % relative
CO content measurement		6 % relative
CO ₂ content measurement		10 % relative
O ₂ content measurement		6 % relative

Duct dimensions		Circular	Rectangular
Diameter			a m
Area			b m
			Area m ²

All Pressures should be entered in Pascals, Pa

Measurement Point																		
	Atmospheric Pressure, Pa	Stack Pressure, Pa	Static Pressure, Pa	meas1, Pa	meas2, Pa	meas3, Pa	meas4, Pa	meas5, Pa	Delta P, Pa	Stack Temperature, C	Water Vapour Content, %	CO ₂ , %	N ₂ , %	O ₂ , %	dry molecular wt, g/mol	stack molecular wt, g/mol		
1	101160	101281.1535	121.1535	30.38965751					30.38965751	11.5	11.5	1.33	220	5.1	82.9	12	29.30	29.15
2	101160	101281.1535	121.1535	33.33059211					33	11.4	11.4	1.33	220	5.1	82.9	12	29.30	29.15
3	101160	101281.1535	121.1535	33.33059211					33	11.4	11.4	1.33	220	5.1	82.9	12	29.30	29.15
4	101160	101281.1535	121.1535	35.29121517					35	11.3	11.3	1.33	220	5.1	82.9	12	29.30	29.15
5	101160	101281.1535	121.1535	31.36996904					31	11.2	11.2	1.33	220	5.1	82.9	12	29.30	29.15
6	101160	101281.1535	121.1535	35.29121517					35	11.2	11.2	1.33	220	5.1	82.9	12	29.30	29.15
7	101160	101281.1535	121.1535	21.56685372					22	11.4	11.4	1.33	220	5.1	82.9	12	29.30	29.15
8	101160	101281.1535	121.1535	22.54716525					23	11.3	11.3	1.33	220	5.1	82.9	12	29.30	29.15
9	101160	101281.1535	121.1535	26.46841138					26	11.3	11.3	1.33	220	5.1	82.9	12	29.30	29.15
10	101160	101281.1535	121.1535	30.38965751					30	11.3	11.3	1.33	220	5.1	82.9	12	29.30	29.15
11	101160	101281.1535	121.1535	34.31090364					34	11.4	11.4	1.33	220	5.1	82.9	12	29.30	29.15
12	101160	101281.1535	121.1535	34.31090364					34	11.4	11.4	1.33	220	5.1	82.9	12	29.30	29.15
Mean		101281	121.2	30.7	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	30.7	11.3	11.3	1.3	220.0	5.1	82.9	12.0	29.30	29.15

$$\rho = \frac{\text{molar mass} \cdot \text{absolute pressure}}{R \cdot \text{gas temperature}}$$

Mean density	1.249 kg/m3
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$$Velocity = K \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$

Mean velocity	5.83 m/sec
Standard uncertainty of velocity	0.28 m/sec
Expanded uncertainty in velocity	0.56 m/sec

Flow rate	Circular duct	Rectangular duct
	36120 m ³ /hour	0 m ³ /hour
Volume flow rate expanded uncertainty	3532 m ³ /hour	#DIV/0!
Volume flow rate expanded uncertainty	9.8 % of value	#DIV/0!

Developed for the STA by NPL, David Butterfield & Chris Dimopoulos

SCV 2E Uncertainty Calculations

Uncertainty calculation for gaseous measurement of NOx BS EN 14792:2017 - PG-250 AS0208
v3.7
Sep-19

Limit value	107 mg/m ³ (corrected)	Cal gas conc	160.75 mg.m ⁻³
Measured concentration	30.79 mg/m ³ (101.3kPa, 273K)	Full Scale	205.30 mg/m ³
Measured concentration	53.85 mg/m ³ (Corrected)		
NO/NO2 ratio	100.00	Gas	NO
		Full Scale	100 ppm
		Cal gas conc	78.3 ppm
		Conversion	2.05

Performance characteristics	Value	specification
Response time	70 seconds	≤200 seconds
Logger sampling interval	60 seconds	
Measurement period	61 minutes	
Number of readings in measurement	61	
Standard deviation of repeatability at zero	0.03	≤±2%, range
Standard deviation of repeatability at span level	0.15	≤±2%, range
Standard deviation of reproducibility	0	≤±3.3%, range
Deviation from linearity(lack of fit)	0.35	≤±2 % range
Zero drift	0	≤-5% span value
Span drift	0	≤-5% span value
Influence of sample gas flow	2	≤±2% range
Influence of atmospheric pressure	2	≤±2% range
Influence of ambient temperature	0.18	≤±2% range
CO (mg/m ³)	300	≤±5% range
HCl (mg/m ³)	50	
SO2 (mg/m ³)	1000	
N2O (mg/m ³)	20	
Influence of voltage	0	≤±4% range (Total)
Influence from vibration	0	
Losses in the line (leak)	0	≤±2% range/10V
Converter efficiency	95.5	≤±2% range
Uncertainty of calibration gas	1	≤±5% of value
		≤± 2% of value

Performance characteristic	Uncertainty	Value of uncertainty quantity	mg/m3
Standard deviation of repeatability at zero	U ₀		0.00
Standard deviation of repeatability at span level	U ₀		0.04
Standard deviation of reproducibility	U ₀		0.00
Lack of fit	U _{lin}		0.41
Drift	U _{der}		0.00
Influence of sample gas flow	U _{press}		0.00
Influence of atmospheric pressure	U _{press}		0.68
Influence of ambient temperature	U _{temp}		0.03
CO (mg/m ³)	U _{cert}		0.28
HCl (mg/m ³)	U _{cert}		0.00
SO2 (mg/m ³)	U _{cert}		0.00
N2O (mg/m ³)	U _{cert}		0.05
Influence of voltage	U _{cert}		0.00
Influence from vibration	U _{cert}		0.00
Losses in the line (leak)	U _{cert}		0.00
Converter efficiency	U _{conv}		0.80
Uncertainty of calibration gas	U _{cal}		0.15
Uncertainty in factor	U _f		1.96

Measurement uncertainty			
Combined uncertainty	k =	2	1.19 mg/m ³
Expanded uncertainty			2.37 mg/m ³
Uncertainty corrected to std conds			
Expressed with a level of confidence of 95%		5.71	5.71 mg.m ⁻³
Expanded uncertainty			10.60 % value
Expressed with a level of confidence of 95%			
Expanded uncertainty			
Expressed with a level of confidence of 95%			2.21 % ELV

Correction for reference conditions				
	ref	O2, %	Moisture, %	Pressure, KPa
	measured	3.00		101.30
	Uncert	10.71	0.00	101.30
		0.37	1.00	0.00
		1.75	1.00	1.00
Factors				
Uncertainty in factor			0.06	0.01
Correction Factor			1.75 uf	0.06

Effect of drift	0.00 mg/m3
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	ranges	min	max	value at calib
flow		0.40	0.4	0.4 l/min
pressure		101.0	102	101.1 kPa
temp		279	283	280 K
CO range		100	300	0 mg/m3
HCl range		0	0	0 mg/m3
SO2 range		0	5	0 mg/m3
N2O range		0	2	0 mg/m3
Voltage		110	110	110 V

Use largest of sum of all positive or all negative influences		
Criteria	0.33 all +ves	0.00 all -ves
sum	0.00	<4% range
0.16 %	0.33 largest	
Value to use for interference uncertainty		
U _{int}	0.33	

Uncertainty calculation for gaseous measurement of CO BS EN 15058:2017 - PG-250 AS0208
v4.3
Sep-18

Limit value	None	mg/m ³ (corrected)	Cal gas conc	190.13 mg/m ³
Measured concentration	176.23	mg/m ³ (101.3kPa, 273K)	Full Scale	250.00 mg/m ³
Measured concentration	308.22	mg/m ³ (Corrected)		
			Gas	CO
			Full Scale	200 ppm
			Cal gas conc	152.1 ppm
			Conversion	1.25

Performance characteristics	Value	Specification
Response time	60 seconds	≤200 seconds
Logger sampling interval	60 seconds	
Measurement period	61 minutes	
Number of readings in measurement	61	
Standard deviation of repeatability at zero	0.04 % full scale	≤±2% range
Standard deviation of repeatability at span level	0.1 % full scale	≤±2% range
Standard deviation of reproducibility	0 % full scale	≤±3.3% range
Deviation from linearity(lack of fit)	0.2 % full scale	≤±2 % range
Zero drift	0.8 mg/m ³	≤5% span value
Span drift	0 mg/m ³	≤5% span value
Influence of sample gas flow	2 % full scale/10l	≤±2% range
Influence of atmospheric pressure	2 % full scale/3kPa	≤±2% range
Influence of ambient temperature	0.05 % full scale/20K	≤±5% range
NO2 (mg/m ³)	30 mg/m ³	
N2O (mg/m ³)	20 mg/m ³	
CO2 (% vol)	15 % vol	≤±4% range (Total)
SO2 (mg/m ³)	200 mg/m ³	
Influence of voltage	-1.3 % full scale/10V	≤±2% range/10V
Influence from vibration	0 % full scale	≤±2% range
Losses in the line (leak)	0 % value	≤± 5% of value
Uncertainty of calibration gas	1 % value	≤± 2% of value

Performance characteristic	Uncertainty	Value of uncertainty quantity	mg/m ³
Standard deviation of repeatability at zero	U ₀		0.00
Standard deviation of repeatability at span level	U _s		0.03
Standard deviation of reproducibility	U _r		0.00
Lack of fit	U _{lf}		0.29
Drift	U _{dr}		0.46
Influence of sample gas flow	U _{gsf}		0.00
Influence of atmospheric pressure	U _{ap}		0.82
Influence of ambient temperature	U _{at}		0.01
NO2 (mg/m ³)	U _{no2}		0.04
N2O (mg/m ³)	U _{n2o}		0.06
CO2 (% vol)	U _{co2}		0.42
SO2 (mg/m ³)	U _{so2}		-0.02
Influence of voltage	U _v		0.00
Influence from vibration	U _{vib}		0.00
Losses in the line (leak)	U _{leak}		0.00
Uncertainty of calibration gas	U _{cal}		0.88
Uncertainty in factor	uf		11.22

Measurement uncertainty			
Combined uncertainty		1.42	mg/m ³
Expanded uncertainty	k = 2	2.84	mg/m ³
Uncertainty corrected to std conds		22.98	mg/m ³
Expanded uncertainty expressed with a level of confidence of 95%		22.98 mg/m ³	
Expanded uncertainty expressed with a level of confidence of 95%		7.46 % value	

Correction for reference conditions				
	O ₂ , %	Moisture, %	Pressure, kPa	Temperature, K
	ref	3.00	0.00	101.30
	measured	10.71	0.00	101.30
	Uncert	0.37	1.00	0.00
Factors		1.75	1.00	1.00
Uncertainty in factor		0.06	0.01	0.00
Correction Factor		1.75 uf		0.06

Effect of drift	0.80 mg/m ³
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	ranges	min	max	value at callib
flow		0.40	0.4	0.4 l/min
pressure		101.0	102	101.1 kPa
temp		279	283	280 K
NO2 range		0	4	0 mg/m ³
N2O range		0	2	0 mg/m ³
CO2 range		10	15	0 % vol
SO2 range		0	5	0 mg/m ³
Voltage		110	110	110 V

Use largest of sum of all positive or all negative influences		
Criteria	0.52 all +ves	
sum <4% range	0.02 all -ves	
	0.52 largest	
Value to use for interference uncertainty		
U _{int}	0.52	

Uncertainty calculation for gaseous measurement of O₂ BS EN 14789:2017 - PG-250 AS0208

v3.1
Sep-18

Limit value	N/A	Cal gas conc	15.01 % vol
Measured concentration	10.71 % vol	Full Scale	25.00 % vol

Performance characteristics	Value		specification
Response time	65	seconds	≤200
Logger sampling interval	60	seconds	
Measurement period	61	minutes	
Number of readings in measurement	0.05	% vol	<0.2 % vol
Standard deviation of repeatability at zero	0.1	% vol	<0.2 % vol
Standard deviation of repeatability at span level	0.15	% vol	<0.2 % vol
Standard deviation of reproducibility	0.26	% vol	<0.3 % vol
Deviation from linearity(lack of fit)	0.02	% vol	<0.2 % vol
Zero drift	0.07	% vol	<0.2 % vol
Span drift	0.2	% vol/100h	<0.2 % vol
Influence of sample gas flow	0.2	% vol/3kPa	<0.2 % vol
Influence of atmospheric pressure	-0.07	% vol/20K	<0.5 % vol
Influence of ambient temperature	0.14	% vol	<0.4 % vol
Cross sensitivity	0	% vol/10V	<0.2 % vol
Influence of voltage	0	% vol	<0.2 % vol
Influence from vibration	0	% value	≤± 2% of value
Losses in the line (leak)	0	% value	≤± 2% of value
Uncertainty of calibration gas	1	% value	

Effect of drift	0.07 % vol
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	ranges	min	max	value at calib
flow		0.40	0.4	0.4 l/min
pressure		101.0	102	101.1 kPa
temp		279	283	280 K
Voltage		110	110	110 V

Performance characteristic	Uncertainty	Value of uncertainty quantity	% vol
Standard deviation of repeatability at zero	U ₀		0.00
Standard deviation of repeatability at span level	U _{FS}		0.00
Standard deviation of reproducibility	U _{RP}		0.02
Lack of fit	U _{fit}		0.15
Drift	U _{dr}		0.04
Influence of sample gas flow	U _{spres}		0.000
Influence of atmospheric pressure	U _{apres}		0.03
Influence of ambient temperature	U _{temp}		-0.01
Cross sensitivity	U _{interf}		0.08
Influence of voltage	U _{volt}		0.00
Influence from vibration	U _{vb}		0.00
Losses in the line (leak)	U _{leak}		0.00
Uncertainty of calibration gas	U _{cal}		0.05

Measurement uncertainty			
Combined uncertainty		0.19	% vol
Expanded uncertainty	k = 2	0.37	% vol
Expanded uncertainty	expressed with a level of confidence of 95%	0.37 % vol	
Expanded uncertainty	expressed with a level of confidence of 95%	3.50 % value	

Uncertainty calculation for Velocity and Volume Flow Rate Measurement by Pitot tube EN ISO 16911-1

v1.3

Jan-16

Enter data in orange cells only

Constants		8.314 J/(K.mol)
Gas constant		
Velocity meas. during calibration	3 m/s	
Air density meas. during calibration	1.23 kg/m³	
DP meas. during calibration	7.9 Pa	
Uncertainty of velocity meas. at calibration	2.2 %	
Uncertainty of air density meas. at calibration	0.075 %	
Uncertainty of DP meas. at calibration	3.95 %	
Pitot coefficient, K	0.834	
Expanded uncertainty (95%, k=2) as % of value	9.0 %	
Expanded uncertainty (95%, k=2)	0.08	

Characteristics of pressure sensor used for Delta P		Enter uncertainties as (95%,k=2) where relevant
Repeatability of Delta P transducer	1 % of value	
Range of Delta P transducer	2451 Pa	
Resolution of Delta P transducer	1.96 Pa	
Drift of Delta P transducer	0.1 % of range between calibrations	
Lack of fit of measurement system	0.1 % of range	
Uncertainty in Delta P transducer	10.0 Pa	
Enter uncertainties as (95%,k=2) where relevant		
Uncertainty in temperature readout system	1 °C	
Uncertainty in atmospheric pressure transducer	170 Pa	
Uncertainty in duct area measurement	0.8 %	

Uncertainty in stack gas composition	
Enter uncertainties as (95%,k=2) where relevant	
Water vapour measurement	20 % relative
CO content measurement	6 % relative
CO ₂ content measurement	10 % relative
O ₂ content measurement	6 % relative

Duct dimensions	
Circular	
Diameter	1.48 m
Area	1.7 m²
Rectangular	
a	m
b	m
Area	0.0 m²

All Pressures should be entered in Pascals, Pa

Measurement Point	Atmospheric Pressure, Pa	Stack Pressure, Pa	Static Pressure, Pa	meas1, Pa	meas2, Pa	meas3, Pa	meas4, Pa	meas5, Pa	Delta P, Pa	Stack Temperature, C	Water Vapour Content, %	Dry gas basis				dry molecular wt, g/mol	stack molecular wt, g/mol
1	101020	101230.915	210.915	38.23214977					38.23214977	16.5		CO ₂ , %	N ₂ , %	O ₂ , %		29.38	29.17
2	101020	101230.915	210.915	24.50778831					25	16.5		1.79	100	6	83.6	10.4	29.38
3	101020	101230.915	210.915	49.01557663					49	16.7		1.79	100	6	83.6	10.4	29.38
4	101020	101230.915	210.915	50.97619969					51	17.5		1.79	100	6	83.6	10.4	29.38
5	101020	101230.915	210.915	42.1539959					42	17.8		1.79	100	6	83.6	10.4	29.38
6	101020	101230.915	210.915	39.2124613					39	18		1.79	100	6	83.6	10.4	29.38
7	101020	101230.915	210.915	33.35059211					33	13.8		1.79	100	6	83.6	10.4	29.38
8	101020	101230.915	210.915	39.2124613					39	13.9		1.79	100	6	83.6	10.4	29.38
9	101020	101230.915	210.915	42.1539959					42	14.1		1.79	100	6	83.6	10.4	29.38
10	101020	101230.915	210.915	50.97619969					51	14.8		1.79	100	6	83.6	10.4	29.38
11	101020	101230.915	210.915	50.97619969					51	15.4		1.79	100	6	83.6	10.4	29.38
12	101020	101230.915	210.915	55.87775735					56	16		1.79	100	6	83.6	10.4	29.38
Mean		101231	210.9	43.1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	43.1	15.9		1.8	100.0	6.0	83.6	10.4	29.38

$$\rho = \frac{\text{molar mass} \cdot \text{absolute pressure}}{R \cdot \text{gas temperature}}$$

Mean density	1.229 kg/m3
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$$Velocity = K \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$

Mean velocity	6.94 m/sec
Standard uncertainty of velocity	0.32 m/sec
Expanded uncertainty in velocity	0.64 m/sec

Flow rate	Circular duct	Rectangular duct
	42992 m³/hour	0 m³/hour
Volume flow rate expanded uncertainty	4054 m³/hour	#DIV/0!
Volume flow rate expanded uncertainty	9.4 % of value	#DIV/0!

Developed for the STA by NPL, David Butterfield & Chris Dimopoulos

SCV 2F Uncertainty Calculations

Uncertainty calculation for gaseous measurement of NOx BS EN 14792:2017 - PG-250 AS0208
v3.7
Sep-19

Limit value	107 mg/m ³ (corrected)	Cal gas conc	160.75 mg.m ⁻³
Measured concentration	36.37 mg/m ³ (101.3kPa, 273K)	Full Scale	205.30 mg/m ³
Measured concentration	55.55 mg/m ³ (Corrected)		
NO/NO2 ratio	100.00	Gas	NO
		Full Scale	100 ppm
		Cal gas conc	76.3 ppm
		Conversion	2.05

Performance characteristics	Value	specification
Response time	70	seconds
Logger sampling interval	60	seconds
Measurement period	61	minutes
Number of readings in measurement	61	
Standard deviation of repeatability at zero	0.03	% full scale
Standard deviation of repeatability at span level	0.15	% full scale
Standard deviation of reproducibility	0	% full scale
Deviation from linearity(lack of fit)	0.35	% full scale
Zero drift	0	mg/m3
Span drift	0	mg/m3
Influence of sample gas flow	2	% full scale/10l
Influence of atmospheric pressure	2	% full scale/3kPa
Influence of ambient temperature	0.18	% full scale/20K
CO (mg/m3)	0.4	mg/m3
HCl (mg/m3)	1.1	mg/m3
SO2 (mg/m3)	0.5	% vol
N2O (mg/m3)	0.8	mg/m3
Influence of voltage	0	% full scale/10V
Influence from vibration	0	% full scale
Losses in the line (leak)	0	% value
Converter efficiency	95.5	%
Uncertainty of calibration gas	1	% value

Performance characteristic	Uncertainty	Value of uncertainty quantity	mg/m3
Standard deviation of repeatability at zero	U ₀		0.00
Standard deviation of repeatability at span level	U _s		0.04
Standard deviation of reproducibility	U _{sp}		0.00
Lack of fit	U _{lin}		0.41
Drift	U _{dr}		0.00
Influence of sample gas flow	U _{spfl}		0.00
Influence of atmospheric pressure	U _{spres}		0.68
Influence of ambient temperature	U _{spamp}		0.03
CO (mg/m3)	U _{uncert}		0.28
HCl (mg/m3)	U _{uncert}		0.00
SO2 (mg/m3)	U _{uncert}		0.00
N2O (mg/m3)	U _{uncert}		0.05
Influence of voltage	U _{uncert}		0.00
Influence from vibration	U _{uncert}		0.00
Losses in the line (leak)	U _{uncert}		0.00
Converter efficiency	U _{uncert}		0.95
Uncertainty of calibration gas	U _{uncert}		0.18
Uncertainty in factor	U _f		1.78

Measurement uncertainty			
Combined uncertainty	k =	2	1.29 mg/m ³
Expanded uncertainty			2.58 mg/m ³
Uncertainty corrected to sid conds			5.31 mg/m ³
Expanded uncertainty expressed with a level of confidence of 95%			5.31 mg.m ⁻³
Expanded uncertainty expressed with a level of confidence of 95%			9.57 % value
Expanded uncertainty expressed with a level of confidence of 95%			2.41 % ELV

Correction for reference conditions				
	ref	measured	Uncert	
Factors				
Uncertainty in factor				
Correction factor				

Effect of drift	0.00 mg/m3
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	ranges	min	max	value at calib
flow		0.40	0.4	0.4 l/min
pressure		101.0	102	101.1 kPa
temp		279	283	280 K
CO range		100	300	0 mg/m3
HCl range		0	0	0 mg/m3
SO2 range		0	5	0 mg/m3
N2O range		0	2	0 mg/m3
Voltage		110	110	110 V

Use largest of sum of all positive or all negative influences		
Criteria	sum	<4% range
	0.33 all +ves	
	0.00 all -ves	
	0.33 largest	
Value to use for interference uncertainty		
U _{int}	0.33	

Uncertainty calculation for gaseous measurement of CO BS EN 15058:2017 - PG-250 AS0208
v4.3
Sep-18

Limit value	None	mg/m ³ (corrected)	Cal gas conc	190.13 mg/m ³
Measured concentration	45.10 mg/m ³ (101.3kPa, 273K)	Full Scale		250.00 mg/m ³
Measured concentration	68.87 mg/m ³ (Corrected)			
		Gas	CO	
		Full Scale	200 ppm	
		Cal gas conc	152.1 ppm	
		Conversion	1.25	

Correction for reference conditions				
	ref	O ₂ , %	Moisture, %	Pressure, kPa
	measured	9.21	0.00	101.30
	Uncert	0.37	1.00	0.00
Factors		1.53	1.00	1.00
Uncertainty in factor		0.05	0.01	0.00
Correction Factor		1.53	uf	0.05

Effect of drift	0.80 mg/m ³
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Performance characteristics	Value	Specification
Response time	seconds	≤200
Logger sampling interval	60 seconds	
Measurement period	61 minutes	
Number of readings in measurement	61	
Standard deviation of repeatability at zero	0.04 % full scale	≤±2% range
Standard deviation of repeatability at span level	0.1 % full scale	≤±2% range
Standard deviation of reproducibility	0 % full scale	≤±3 3% range
Deviation from linearity(lack of fit)	0.2 % full scale	≤±2 % range
Zero drift	0.8 mg/m ³	≤5% span value
Span drift	0 mg/m ³	≤5% span value
Influence of sample gas flow	2 % full scale/10l	≤±2% range
Influence of atmospheric pressure	2 % full scale/3kPa	≤±2% range
Influence of ambient temperature	0.05 % full scale/20K	≤±5% range
NO ₂ (mg/m ³)	30 mg/m ³	
N ₂ O (mg/m ³)	20 mg/m ³	
CO ₂ (% vol)	15 % vol	
SO ₂ (mg/m ³)	200 mg/m ³	
Influence of voltage	-1.3 % full scale/10V	≤±4% range (Total)
Influence from vibration	0 % full scale	≤±2% range/10V
Losses in the line (leak)	0 % value	≤±2% range
Uncertainty of calibration gas	1 % value	≤± 5% of value
		≤± 2% of value

	ranges	min	max	value at calib
flow	0.40	0.4		0.4 l/min
pressure	101.0	102		101.1 kPa
temp	279	283		280 K
NO ₂ range	0	4		0 mg/m ³
N ₂ O range	0	2		0 mg/m ³
CO ₂ range	10	15		0 % vol
SO ₂ range	0	5		0 mg/m ³
Voltage	110	110		110 V

Performance characteristic	Uncertainty	Value of uncertainty quantity	mg/m ³
Standard deviation of repeatability at zero	U ₀		0.00
Standard deviation of repeatability at span level	U _s		0.03
Standard deviation of reproducibility	U _{rp}		0.00
Lack of fit	U _{lit}		0.29
Drift	U _{dr}		0.46
Influence of sample gas flow	U _{spres}		0.00
Influence of atmospheric pressure	U _{spres}		0.82
Influence of ambient temperature	U _{temp}		0.01
NO ₂ (mg/m ³)	U _{interf}		0.04
N ₂ O (mg/m ³)	U _{interf}		0.06
CO ₂ (% vol)	U _{interf}		0.42
SO ₂ (mg/m ³)	U _{interf}		-0.02
Influence of voltage	U _{vol}		0.00
Influence from vibration	U _{vib}		0.00
Losses in the line (leak)	U _{leak}		0.00
Uncertainty of calibration gas	U _{cal}		0.23
Uncertainty in factor	uf		2.21

Use largest of sum of all positive or all negative influences		
Criteria	0.52 all +ves	
sum <4% range	0.02 all -ves	
	0.52 largest	
Value to use for interference uncertainty		
U _{int}	0.52	

Measurement uncertainty			
Combined uncertainty	1.14	mg/m ³	
Expanded uncertainty	2	mg/m ³	
Uncertainty corrected to std conds	5.62	mg/m ³	
Expanded uncertainty expressed with a level of confidence of 95%	5.62 mg.m ³		
Expanded uncertainty expressed with a level of confidence of 95%	8.16 % value		

Uncertainty calculation for gaseous measurement of O₂ BS EN 14789:2017 - PG-250 AS0208
v3.1
Sep-18

Limit value	N/A	Cal gas conc	15.01 % vol
Measured concentration	9.21 % vol	Full Scale	25.00 % vol

Performance characteristics	Value	Specification
Response time	65 seconds	≤200
Logger sampling interval	60 seconds	
Measurement period	61 minutes	
Number of readings in measurement	61	
Standard deviation of repeatability at zero	0.05 % vol	<0.2 % vol
Standard deviation of repeatability at span level	0.1 % vol	<0.2 % vol
Standard deviation of reproducibility	0.15 % vol	<0.2 % vol
Deviation from linearity(lack of fit)	0.26 % vol	<0.3 % vol
Zero drift	0.02 % vol	<0.2 % vol
Span drift	0.07 % vol	<0.2 % vol
Influence of sample gas flow	0.2 % vol/10l/h	<0.2 % vol
Influence of atmospheric pressure	0.2 % vol/3kPa	<0.2 % vol
Influence of ambient temperature	-0.07 % vol/20K	<0.5 % vol
Cross sensitivity	0.14 % vol	<0.4 % vol
Influence of voltage	0 % vol/10V	<0.2 % vol
Influence from vibration	0 % vol	<0.2 % vol
Losses in the line (leak)	0 % value	≤± 2% of value
Uncertainty of calibration gas	1 % value	≤± 2% of value

Effect of drift	0.06 % vol
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	ranges	max	value at calib
min	0.40	0.4	0.4 l/min
pressure	101.0	102	101.1 kPa
temp	279	283	280 K
Voltage	110	110	110 V

Performance characteristic	Uncertainty	Value of uncertainty quantity	% vol
Standard deviation of repeatability at zero	U ₁₀		0.00
Standard deviation of repeatability at span level	U ₁₅		0.00
Standard deviation of reproducibility	U _{1p}		0.02
Lack of fit	U _{fit}		0.15
Drift	U _{dr}		0.04
Influence of sample gas flow	U _{spres}		0.000
Influence of atmospheric pressure	U _{apres}		0.03
Influence of ambient temperature	U _{temp}		-0.01
Cross sensitivity	U _{interf}		0.08
Influence of voltage	U _{volt}		0.00
Influence from vibration	U _{vb}		0.00
Losses in the line (leak)	U _{leak}		0.00
Uncertainty of calibration gas	U _{cal}		0.05

Measurement uncertainty			
Combined uncertainty		0.18	% vol
Expanded uncertainty	k = 2	0.37	% vol
Expanded uncertainty	expressed with a level of confidence of 95%	0.37 % vol	
Expanded uncertainty	expressed with a level of confidence of 95%	4.00 % value	

Uncertainty calculation for Velocity and Volume Flow Rate Measurement by Pitot tube EN ISO 16911-1

v1.3

Jan-16

Enter data in orange cells only

Constants		8.314 J/(K.mol)
Velocity meas. during calibration	3 m/s	
Air density meas. during calibration	1.23 kg/m ³	
DP meas. during calibration	7.9 Pa	
Uncertainty of velocity meas. at calibration	2.2 %	
Uncertainty of air density meas. at calibration	0.075 %	
Uncertainty of DP meas. at calibration	3.95 %	
Pitot coefficient, K	0.834	
Expanded uncertainty (95%, k=2) as % of value	9.0 %	
Expanded uncertainty (95%, k=2)	0.08	

Characteristics of pressure sensor used for Delta P		Enter uncertainties as (95%,k=2) where relevant
Repeatability of Delta P transducer	1 % of value	
Range of Delta P transducer	2451 Pa	
Resolution of Delta P transducer	1.95 Pa	
Drift of Delta P transducer	0.1 % of range between calibrations	
Lack of fit of measurement system	0.1 % of range	
Uncertainty in Delta P transducer	10.0 Pa	
Enter uncertainties as (95%,k=2) where relevant		
Uncertainty in temperature readout system	1 °C	
Uncertainty in atmospheric pressure transducer	170 Pa	
Uncertainty in duct area measurement	0.8 %	

Uncertainty in stack gas composition		Enter uncertainties as (95%,k=2) where relevant
Water vapour measurement	20 % relative	
CO content measurement	6 % relative	
CO ₂ content measurement	10 % relative	
O ₂ content measurement	6 % relative	

Duct dimensions		Circular	Rectangular
Diameter		1.48 m	a m
Area		1.7 m ²	b m
			Area m ²

All Pressures should be entered in Pascals, Pa

Measurement Point																	
	Atmospheric Pressure, Pa	Stack Pressure, Pa	Static Pressure, Pa	meas1, Pa	meas2, Pa	meas3, Pa	meas4, Pa	meas5, Pa	Delta P, Pa	Stack Temperature, C	Water Vapour Content, %	CO ₂ , ppm	CO ₂ , %	N ₂ , %	O ₂ , %	drymolecular wt, g/mol	stack molecular wt, g/mol
1	101020	101245.3	225.3	43.13370743					43.13370743	13.2		1.5	30	6.5	84.0	9.5	29.42
2	101020	101245.3	225.3	53.9713429					54	13.4		1.5	30	6.5	84.0	9.5	29.25
3	101020	101245.3	225.3	50.97619669					51	13.3		1.5	30	6.5	84.0	9.5	29.25
4	101020	101245.3	225.3	43.13370743					43	13.1		1.5	30	6.5	84.0	9.5	29.25
5	101020	101245.3	225.3	47.05495356					47	12.9		1.5	30	6.5	84.0	9.5	29.25
6	101020	101245.3	225.3	46.07464203					46	12.9		1.5	30	6.5	84.0	9.5	29.25
7	101020	101245.3	225.3	37.25188824					37	13.3		1.5	30	6.5	84.0	9.5	29.25
8	101020	101245.3	225.3	37.25188824					37	13.2		1.5	30	6.5	84.0	9.5	29.25
9	101020	101245.3	225.3	40.19277283					40	13.1		1.5	30	6.5	84.0	9.5	29.25
10	101020	101245.3	225.3	49.95688816					50	13		1.5	30	6.5	84.0	9.5	29.25
11	101020	101245.3	225.3	62.7999808					63	13		1.5	30	6.5	84.0	9.5	29.25
12	101020	101245.3	225.3	57.83838042					58	13.5		1.5	30	6.5	84.0	9.5	29.25
Mean	101020	101245	225.3	47.5	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	47.5	13.2		1.5	30.0	6.5	84.0	9.5	29.42

$$\rho = \frac{\text{molar mass} \cdot \text{absolute pressure}}{R \cdot \text{gas temperature}}$$

Mean density	1.245 kg/m3
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$$Velocity = K \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$

Mean velocity	7.26 m/sec
Standard uncertainty of velocity	0.33 m/sec
Expanded uncertainty in velocity	0.67 m/sec

	Circular duct	Rectangular duct
Flow rate	44963 m ³ /hour	0 m3/hour
Volume flow rate expanded uncertainty	4208 m ³ /hour	#DIV/0!
Volume flow rate expanded uncertainty	9.4 % of value	#DIV/0!

Developed for the STA by NPL, David Butterfield & Chris Dimopoulos

2.2.7 - Calculations Used in Reporting Results

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

Nozzle Selection

For isokinetic sampling, the pressure difference of the orifice meter must equal the pressure difference of the Pitot tube pressure multiplied by the K-factor. Where:

$$K = \text{Constant} \times C_p^2 \times D_n^4 \times DH_{@} \times \left(\frac{M_d}{M_s} \right) \left(\frac{1 - B_{wm}}{1 - B_{ws}} \right)^2 \left(\frac{T_m + 273}{T_s + 273} \right) \left(\frac{P_s}{P_m} \right)$$

$$DH = K \times D_p$$

Where:-

Constant: is a constant dependent on the units used to measure the nozzle (8.038×10^{-5} for mm)

D_n the nozzle diameter mm

$DH_{@}$ a constant dependent on the sampler control box orifice and gas meter

B_{ws} the percent water vapour in the emission as a fraction i.e. 12% = 0.12

B_{wm} the percentage water vapour in the air around the meter box often assumed to be zero

C_p Pitot tube coefficient dependent on the Pitot tube type

T_m the meter temperature in °C

T_s the stack temperature in °C

P_s the stack pressure

P_m the meter pressure

M_d dry gas molecular weight

M_s apparent stack gas molecular weight

DH pressure drop across the orifice (mm water)

DP differential Pitot pressure (mm water)

From this the correct nozzle size can be determined.

$$D_n = \sqrt{\left(\frac{\text{Constant} \cdot Q_m \cdot P_m}{(T_m + 273) C_p} \right) \left(\frac{1 - B_{wm}}{1 - B_{ws}} \right) \sqrt{\frac{(T_s + 273) M_s}{(P_s \cdot (\Delta P)_{avg})}}}$$

Where the Constant = 0.6071 Metric

Q_m = Orifice flow rate normally 21.2 actual lmin^{-1}

$$= K_m \sqrt{\frac{(T_m + 273) \Delta H}{P_m M_m}}$$

Where K_m = Orifice meter coefficient

$$K_m = Q_m \sqrt{\frac{P_m M_m}{\Delta H (T_m + 273)}} = \text{Const} \sqrt{\frac{1}{\Delta H_{@}}}$$

Where Const = 183.7 metric

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

Moisture Determination Calculations

These calculations are based at 273K and 101.325kPa

To calculate moisture the following equation is used:

$$B_{ws} = \frac{0.001245 \times W_I \times 100}{(0.001245 \times W_I) + 0.359V_m \left(\frac{P_b + \frac{\Delta H_{avg}}{13.6}}{(T_m + 273)} \right)}$$

Particulate Concentration C_s in stack Gases

At 273K and 101.325kPa and dry gas

$$C_s = \frac{W_t}{V_m} \times \frac{T_m + 273}{273} \times \frac{760}{\left(P_b + \frac{\Delta H_{avg}}{13.6} \right)} \times 1000 \quad \text{mg/Nm}^3$$

Oxygen Concentration Correction C_{oxy} to Particulate concentration

$$C_{oxy} = C \times \frac{(20.9 - \%O_2 \text{ ref})}{(20.9 - \%O_2 \text{ Meas})} \quad \text{mg/Nm}^3$$

Dry Molecular Weight of gases

$$M_D = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%CO + \%N)$$

Stack Molecular Weight of gases

$$M_s = 0.18(B_{ws}) + \frac{M_d}{100}(100 - B_{ws})$$

Stack Gas Velocity

$$(V_s)_{avg} = 34.96 \times C_p \times \sqrt{(\Delta P)_{avg}} \sqrt{\frac{T_s + 273}{P_s M_s}} \quad \text{m/s}$$

Mass Emission Rate M_R

$$M_R = \frac{C_m \times (V_s)_{avg} \times A \times 3600}{10^6} \quad \text{kg/hr}$$

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

IsoKinicity

$$I = \frac{2.12 \times 10^8 \times V_m \times Y \times \left(P_b + \left(\frac{\Delta H_{avg}}{13.6} \right) \right) \left(\frac{273 + T_s}{273 + T_m} \right)}{\Theta P_s \pi D_n^2 (Vs)_{avg} (100 - B_{ws})} \%$$

W_I	= the weight change of the impingers during sampling in g
V_m	= volume of dry gas sample in litres at temperature of the meter box
B_{ws}	= the percent water vapour in the emission
Q	= length of time sampling in minutes
Y	= Gas Meter Calibration correction factor
V_s	= Velocity of stack gas m/s
C_M	= measured concentration of particulate matter (mg/m^3)
T_m	= average temperature at dry gas meter ($^{\circ}C$)
P_b	= atmospheric pressure (mmHg)
$\%O_{2ref}$	= % oxygen at standard temperature & pressure
$\%O_{2Meas}$	= % oxygen measured on site
C_P	= Pitot tube coefficient
DP	= mean differential Pitot pressure drop (mm H_2O)
DH	= mean orifice pressure drop (mm H_2O)
D_s	= diameter of stack (m)
D_n	= Nozzle diameter (mm)
T_s	= stack temperature ($^{\circ}C$)
M_d	= molecular weight of dry stack gas
B_w	= moisture fraction
P_s	= stack pressure (mmHg)
A	= duct c.s.a. (m^2)
M_s	= molecular weight of wet stack gas
M_d	= molecular weight of dry stack gas
W_t	= total weight of particulate matter (g)