



## Test Report



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### OXIDES OF NITROGEN (AS NO<sub>2</sub>) 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: **20th - 22nd July 2021**

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**

Address: **Hampton Road  
Teddington  
Middlesex  
TW11 0LW**

Date of Report: **9th August 2021**

Report Author: **Matthew Ellison**

Reference: XP3538LD/INTERTEK/SHLNG/JUL2021/SCV/PPC/Q3/V1

Report Approver:	Chris Dimopoulos	NPL Authorised Signatory
MCERTS Registration:	MM-07-812	Name: Mr R Robinson (for NPLML)
Level & TEs Held:	Level 2, TE1, TE2, TE3 & TE4	Signature:
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. Two 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 20th and 22nd July 2021. The report documents the results obtained.

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1.2.1 SCV A (Phase One) Monitoring Results

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

Field	Units	Oxides of Nitrogen (as NO <sub>2</sub> )	Carbon Monoxide	Oxygen	Moisture
Emission Limit Value	mg/m <sup>3</sup> , Reference Conditions	107	N/A	N/A	N/A
Periodic Monitoring Result	Reference Conditions	48.6	546	12.2	2.4
Uncertainty (95% Confidence Level)	Reference Conditions	10.3	87.6	0.7	N/A
	Units	mg/m <sup>3</sup>	mg/m <sup>3</sup>	%Vol/Vol	%Vol/Vol
Average Stack Flow	m <sup>3</sup> /s at Reference Conditions	3.8			
Reference Conditions		273K, 101.3 kPa, 3% Oxygen on a dry gas basis			
Date	dd/mm/yyyy	20/07/2021			
Sample Period	From hh:mm	12:00			
	To hh:mm	13:00			
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)	82			
Burner Demand	Burner Demand (%)	19			

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1.2.2 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 <sub>2</sub> )	Carbon Monoxide	Oxygen	Moisture
Emission Limit Value	mg/m <sup>3</sup> , Reference Conditions	107	N/A	N/A	N/A
Periodic Monitoring Result	Reference Conditions	47.1	540	12.9	2.2
Uncertainty (95% Confidence Level)	Reference Conditions	11.9	93.2	0.7	N/A
	Units	mg/m <sup>3</sup>	mg/m <sup>3</sup>	%Vol/Vol	%Vol/Vol
Average Stack Flow	m <sup>3</sup> /s at Reference Conditions	3.3			
Reference Conditions		273K, 101.3 kPa, 3% Oxygen on a dry gas basis			
Date	dd/mm/yyyy	20/07/2021			
Sample Period	From hh:mm	14:45			
	To hh:mm	15:45			
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)	85			
Process Status	Burner Demand (%)	23			

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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.

<b>Continuous or Batch Process?</b>	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.		
<b>What part of the batch process was sampled? (If applicable)</b>	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.		
<b>What fuel was used during monitoring? (If applicable)</b>	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.		
<b>What feedstock was used during monitoring? (If applicable)</b>	N/A		
<b>What was the load during monitoring?</b>	<b>Emission Point</b>	<b>Load (Ton/hr)</b>	<b>Burner Demand (%)</b>
	SCV 1A	82	19
	SCV 2F	85	23
<b>What abatement systems are present? Were they in operation?</b>	Each SCV uses water injection to abate NOx emissions. The system was in operation during the periodic monitoring of each SCV.		
<b>Periodic monitoring results and corresponding CEM values</b>	No CEMs are installed on the SCVs monitored during this visit.		

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**1.4 Monitoring Deviations**

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

**1.5 Conclusions**

NPL carried out the emissions monitoring at South Hook LNG over a period of week. Two 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. Environmental Agency - Manual Stack emission monitoring performance standard for Organisations.
3. Environmental Agency – M1 Technical Guidance Note – Sampling requirements for stack emission monitoring.
4. Environmental Agency – Monitoring stack emissions: techniques and standards for periodic monitoring - online guidance.
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



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### 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	Sep-2023	Sep-2023	Sep-2023	Dec-2023	Sep-2023
Ann-Marie Leman	Trainee	MM-19-1562	N/A	N/A	N/A	N/A	N/A	N/A

### 2.1.2 Emissions Testing Procedures

	Instrumental Methods			Manual Methods		
Determinand	NO <sub>x</sub>	CO	O <sub>2</sub>	H <sub>2</sub> 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 EN ISO 16911:2013
Instrument	Horiba PG-250	Horiba PG-250	Horiba PG-250	N/A	Pitot	Type K Thermocouple
Instrument Serial No.	AS0246	AS0246	AS0246	N/A	AS0638	AS0638
Principle	Chemiluminescence	NDIR	Zirconia	Saturation Chart	Differential Pressure	Temperature
Operational Range	0 - 250 ppm	0 - 200 ppm	0 - 25%	N/A	N/A	N/A
Certified Range	0 - 125 mg/m <sup>3</sup>	0 - 95 mg/m <sup>3</sup>	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	183642	154.9 ppm	1%
Nitrogen Oxide		183642	79.4 ppm	1%
Oxygen		250638SG	15.04%	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	154.9 ppm
Oxides of Nitrogen (as NO <sub>2</sub> )	0 - 100 ppm	79.4 ppm
Oxygen	0 - 25%	15.04%

A leak test was conducted before testing to confirm hydraulic integrity of the gaseous sampling system. This was conducted by sending nitrogen down the entire sample line and ensuring a zero reading was obtained.

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 INTK54JUL21/Equipment Checklist.

### 2.1.4 Data Capture Location Reference

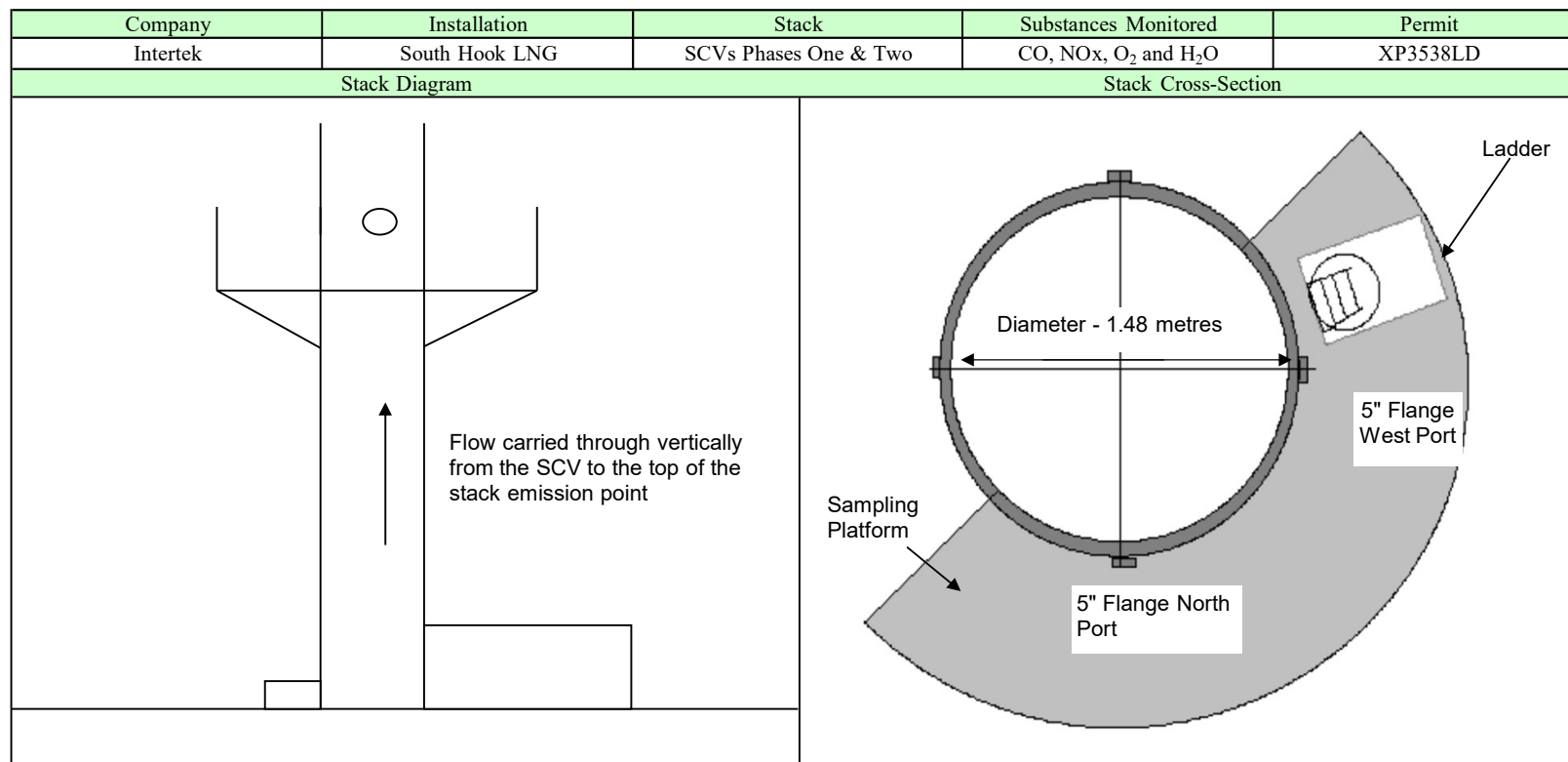
All data collected using the NPL computer system on site is backed up at the end of each day onto a memory stick. When the team returns to site this information is then uploaded onto the NPL servers and stored in the relevant location for that job. The link below is where the South Hook emissions data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

P:\Stack Emissions Team\South Hook LNG - Intertek\INTK54JUL21\7. Monitoring Record Sheets

## **APPENDIX TWO**

## **2.2.1 - Stack Diagram**

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Position	1	2	3	4	5	6
% of Diameter	4.1	14.9	29.7	70.3	85.1	95.9
Insertion, m	0.06	0.22	0.44	1.04	1.26	1.42
Insertion plus offset, m	0.16	0.32	0.54	1.14	1.36	1.52

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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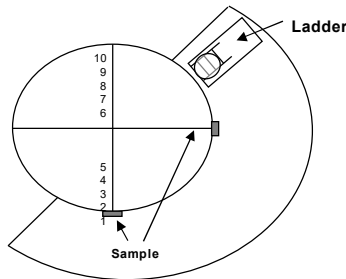
Monitoring Objective	Traverse	Site:	South Hook LNG Terminal		Stack ID:	SCV 1A		
Date	20/07/2021	Site Team:	MRE/AML		Time of Survey:	11:00		
Tape Measure ID	AS0589	Diagram of Sample Location:						
Barometer ID	AS0500							
Traverse Pitot Type	S-Type							
Traverse Pitot Tube ID	AS0681							
Pitot Assembly Visual Inspection (Pre)	Pass							
Pre Test Leak Check <2.5 mm H2O	Pass							
Traverse Manometer Type	Digital							
Traverse Manometer ID	AS0638							
Traverse Manometer Range	255							
Traverse Temp. Readout ID	AS0638							
Traverse Thermocouple ID	AS0451a							
Static Pressure	$\Delta p$ (mmH2O)	Comments/Deviations:						
	9.75							
	Pass							
Swirl Test Conducted	Yes	None						
Protractor ID	AS0626							
Post-Test Blockage Test (L-Type only)								
Post Test Leak Check <2.5 mm H2O	Pass							
Pitot Assembly Visual Inspection (Post)	Pass	Duct Dimensions						
Conditions	Value	Units	Port ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Port Depth
Stack pressure	753.29	mmHg	A					
Ref O <sub>2</sub> Value	3	%	B					
Moisture Content	2.38	%	C					
CO	220	ppm	D					
CO <sub>2</sub>	4.6	%	Circular Duct					
N <sub>2</sub>	83.38	%	Line ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Diameter
O <sub>2</sub>	12.00	%	A					
Dry Molecular wt	29.22		B					
Stack Molecular wt	28.95		Rectangular Duct					
Duct Diameter	1.48	m	Line ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Depth
Duct Depth		m	A					
Duct Width		m	B					
Area of stack	1.72	m <sup>2</sup>	C					
Pbar	1003.1	mbar	D					
Pbar	752.6	mmHg		Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Width
Pitot tube coeff	0.831		Outside Side Division					
Reference Temp	273	K					Static Measurement	$\Delta p$ (mmH2O)
Reference Pressure	760	mmHg					Measurement Line	Reading 1      Reading 2(180°)
Ambient Temperature		° C	Enter manually from previous visit		Circular Duct	Rectangular Duct	A	9.50      9.40
			Duct Diameter (m)		1.48		B	10.00      10.10
			Duct Depth (m)				C	
			Duct Width (m)				D	

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SAMPLING LINE: North										
Traverse Point	Distance into duct (m)	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Average mm H <sub>2</sub> O	$\Delta p$ Pa	Stack Temp T <sub>s</sub> °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	$\sqrt{\Delta p}$
1	1.42	1.70	1.70	1.70	1.70	16.67	20.3	4.39	7	1.30
2	1.26	2.10	2.10	2.10	2.10	20.59	20.4	4.88	7	1.45
3	1.04	2.30	2.30	2.30	2.30	22.55	20.6	5.11	6	1.52
4	0.44	1.70	1.70	1.70	1.70	16.67	20.7	4.40	6	1.30
5	0.22	1.90	1.90	1.90	1.90	18.63	20.7	4.65	7	1.38
6	0.06	2.30	2.30	2.30	2.30	22.55	20.6	5.11	8	1.52
SAMPLING LINE: West										
Traverse Point	Distance into duct (m)	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Average mm H <sub>2</sub> O	$\Delta p$ Pa	Stack Temp T <sub>s</sub> °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	$\sqrt{\Delta p}$
1	1.42	1.80	1.80	1.80	1.80	17.65	20.8	4.53	5	1.34
2	1.26	1.40	1.40	1.40	1.40	13.72	20.6	3.99	6	1.18
3	1.04	1.60	1.60	1.60	1.60	15.68	20.3	4.26	5	1.26
4	0.44	2.40	2.40	2.40	2.40	23.53	20.0	5.22	7	1.55
5	0.22	2.90	2.90	2.90	2.90	28.43	19.8	5.73	7	1.70
6	0.06	3.60	3.60	3.60	3.60	35.29	20.0	6.39	8	1.90
Average values		2.1	2.1	2.1	2.1	21.0	20.4	4.9	6.6	1.5
Duct / Stack Flow Characteristics:						Average	Units	Flow Criteria Measurements		
Stack Velocity at stack gas T & P and a wet gas basis						4.89	ms <sup>-1</sup>	Is the Flow Ratio 3:1 or less?		2.6
Stack flow @ STP, O <sub>2</sub> (ref) and on a dry gas basis						3.76	m <sup>3</sup> s <sup>-1</sup>			:1
Stack flow @ stack gas T & P and on a wet gas basis						8.41	m <sup>3</sup> s <sup>-1</sup>	Any local negative flow?		NO
Stack flow @ stack gas T & P and on a dry gas basis						8.21	m <sup>3</sup> s <sup>-1</sup>	Flow <15° of duct axis?		YES
Stack flow @ STP and on a wet gas basis						7.75	m <sup>3</sup> s <sup>-1</sup>	Minimum $\Delta p$ detected > 5 Pa		YES
Stack flow @ STP, O <sub>2</sub> (ref) and on a wet gas basis						3.86	m <sup>3</sup> s <sup>-1</sup>			



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Monitoring Objective	Traverse	Site:	South Hook LNG Terminal		Stack ID:	SCV2F		
Date	20/07/2021	Site Team:	MRE/AML		Time of Survey:	14:15		
Tape Measure ID	AS0589	Diagram of Sample Location:						
Barometer ID	AS0500							
Traverse Pitot Type	S-Type							
Traverse Pitot Tube ID	AS0466							
Pitot Assembly Visual Inspection (Pre)	Pass							
Pre Test Leak Check <2.5 mm H2O	Pass							
Traverse Manometer Type	Digital							
Traverse Manometer ID	AS0638							
Traverse Manometer Range	255							
Traverse Temp. Readout ID	AS0638							
Traverse Thermocouple ID	AS0451a							
Static Pressure	$\Delta p$ (mmH2O)	Comments/Deviations:						
	18.43							
	Pass							
Swirl Test Conducted	Yes	None						
Protractor ID	AS0626							
Post-Test Blockage Test (L-Type only)								
Post Test Leak Check <2.5 mm H2O	Pass							
Pitot Assembly Visual Inspection (Post)	Pass	Duct Dimensions						
Conditions	Value	Units	Port ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Port Depth
Stack pressure	753.93	mmHg	A					
Ref O <sub>2</sub> Value	3	%	B					
Moisture Content	2.18	%	C					
CO	178	ppm	D					
CO <sub>2</sub>	4.5	%	Circular Duct					
N <sub>2</sub>	82.68	%	Line ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Diameter
O <sub>2</sub>	12.80	%	A					
Dry Molecular wt	29.23		B					
Stack Molecular wt	28.99		Rectangular Duct					
Duct Diameter	1.48	m	Line ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Depth
Duct Depth		m	A					
Duct Width		m	B					
Area of stack	1.72	m <sup>2</sup>	C					
Pbar	1003.1	mbar	D					
Pbar	752.6	mmHg		Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Width
Pitot tube coeff	0.831		Outside Side Division					
Reference Temp	273	K					Static Measurement	$\Delta p$ (mmH2O)
Reference Pressure	760	mmHg					Measurement Line	Reading 1      Reading 2(180°)
Ambient Temperature		° C	Enter manually from previous visit		Circular Duct	Rectangular Duct	A	18.40      18.60
			Duct Diameter (m)		1.48		B	18.40      18.30
			Duct Depth (m)				C	
			Duct Width (m)				D	

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SAMPLING LINE: North										
Traverse Point	Distance into duct (m)	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Average mm H <sub>2</sub> O	$\Delta p$ Pa	Stack Temp T <sub>s</sub> °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	$\sqrt{\Delta p}$
1	1.42	1.80	1.80	1.80	1.80	17.65	19.3	4.51	8	1.34
2	1.26	1.70	1.70	1.70	1.70	16.67	19.0	4.38	8	1.30
3	1.04	2.00	2.00	2.00	2.00	19.61	18.7	4.75	8	1.41
4	0.44	1.70	1.70	1.70	1.70	16.67	18.6	4.38	6	1.30
5	0.22	2.00	2.00	2.00	2.00	19.61	18.6	4.75	7	1.41
6	0.06	2.00	2.00	2.00	2.00	19.61	19.0	4.75	8	1.41
SAMPLING LINE: West										
Traverse Point	Distance into duct (m)	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Spot Reading mm H <sub>2</sub> O	$\Delta p$ Average mm H <sub>2</sub> O	$\Delta p$ Pa	Stack Temp T <sub>s</sub> °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	$\sqrt{\Delta p}$
1	1.42	1.70	1.70	1.70	1.70	16.67	18.8	4.38	7	1.30
2	1.26	1.60	1.60	1.60	1.60	15.68	19.0	4.25	7	1.26
3	1.04	1.50	1.50	1.50	1.50	14.70	19.0	4.11	6	1.22
4	0.44	2.10	2.10	2.10	2.10	20.59	18.8	4.87	7	1.45
5	0.22	2.60	2.60	2.60	2.60	25.49	18.9	5.42	8	1.61
6	0.06	3.40	3.40	3.40	3.40	33.33	19.6	6.20	10	1.84
Average values		2.0	2.0	2.0	2.0	19.7	18.9	4.7	7.5	1.4
Duct / Stack Flow Characteristics:						Average	Units	Flow Criteria Measurements		
Stack Velocity at stack gas T & P and a wet gas basis						4.73	ms <sup>-1</sup>	Is the Flow Ratio 3:1 or less?		2.3
Stack flow @ STP, O <sub>2</sub> (ref) and on a dry gas basis						3.34	m <sup>3</sup> s <sup>-1</sup>			:1
Stack flow @ stack gas T & P and on a wet gas basis						8.13	m <sup>3</sup> s <sup>-1</sup>	Any local negative flow?		NO
Stack flow @ stack gas T & P and on a dry gas basis						7.95	m <sup>3</sup> s <sup>-1</sup>	Flow <15° of duct axis?		YES
Stack flow @ STP and on a wet gas basis						7.54	m <sup>3</sup> s <sup>-1</sup>	Minimum $\Delta p$ detected > 5 Pa		YES
Stack flow @ STP, O <sub>2</sub> (ref) and on a wet gas basis						3.41	m <sup>3</sup> s <sup>-1</sup>			

### **2.2.3 - One Minute Averaged Gaseous Emissions Data**

NATIONAL PHYSICAL LABORATORY  
Continuation Sheet

**One Minute Averaged Gaseous Emissions Results**

South Hook LNG - SCV 1A			
273K, 101.3 kPa, 3% Oxygen on a dry basis			
Species	Carbon Monoxide	Oxides of Nitrogen	Oxygen
Units	mg/m3	mg/m3	%
20/07/2021 12:00	474	46.2	11.9
20/07/2021 12:01	477	46.7	11.8
20/07/2021 12:02	486	46.6	11.8
20/07/2021 12:03	479	46.9	11.8
20/07/2021 12:04	499	46.5	11.9
20/07/2021 12:05	502	45.7	12.0
20/07/2021 12:06	466	47.9	12.2
20/07/2021 12:07	488	47.0	12.4
20/07/2021 12:08	496	45.6	12.4
20/07/2021 12:09	535	44.4	12.5
20/07/2021 12:10	517	44.9	12.5
20/07/2021 12:11	530	44.6	12.6
20/07/2021 12:12	536	44.5	12.7
20/07/2021 12:13	591	43.7	12.9
20/07/2021 12:14	581	44.4	12.9
20/07/2021 12:15	571	45.9	12.5
20/07/2021 12:16	552	48.0	12.2
20/07/2021 12:17	522	49.5	12.1
20/07/2021 12:18	507	50.8	11.9
20/07/2021 12:19	486	51.1	11.9
20/07/2021 12:20	486	51.2	11.9
20/07/2021 12:21	481	50.9	11.9
20/07/2021 12:22	500	50.4	11.9
20/07/2021 12:23	546	50.1	11.8
20/07/2021 12:24	573	50.1	11.9
20/07/2021 12:25	530	52.3	11.9
20/07/2021 12:26	573	49.9	12.1
20/07/2021 12:27	528	49.5	12.0
20/07/2021 12:28	549	49.2	12.2
20/07/2021 12:29	529	50.3	12.4
20/07/2021 12:30	575	47.4	12.6
20/07/2021 12:31	562	47.8	12.6
20/07/2021 12:32	569	47.7	12.6
20/07/2021 12:33	609	47.0	12.8
20/07/2021 12:34	601	47.6	12.7
20/07/2021 12:35	633	47.0	12.8
20/07/2021 12:36	614	48.2	12.6
20/07/2021 12:37	612	48.9	12.4
20/07/2021 12:38	576	50.6	12.2
20/07/2021 12:39	559	50.9	12.0
20/07/2021 12:40	536	52.0	11.8
20/07/2021 12:41	538	51.8	11.9
20/07/2021 12:42	541	51.4	11.8
20/07/2021 12:43	529	51.7	11.8
20/07/2021 12:44	543	51.3	11.8
20/07/2021 12:45	550	51.1	11.8
20/07/2021 12:46	537	51.1	11.9
20/07/2021 12:47	573	50.1	12.0
20/07/2021 12:48	576	49.3	12.1
20/07/2021 12:49	536	50.2	12.2
20/07/2021 12:50	522	50.7	12.3
20/07/2021 12:51	552	48.3	12.5
20/07/2021 12:52	556	48.5	12.5
20/07/2021 12:53	567	48.1	12.6
20/07/2021 12:54	568	48.2	12.7
20/07/2021 12:55	598	47.9	12.8
20/07/2021 12:56	615	47.9	12.8
20/07/2021 12:57	606	48.5	12.7
20/07/2021 12:58	605	49.3	12.5
20/07/2021 12:59	592	50.1	12.3
20/07/2021 13:00	556	51.4	12.1
Minimum	466	43.7	11.8
Maximum	633	52.3	12.9
Average	546	48.6	12.2

NATIONAL PHYSICAL LABORATORY  
Continuation Sheet

**One Minute Averaged Gaseous Emissions Results**

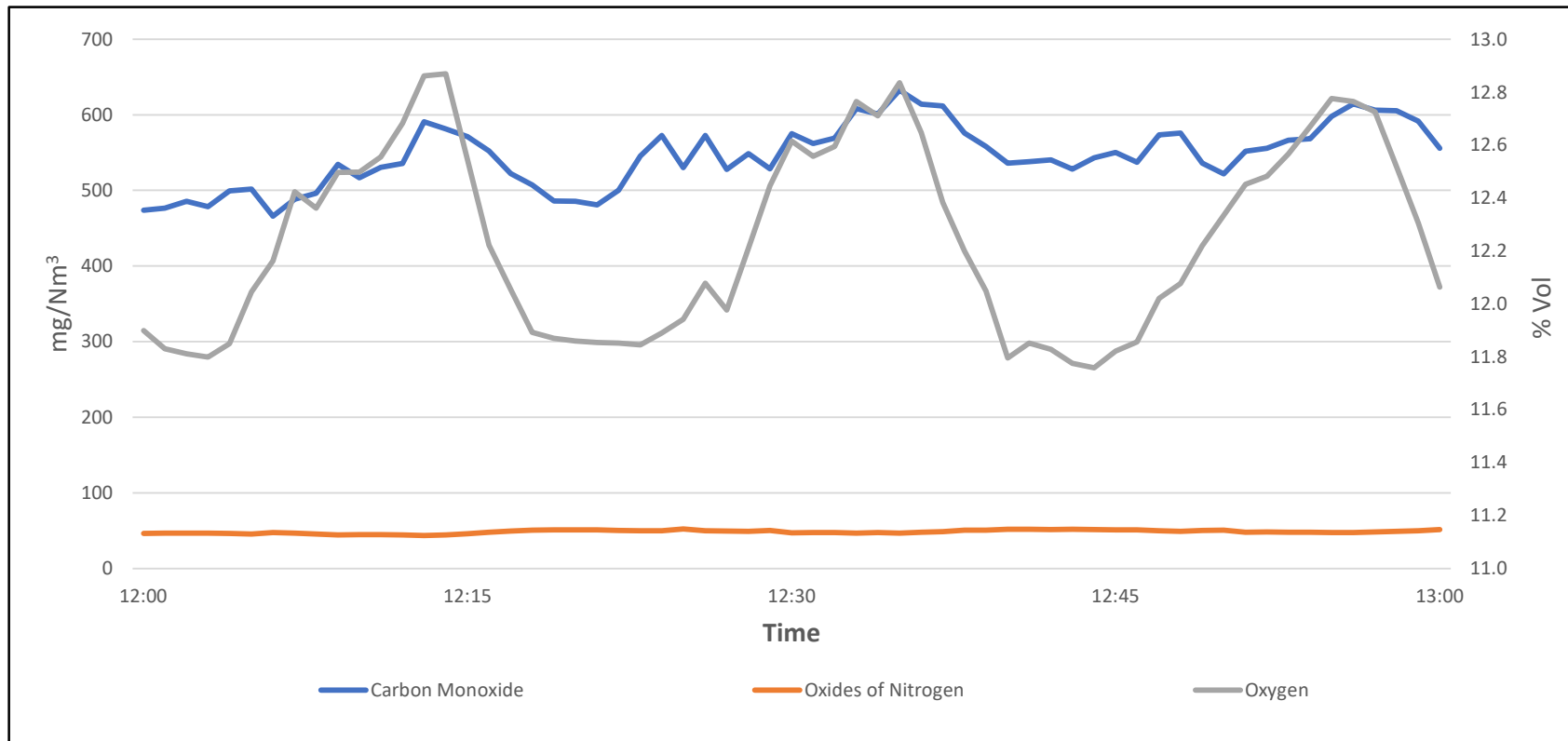
South Hook LNG - SCV 2F			
273K, 101.3 kPa, 3% Oxygen on a dry basis			
Species	Carbon Monoxide	Oxides of Nitrogen	Oxygen
Units	mg/m3	mg/m3	%
20/07/2021 14:45	554	46.2	13.0
20/07/2021 14:46	565	46.2	13.1
20/07/2021 14:47	603	45.2	13.3
20/07/2021 14:48	567	46.2	13.0
20/07/2021 14:49	568	46.3	13.1
20/07/2021 14:50	529	48.7	13.1
20/07/2021 14:51	579	46.7	13.1
20/07/2021 14:52	587	46.2	13.1
20/07/2021 14:53	597	45.7	13.1
20/07/2021 14:54	602	45.6	13.1
20/07/2021 14:55	607	45.3	13.1
20/07/2021 14:56	624	45.0	13.1
20/07/2021 14:57	544	46.5	12.7
20/07/2021 14:58	506	47.4	12.4
20/07/2021 14:59	508	47.3	12.5
20/07/2021 15:00	491	47.5	12.5
20/07/2021 15:01	487	47.2	12.5
20/07/2021 15:02	498	47.5	12.5
20/07/2021 15:03	515	47.3	12.5
20/07/2021 15:04	496	47.6	12.6
20/07/2021 15:05	495	47.6	12.5
20/07/2021 15:06	484	47.8	12.5
20/07/2021 15:07	463	49.4	12.6
20/07/2021 15:08	499	49.2	12.9
20/07/2021 15:09	544	46.7	12.9
20/07/2021 15:10	524	47.3	12.9
20/07/2021 15:11	529	47.3	12.8
20/07/2021 15:12	551	47.0	13.0
20/07/2021 15:13	539	47.3	12.9
20/07/2021 15:14	566	46.7	13.0
20/07/2021 15:15	555	46.8	13.0
20/07/2021 15:16	554	46.8	13.0
20/07/2021 15:17	581	46.5	13.1
20/07/2021 15:18	610	45.7	13.2
20/07/2021 15:19	593	46.3	13.2
20/07/2021 15:20	597	46.3	13.2
20/07/2021 15:21	592	46.1	13.2
20/07/2021 15:22	607	45.9	13.2
20/07/2021 15:23	597	46.0	13.1
20/07/2021 15:24	520	47.9	12.6
20/07/2021 15:25	449	51.2	12.5
20/07/2021 15:26	489	49.3	12.5
20/07/2021 15:27	516	48.1	12.6
20/07/2021 15:28	526	47.4	12.7
20/07/2021 15:29	540	47.3	12.7
20/07/2021 15:30	540	47.4	12.7
20/07/2021 15:31	553	46.8	12.8
20/07/2021 15:32	570	46.3	12.9
20/07/2021 15:33	525	46.8	12.7
20/07/2021 15:34	497	47.6	12.6
20/07/2021 15:35	481	48.0	12.6
20/07/2021 15:36	499	47.6	12.6
20/07/2021 15:37	484	48.3	12.6
20/07/2021 15:38	493	48.2	12.7
20/07/2021 15:39	503	47.7	12.7
20/07/2021 15:40	495	48.0	12.8
20/07/2021 15:41	512	48.0	12.9
20/07/2021 15:42	569	46.5	13.2
20/07/2021 15:43	512	50.0	13.3
20/07/2021 15:44	589	46.3	13.3
20/07/2021 15:45	588	45.8	13.3
Minimum	449	45.0	12.4
Maximum	624	51.2	13.3
Average	540	47.1	12.9

## **2.2.4 - Gaseous Emissions Graphical Data**

## South Hook LNG - SCV 1A

### Gaseous Emissions Graphical Data for Carbon Monoxide, Oxides of Nitrogen and Oxygen

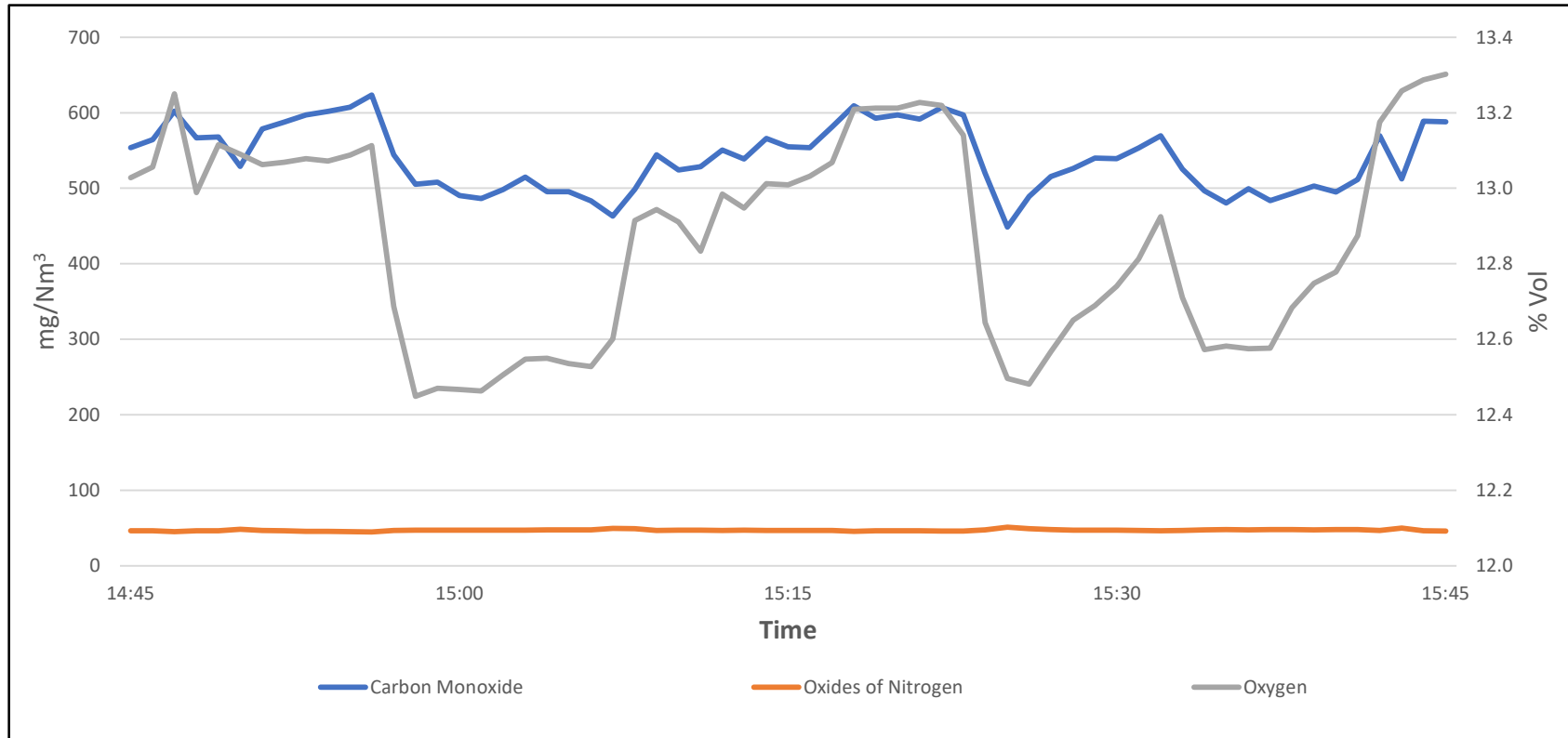
Reference Conditions - 273.15K, 101.3 kPa, 3% Oxygen on a dry gas basis



## South Hook LNG - SCV 2F

### Gaseous Emissions Graphical Data for Carbon Monoxide, Oxides of Nitrogen and Oxygen

Reference Conditions - 273.15K, 101.3 kPa, 3% Oxygen on a dry gas basis





## **2.2.5 - Gas Calibration Log**

NATIONAL PHYSICAL LABORATORY  
Continuation Sheet

GAS CALIBRATION RECORD									
Client:	Intertek Ltd	Job Reference:	INTK54JUL21	Calibration By:	M Ellison	Comments:			
Site:	South Hook LNG	Date:	20/07/2021	MCERTs ID:	MM-05-682				
Stack:	SCV 1A	Leak Check Method:	Flow Method	Test Team :	MRE/AML				
Species	Carbon Monoxide	Oxides of Nitrogen	Oxygen						
Analyser Type/ID	Horiba PG250 AS0246	Horiba PG250 AS0246	Horiba PG250 AS0246						
Gas Cylinder ID	183642	183642	250638SG						
Gas Cylinder Concentration	154.9 ppm	79.4 ppm	15.04 % Vol						
Concentration Uncertainty	1 %	1 %	1 %						
Span Value	154.9 ppm	79.4 ppm	15.04 % Vol						
Analyser Range 0 -	200 ppm	100 ppm	25 % Vol						
ANALYSER ADJUSTMENT									
Check Zero	Time	11:26	11:26	11:26					
	Reading	-1.2 ppm	0 ppm	-0.03 % Vol					
	Gain	0	2	6					
Adjust Zero	Time	11:27	11:27	11:27					
	Reading	1.2 ppm	0 ppm	-0.01 % Vol					
	Gain	0	3	5					
Check Span	Time	11:33	11:33	11:39					
	Reading	143.1 ppm	78.8 ppm	15.01 % Vol					
	Gain	1.868	0.999	1.091					
Adjust Span	Time	11:36	11:36	11:40					
	Reading	153.8 ppm	79.5 ppm	15.05 % Vol					
	Gain	1.999	1.003	1.093					
Check Zero	Time	11:42	11:42	11:42					
	Reading	1.8 ppm	0.2 ppm	0.05 % Vol					
Zero Drift	0.60 ppm	0.20 ppm	0.06 % Vol						
Acceptance	Accept <2% Range	Accept <2% Range	Accept <2% Range						
SAMPLING SYSTEM CHECK -									
FLOW METHOD									
Expected Flow	0.4 l/min	0.4 l/min	0.4 l/min						
Time	11:43	11:43	11:43						
Reading	0	0	0						
PASS/FAIL	PASS	PASS	PASS						
POST TEST DRIFT CHECK									
Span Value	154.9 ppm	79.4 ppm	15.04 % Vol						
Check Zero	Time	13:06	13:06	13:06					
	Reading	0.4 ppm	0.1 ppm	0.02 % Vol					
	Drift (%)	0.5	0.1	0.2					
	Acceptance	Accept	Accept	Accept					
Check Span	Time	13:11	13:11	13:16					
	Reading	155.9 ppm	80.4 ppm	15.07 % Vol					
	Drift (%)	1.4	1.1	0.1					
	Acceptance	Accept	Accept	Accept					

NATIONAL PHYSICAL LABORATORY  
Continuation Sheet

GAS CALIBRATION RECORD									
Client:	Intertek Ltd	Job Reference:	INTK54JUL21	Calibration By:	M Ellison	Comments:			
Site:	South Hook LNG	Date:	20/07/2021	MCERTs ID:	MM-05-682				
Stack:	SCV 2F	Leak Check Method:	Flow Method	Test Team :	MRE/AML				
Species	Carbon Monoxide	Oxides of Nitrogen	Oxygen						
Analyser Type/ID	Horiba PG250 AS0246	Horiba PG250 AS0246	Horiba PG250 AS0246						
Gas Cylinder ID	183642	183642	250638SG						
Gas Cylinder Concentration	154.9 ppm	79.4 ppm	15.04 % Vol						
Concentration Uncertainty	1 %	1 %	1 %						
Span Value	154.9 ppm	79.4 ppm	15.04 % Vol						
Analyser Range 0 -	200 ppm	100 ppm	25 % Vol						
ANALYSER ADJUSTMENT									
Check Zero	Time	13:48	13:48	13:48					
	Reading	-0.1 ppm	0 ppm	0.09 % Vol					
	Gain	0	3	5					
Adjust Zero	Time	13:48	13:48	13:48					
	Reading	0.5 ppm	0 ppm	-0.03 % Vol					
	Gain	0	3	6					
Check Span	Time	13:52	13:52	13:57					
	Reading	155.3 ppm	78.5 ppm	14.98 % Vol					
	Gain	1.999	1.003	1.093					
Adjust Span	Time	13:53	13:53	13:57					
	Reading	152.5 ppm	79.4 ppm	15.05 % Vol					
	Gain	1.999	1.014	1.097					
Check Zero	Time	14:01	14:01	14:01					
	Reading	0.2 ppm	0.1 ppm	0.02 % Vol					
Zero Drift	0.30 ppm	0.10 ppm	0.05 % Vol						
Acceptance	Accept <2% Range	Accept <2% Range	Accept <2% Range						
SAMPLING SYSTEM CHECK -									
FLOW METHOD									
Expected Flow	0.4 l/min	0.4 l/min	0.4 l/min						
Time	14:02	14:02	14:02						
Reading	0	0	0						
PASS/FAIL	PASS	PASS	PASS						
POST TEST DRIFT CHECK									
Span Value	154.9 ppm	79.4 ppm	15.04 % Vol						
Check Zero	Time	15:59	15:59	15:59					
	Reading	0.4 ppm	0.1 ppm	-0.02 % Vol					
	Drift (%)	0.1	0.1	0.1					
	Acceptance	Accept	Accept	Accept					
Check Span	Time	16:04	16:04	16:09					
	Reading	159.2 ppm	78.1 ppm	15.1 % Vol					
	Drift (%)	4.3	1.6	0.3					
	Acceptance	Drift Correct	Accept	Accept					

## **2.2.6 - Uncertainty Calculations**

## **SCV 1A Uncertainty Calculations**

# NATIONAL PHYSICAL LABORATORY

## Continuation Sheet

### Uncertainty calculation for gaseous measurement of O2 according to BS EN 14789:2017 - Horiba PG250 AS0246

v1.0

May-20

		Cal gas conc	15.04 % vol
Measured concentration	12.24 % vol	Full Scale	25.00 % vol

Performance characteristics	Value		specification		
Standard deviation of repeatability at zero	0.0	% range	≤0.2 % vol		
Standard deviation of repeatability at span level	0.2	% range	≤0.2 % vol		
Deviation from linearity(lack of fit)	0.5	% range	≤0.3 % vol		
Zero drift	0.2	% of span value	≤±5% span value		
Span drift	0.1	% of span value	≤±5% span value		
Influence of sample gas flow	0.2	% vol/10l/h	≤0.2 % vol	flow	ranges
Influence of atmospheric pressure	0.2	% vol/3kPa	≤0.2 % vol	pressure	min max value at calib
Influence of ambient temperature	-0.1	% vol/20K	≤0.5 % vol	temp	
Cross sensitivity	0.6	% vol	≤0.4 % vol	Voltage	
Influence of voltage	0.0	% vol/10V	≤0.2 % vol		
Influence from vibration	0.0	% vol	≤0.2 % vol		
Uncertainty of calibration gas	1.0	% value	≤± 2% of value		

Performance characteristic	Uncertainty	Value of uncertainty quantity	% vol
Standard deviation of repeatability at zero	$u_{r0}$		0.00
Standard deviation of repeatability at span level	$u_{rs}$		0.04
Lack of fit	$u_{fit}$		0.08
Zero drift	$u_{0dr}$		0.02
Span drift	$u_{sdr}$		0.01
Influence of sample gas flow	$u_{spres}$		0.001
Influence of atmospheric pressure	$u_{apres}$		0.010
Influence of ambient temperature	$u_{temp}$		-0.005
Cross sensitivity	$u_{interf}$		0.32
Influence of voltage	$u_{volt}$		0.000
Influence from vibration	$u_{vib}$		0.00
Uncertainty of calibration gas	$u_{cal}$		0.06

Measurement uncertainty			
Combined uncertainty		0.34	% vol
Expanded uncertainty	k = 2	0.68	% vol
Expanded uncertainty	expressed with a level of confidence of 95%	0.68	% vol
Expanded uncertainty	expressed with a level of confidence of 95%	5.56	% value

# NATIONAL PHYSICAL LABORATORY

## Continuation Sheet

Uncertainty calculation for gaseous measurement of CO according to BS EN 15058:2017 - Horiba PG250 AS0246

v1.0 May-20

Emission Limit Value	N/A	mg/m <sup>3</sup> (Corrected)	Cal gas conc.	193.69	mg.m <sup>3</sup>
Measured concentration	265.43	mg/m <sup>3</sup> (101.3kPa, 273K)	Range	250.09	mg/m <sup>3</sup>
Measured concentration	545.65	mg/m <sup>3</sup> (Corrected)			
			Gas	CO	
			Full Scale	200.0	ppm
			Cal gas conc	154.9	ppm
			Conversion	1.25	

Correction for reference conditions					
		O <sub>2</sub> , %	Moisture, %	Pressure, KPa	Temperature, K
	ref	3.00	0.0	101.3	273.0
	measured	12.24	0.0	101.3	273.0
	Uncert	0.68	0.0	0.0	0.0
Factors		2.06	1.00	1.00	1.00
Uncertainty in factor		0.16	0.00	0.00	0.00
Correction Factor (no O <sub>2</sub> factor)		1.00		0.00	
Correction Factor (incl. O <sub>2</sub> factor)		2.06	uf	0.16	

Performance characteristics	Value		specification
Standard deviation of repeatability at zero	0.1	% of range	≤±1% range
Standard deviation of repeatability at span level	0.1	% of range	≤±2% range
Standard deviation of reproducibility	0.0	% full scale	≤±3.3% range
Deviation from linearity(lack of fit)	1.7	% of range	≤±2 % range
Zero drift	0.5	% of span value	≤±5% span value
Span drift	1.4	% of span value	≤±5% span value
Influence of sample gas flow	2.0	% full scale/10l	≤±2% range
Influence of atmospheric pressure	2.0	% full scale /3kPa	≤±2% range
Influence of ambient temperature	0.1	% full scale/20K	≤±5% range
Cross sensitivity	2.9	% full scale	≤4% range
Influence of voltage	0.0	% full scale/10V	≤±2% range/10V
Influence from vibration	0.0	% full scale	≤±2% range
Uncertainty of calibration gas	1.0	% value	≤± 2% of value

	min	max	value at calib
Flow	0.3	0.5	0.4 l/min
pressure	101.4	101.9	101.6 kPa
Temp	301	305	302 K
Voltage	105	115	110 V

Performance characteristic	Uncertainty	Value of uncertainty quantity	mg/m3
Standard deviation of repeatability at zero	u <sub>d0</sub>		0.00
Standard deviation of repeatability at span level	u <sub>rs</sub>		0.30
Standard deviation of reproducibility	u <sub>rp</sub>		0.00
Lack of fit	u <sub>lt</sub>		2.40
Zero drift	u <sub>odr</sub>		0.58
Span drift	u <sub>sdr</sub>		1.52
Influence of sample gas flow	u <sub>spres</sub>		0.03
Influence of atmospheric pressure	u <sub>apres</sub>		0.25
Influence of ambient temperature	u <sub>temp</sub>		0.01
Cross sensitivity	u <sub>interf</sub>		4.19
Influence of voltage	u <sub>volt</sub>		0.00
Influence from vibration	u <sub>vib</sub>		0.00
Uncertainty of calibration gas	u <sub>cal</sub>		1.33
Uncertainty in std conditions correction factor (no O <sub>2</sub> factor)	u <sub>f</sub>		0.00
Uncertainty in std conditions correction factor (including O <sub>2</sub> factor)	u <sub>cf</sub>		42.43

Measurement uncertainty			
Combined uncertainty		5.28	mg/m <sup>3</sup>
Expanded uncertainty	k = 2	10.55	mg/m <sup>3</sup>
Uncertainty corrected to std conditions (no O <sub>2</sub> factor)		10.55	mg/m <sup>3</sup>
Uncertainty corrected to std conditions (including O <sub>2</sub> factor)		87.59	mg/m <sup>3</sup>
Expanded uncertainty	expressed with a level of confidence of 95%	87.59	mg.m <sup>-3</sup>
Expanded uncertainty	expressed with a level of confidence of 95%	16.05	% value
Expanded uncertainty	expressed with a level of confidence of 95%	N/A	% ELV

# NATIONAL PHYSICAL LABORATORY

## Continuation Sheet

Uncertainty calculation for gaseous measurement of NOx according to BS EN 14792:2017 - Horiba PG250 AS0246

v1.0 May-20

Emission Limit Value	107 mg/m <sup>3</sup> (Corrected)	Cal gas conc.	163.1 mg.m <sup>-3</sup>
Measured concentration	23.64 mg/m <sup>3</sup> (101.3kPa, 273K)	Range	205.4 mg/m <sup>3</sup>
Measured concentration	48.60 mg/m <sup>3</sup> (Corrected)		
NO/NO2 ratio	99	Gas	NOx
		Full Scale	100 ppm
		Cal gas conc	79.4 ppm
		Conversion	2.05

Correction for reference conditions				
		O2, %	Moisture, %	Pressure, KPa
	ref	3.00	0.0	101.3
	measured	12.24	0.0	101.3
	Uncert	0.68	0.0	0.0
Factors		2.06	1.00	1.00
Uncertainty in factor		0.18	0.00	0.00
Correction Factor (no O <sub>2</sub> factor)		1.00		0.00
Correction Factor (incl. O <sub>2</sub> factor)		2.06	uf	0.16

Performance characteristics	Value		specification
Standard deviation of repeatability at zero	0.0	% of range	≤±1% range
Standard deviation of repeatability at span level	0.1	% of range	≤±2% range
Standard deviation of reproducibility	0.0	% full scale	≤±3.3% range
Deviation from linearity(lack of fit)	0.6	% of range	≤±2 % range
Zero drift	0.1	% of span value	≤±5% span value
Span drift	1.1	% of span value	≤±5% span value
Influence of sample gas flow	2.0	% full scale/10l	≤±2% range
Influence of atmospheric pressure	2.0	% full scale /3kPa	≤±2% range
Influence of ambient temperature	0.2	% full scale/20K	≤±5% range
Cross sensitivity	0.7	% full scale	≤4% range
Influence of voltage	0.0	% full scale/10V	≤±2% range/10V
Influence from vibration	0.0	% full scale	≤±2% range
Converter efficiency	95.1	%	≥95%
Uncertainty of calibration gas	1.0	% value	≤± 2% of value

	ranges	max	value at calib
	min		
Flow	0.30	0.5	0.4 l/min
pressure	101.4	101.9	101.6 kPa
Temp	301	305	302 K
Voltage	105	115	110 V

Performance characteristic	Uncertainty	Value of uncertainty quantity	mg/m3
Standard deviation of repeatability at zero	u <sub>d0</sub>		0.00
Standard deviation of repeatability at span level	u <sub>rs</sub>		0.14
Standard deviation of reproducibility	u <sub>rp</sub>		0.00
Lack of fit	u <sub>lit</sub>		0.71
Zero drift	u <sub>odr</sub>		0.12
Span drift	u <sub>sdr</sub>		1.07
Influence of sample gas flow	u <sub>spres</sub>		0.02
Influence of atmospheric pressure	u <sub>apres</sub>		0.21
Influence of ambient temperature	u <sub>tamp</sub>		0.03
Cross sensitivity	u <sub>nterff</sub>		0.83
Influence of voltage	u <sub>volt</sub>		0.00
Influence from vibration	u <sub>vib</sub>		0.00
Converter efficiency	u <sub>conv</sub>		0.66
Uncertainty of calibration gas	u <sub>cal</sub>		0.12
Uncertainty in std conditions correction factor (no O <sub>2</sub> factor)	u <sub>y</sub>		0.00
Uncertainty in std conditions correction factor (including O <sub>2</sub> factor)	u <sub>uf</sub>		3.78

Measurement uncertainty			
Combined uncertainty		1.69	mg/m <sup>3</sup>
Expanded uncertainty	k = 2	3.38	mg/m <sup>3</sup>
Uncertainty corrected to std conditions (no O <sub>2</sub> factor)		3.38	mg/m <sup>3</sup>
Uncertainty corrected to std conditions (including O <sub>2</sub> factor)		10.27	mg/m <sup>3</sup>
Expanded uncertainty	expressed with a level of confidence of 95%	10.27	mg.m <sup>-3</sup>
Expanded uncertainty	expressed with a level of confidence of 95%	21.14	% value
Expanded uncertainty	expressed with a level of confidence of 95%	3.16	% ELV



# NATIONAL PHYSICAL LABORATORY

## Continuation Sheet

### 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		Characteristics of pressure sensor used for Delta P	
Gas constant	8.314 J/(K.mol)	Enter uncertainties as (95%,k=2) where relevant	
Velocity meas. during calibration	3.086 m/s	Repeatability of Delta P transducer	1 % of value
Air density meas. during calibration	1.213 kg/m <sup>3</sup>	Range of Delta P transducer	2451 Pa
DP meas. during calibration	8.05 Pa	Resolution of Delta P transducer	1.96 Pa
Uncertainty of velocity meas. at calibration	2.1 %	Drift of Delta P transducer	0.1 % of range between calibrations
Uncertainty of air density meas. at calibration	0.075 %	Lack of fit of measurement system	0.1 % of range
Uncertainty of DP meas. at calibration	3.88 %	Uncertainty in Delta P transducer	10.0 Pa
Pitot coefficient, K	0.831	Enter uncertainties as (95%,k=2) where relevant	
Expanded uncertainty (95%, k=2) as % of value	8.8 %	Uncertainty in temperature readout system	1 °C
Expanded uncertainty (95%, k=2)	0.07	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 <sub>2</sub> content measurement	10 % relative
		O <sub>2</sub> content measurement	6 % relative

Duct dimensions		Circular		Rectangular	
Diameter		1.48 m		a	m
Area		1.7 m <sup>2</sup>		b	m
				Area	0.0 m <sup>2</sup>

### All Pressures should be entered in Pascals, Pa

Measurement Point											Dry gas basis				dry molecular wt, g/mol	stack molecular wt, g/mol	
	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, ppm	CO <sub>2</sub> , %	N <sub>2</sub> , %	O <sub>2</sub> , %		
1	100310	100405.55	95.55	16.7	16.7	16.7	16.7	16.7	16.7	20.3	2.38	220	4.6	83.4	12	29.22	28.95
2	100310	100405.55	95.55	20.6	20.6	20.6	20.6	20.6	20.6	20.4	2.38	220	4.6	83.4	12	29.22	28.95
3	100310	100405.55	95.55	22.5	22.5	22.5	22.5	22.5	22.5	20.6	2.38	220	4.6	83.4	12	29.22	28.95
4	100310	100405.55	95.55	16.7	16.7	16.7	16.7	16.7	16.7	20.7	2.38	220	4.6	83.4	12	29.22	28.95
5	100310	100405.55	95.55	18.6	18.6	18.6	18.6	18.6	18.6	20.7	2.38	220	4.6	83.4	12	29.22	28.95
6	100310	100405.55	95.55	22.5	22.5	22.5	22.5	22.5	22.5	20.6	2.38	220	4.6	83.4	12	29.22	28.95
7	100310	100405.55	95.55	17.6	17.6	17.6	17.6	17.6	17.6	20.8	2.38	220	4.6	83.4	12	29.22	28.95
8	100310	100405.55	95.55	13.7	13.7	13.7	13.7	13.7	13.7	20.6	2.38	220	4.6	83.4	12	29.22	28.95
9	100310	100405.55	95.55	15.7	15.7	15.7	15.7	15.7	15.7	20.3	2.38	220	4.6	83.4	12	29.22	28.95
10	100310	100405.55	95.55	23.5	23.5	23.5	23.5	23.5	23.5	20.0	2.38	220	4.6	83.4	12	29.22	28.95
11	100310	100405.55	95.55	28.4	28.4	28.4	28.4	28.4	28.4	19.8	2.38	220	4.6	83.4	12	29.22	28.95
12	100310	100405.55	95.55	35.3	35.3	35.3	35.3	35.3	35.3	20.0	2.38	220	4.6	83.4	12	29.22	28.95
Mean	100310	100406	95.6	21.0	21.0	21.0	21.0	21.0	21.0	20.4	2.4	220.0	4.6	90.0	12.0	28.73	28.57

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

Mean density	1.176 kg/m <sup>3</sup>
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$$Velocity = K \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$

Mean velocity	4.92 m/sec	
Standard uncertainty of velocity	0.27 m/sec	5.4 % of value
Expanded uncertainty in velocity	0.53 m/sec	10.8 % of value

Flow rate	Circular duct	Rectangular duct
	30484 m <sup>3</sup> /hour	0 m <sup>3</sup> /hour
Volume flow rate expanded uncertainty	3337 m <sup>3</sup> /hour	#DIV/0! m <sup>3</sup> /hour
Volume flow rate expanded uncertainty	10.9 % of value	#DIV/0! % of value

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

## **SCV 2F Uncertainty Calculations**

# NATIONAL PHYSICAL LABORATORY

## Continuation Sheet

### Uncertainty calculation for gaseous measurement of O2 according to BS EN 14789:2017 - Horiba PG250 AS0246

v1.0

May-20

		Cal gas conc	15.04 % vol
Measured concentration	12.86 % vol	Full Scale	25.00 % vol

Performance characteristics	Value		specification			
Standard deviation of repeatability at zero	0.0	% range	≤0.2 % vol			
Standard deviation of repeatability at span level	0.2	% range	≤0.2 % vol			
Deviation from linearity(lack of fit)	0.5	% range	≤0.3 % vol			
Zero drift	0.1	% of span value	≤±5% span value			
Span drift	0.3	% of span value	≤±5% span value			
Influence of sample gas flow	0.2	% vol/10l/h	≤0.2 % vol	flow	min	max
Influence of atmospheric pressure	0.2	% vol/3kPa	≤0.2 % vol	pressure	0.40	0.4
Influence of ambient temperature	-0.1	% vol/20K	≤0.5 % vol	temp	101.4	101.9
Cross sensitivity	0.6	% vol	≤0.4 % vol	Voltage	301	305
Influence of voltage	0.0	% vol/10V	≤0.2 % vol		110	110
Influence from vibration	0.0	% vol	≤0.2 % vol			
Uncertainty of calibration gas	1.0	% value	≤± 2% of value			

Performance characteristic	Uncertainty	Value of uncertainty quantity	% vol
Standard deviation of repeatability at zero	$u_{r0}$		0.00
Standard deviation of repeatability at span level	$u_{rs}$		0.04
Lack of fit	$u_{fit}$		0.08
Zero drift	$u_{0dr}$		0.01
Span drift	$u_{sdr}$		0.03
Influence of sample gas flow	$u_{spres}$		0.000
Influence of atmospheric pressure	$u_{apres}$		0.010
Influence of ambient temperature	$u_{temp}$		-0.005
Cross sensitivity	$u_{interf}$		0.32
Influence of voltage	$u_{volt}$		0.000
Influence from vibration	$u_{vib}$		0.00
Uncertainty of calibration gas	$u_{cal}$		0.06

Measurement uncertainty			
Combined uncertainty		0.34	% vol
Expanded uncertainty	k = 2	0.68	% vol
Expanded uncertainty	expressed with a level of confidence of 95%	0.68	% vol
Expanded uncertainty	expressed with a level of confidence of 95%	5.31	% value

# NATIONAL PHYSICAL LABORATORY

## Continuation Sheet

Uncertainty calculation for gaseous measurement of CO according to BS EN 15058:2017 - Horiba PG250 AS0246

v1.0 May-20

Emission Limit Value	N/A	mg/m <sup>3</sup> (Corrected)	Cal gas conc.	193.69	mg.m <sup>3</sup>
Measured concentration	243.99	mg/m <sup>3</sup> (101.3kPa, 273K)	Range	250.09	mg/m <sup>3</sup>
Measured concentration	539.46	mg/m <sup>3</sup> (Corrected)			
			Gas	CO	
			Full Scale	200.0	ppm
			Cal gas conc	154.9	ppm
			Conversion	1.25	

Correction for reference conditions					
		O <sub>2</sub> , %	Moisture, %	Pressure, KPa	Temperature, K
	ref	3.00	0.0	101.3	273.0
	measured	12.86	0.0	101.3	273.0
	Uncert	0.68	0.0	0.0	0.0
Factors		2.21	1.00	1.00	1.00
Uncertainty in factor		0.19	0.00	0.00	0.00
Correction Factor (no O <sub>2</sub> factor)		1.00		0.00	
Correction Factor (incl. O <sub>2</sub> factor)		2.21	uf	0.19	

Performance characteristics	Value		specification
Standard deviation of repeatability at zero	0.1	% of range	≤±1% range
Standard deviation of repeatability at span level	0.1	% of range	≤±2% range
Standard deviation of reproducibility	0.0	% full scale	≤±3.3% range
Deviation from linearity(lack of fit)	1.7	% of range	≤±2 % range
Zero drift	0.0	% of span value	≤±5% span value
Span drift	0.0	% of span value	≤±5% span value
Influence of sample gas flow	2.0	% full scale/10l	≤±2% range
Influence of atmospheric pressure	2.0	% full scale /3kPa	≤±2% range
Influence of ambient temperature	0.1	% full scale/20K	≤±5% range
Cross sensitivity	2.9	% full scale	≤4% range
Influence of voltage	0.0	% full scale/10V	≤±2% range/10V
Influence from vibration	0.0	% full scale	≤±2% range
Uncertainty of calibration gas	1.0	% value	≤± 2% of value

	min	max	value at calib
Flow	0.3	0.5	0.4 l/min
pressure	101.4	101.9	101.6 kPa
Temp	301	305	302 K
Voltage	105	115	110 V

Performance characteristic	Uncertainty	Value of uncertainty quantity	mg/m3
Standard deviation of repeatability at zero	u <sub>0</sub>		0.00
Standard deviation of repeatability at span level	u <sub>rs</sub>		0.30
Standard deviation of reproducibility	u <sub>rp</sub>		0.00
Lack of fit	u <sub>lt</sub>		2.40
Zero drift	u <sub>odr</sub>		0.00
Span drift	u <sub>sdr</sub>		0.00
Influence of sample gas flow	u <sub>spres</sub>		0.03
Influence of atmospheric pressure	u <sub>apres</sub>		0.25
Influence of ambient temperature	u <sub>temp</sub>		0.01
Cross sensitivity	u <sub>interf</sub>		4.19
Influence of voltage	u <sub>volt</sub>		0.00
Influence from vibration	u <sub>vib</sub>		0.00
Uncertainty of calibration gas	u <sub>cal</sub>		1.22
Uncertainty in std conditions correction factor (no O <sub>2</sub> factor)	u <sub>f</sub>		0.00
Uncertainty in std conditions correction factor (including O <sub>2</sub> factor)	u <sub>cf</sub>		45.27

Measurement uncertainty			
Combined uncertainty		4.99	mg/m <sup>3</sup>
Expanded uncertainty	k = 2	9.98	mg/m <sup>3</sup>
Uncertainty corrected to std conditions (no O <sub>2</sub> factor)		9.98	mg/m <sup>3</sup>
Uncertainty corrected to std conditions (including O <sub>2</sub> factor)		93.20	mg/m <sup>3</sup>
Expanded uncertainty	expressed with a level of confidence of 95%	93.20	mg.m <sup>3</sup>
Expanded uncertainty	expressed with a level of confidence of 95%	17.28	% value
Expanded uncertainty	expressed with a level of confidence of 95%	N/A	% ELV

# NATIONAL PHYSICAL LABORATORY

## Continuation Sheet

Uncertainty calculation for gaseous measurement of NO<sub>x</sub> according to BS EN 14792:2017 - Horiba PG250 AS0246

v1.0 May-20

Emission Limit Value	107 mg/m <sup>3</sup> (Corrected)	Cal gas conc.	163.1 mg.m <sup>-3</sup>
Measured concentration	21.33 mg/m <sup>3</sup> (101.3kPa, 273K)	Range	205.4 mg/m <sup>3</sup>
Measured concentration	47.15 mg/m <sup>3</sup> (Corrected)		
NO/NO <sub>2</sub> ratio	99	Gas	NO <sub>x</sub>
		Full Scale	100 ppm
		Cal gas conc	79.4 ppm
		Conversion	2.05

Correction for reference conditions				
		O <sub>2</sub> , %	Moisture, %	Pressure, KPa
	ref	3.00	0.0	101.3
	measured	12.86	0.0	101.3
	Uncert	0.68	0.0	0.0
Factors		2.21	1.00	1.00
Uncertainty in factor		0.19	0.00	0.00
Correction Factor (no O <sub>2</sub> factor)		1.00		0.00
Correction Factor (incl. O <sub>2</sub> factor)		2.21	uf	0.19

Performance characteristics	Value		specification
Standard deviation of repeatability at zero	0.0	% of range	≤±1% range
Standard deviation of repeatability at span level	0.1	% of range	≤±2% range
Standard deviation of reproducibility	0.0	% full scale	≤±3.3% range
Deviation from linearity(lack of fit)	0.6	% of range	≤±2 % range
Zero drift	0.1	% of span value	≤±5% span value
Span drift	1.6	% of span value	≤±5% span value
Influence of sample gas flow	2.0	% full scale/10l	≤±2% range
Influence of atmospheric pressure	2.0	% full scale /3kPa	≤±2% range
Influence of ambient temperature	0.2	% full scale/20K	≤±5% range
Cross sensitivity	0.7	% full scale	≤4% range
Influence of voltage	0.0	% full scale/10V	≤±2% range/10V
Influence from vibration	0.0	% full scale	≤±2% range
Converter efficiency	95.1	%	≥95%
Uncertainty of calibration gas	1.0	% value	≤± 2% of value

	ranges		
	min	max	value at calib
Flow	0.40	0.4	0.4 l/min
pressure	101.4	101.9	101.6 kPa
Temp	301	305	302 K
Voltage	110	110	110 V

Performance characteristic	Uncertainty	Value of uncertainty quantity	mg/m3
Standard deviation of repeatability at zero	u <sub>d0</sub>		0.00
Standard deviation of repeatability at span level	u <sub>rs</sub>		0.14
Standard deviation of reproducibility	u <sub>rp</sub>		0.00
Lack of fit	u <sub>lit</sub>		0.71
Zero drift	u <sub>odr</sub>		0.12
Span drift	u <sub>sdr</sub>		1.54
Influence of sample gas flow	u <sub>spres</sub>		0.00
Influence of atmospheric pressure	u <sub>apres</sub>		0.21
Influence of ambient temperature	u <sub>tamp</sub>		0.03
Cross sensitivity	u <sub>nterff</sub>		0.83
Influence of voltage	u <sub>volt</sub>		0.00
Influence from vibration	u <sub>vib</sub>		0.00
Converter efficiency	u <sub>conv</sub>		0.60
Uncertainty of calibration gas	u <sub>cal</sub>		0.11
Uncertainty in std conditions correction factor (no O <sub>2</sub> factor)	u <sub>y</sub>		0.00
Uncertainty in std conditions correction factor (including O <sub>2</sub> factor)	u <sub>uf</sub>		3.96

Measurement uncertainty			
Combined uncertainty		2.00	mg/m <sup>3</sup>
Expanded uncertainty	k = 2	4.01	mg/m <sup>3</sup>
Uncertainty corrected to std conditions (no O <sub>2</sub> factor)		4.01	mg/m <sup>3</sup>
Uncertainty corrected to std conditions (including O <sub>2</sub> factor)		11.88	mg/m <sup>3</sup>
Expanded uncertainty	expressed with a level of confidence of 95%	11.88	mg.m <sup>-3</sup>
Expanded uncertainty	expressed with a level of confidence of 95%	25.20	% value
Expanded uncertainty	expressed with a level of confidence of 95%	3.75	% ELV

# NATIONAL PHYSICAL LABORATORY

## Continuation Sheet

### 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		Characteristics of pressure sensor used for Delta P	
Gas constant	8.314 J/(K.mol)	Enter uncertainties as (95%,k=2) where relevant	
Velocity meas. during calibration	3.072 m/s	Repeatability of Delta P transducer	1 % of value
Air density meas. during calibration	1.205 kg/m <sup>3</sup>	Range of Delta P transducer	2451 Pa
DP meas. during calibration	8.23 Pa	Resolution of Delta P transducer	1.96 Pa
Uncertainty of velocity meas. at calibration	2.1 %	Drift of Delta P transducer	0.1 % of range between calibrations
Uncertainty of air density meas. at calibration	0.075 %	Lack of fit of measurement system	0.1 % of range
Uncertainty of DP meas. at calibration	3.80 %	Uncertainty in Delta P transducer	10.0 Pa
Pitot coefficient, K	0.831	Enter uncertainties as (95%,k=2) where relevant	
Expanded uncertainty (95%, k=2) as % of value	8.7 %	Uncertainty in temperature readout system	1 °C
Expanded uncertainty (95%, k=2)	0.07	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 <sub>2</sub> content measurement	10 % relative
		O <sub>2</sub> content measurement	6 % relative

Duct dimensions		Circular		Rectangular	
Diameter		1.48 m		a	m
Area		1.7 m <sup>2</sup>		b	m
				Area	0.0 m <sup>2</sup>

### 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 <sub>2</sub> ppm	CO <sub>2</sub> , %	N <sub>2</sub> , %	O <sub>2</sub> , %	dry molecular wt, g/mol	stack molecular wt, g/mol
1	100310	100490.614	180.614	17.6	17.6	17.6	17.6	17.6	17.6	19.3	2.18	178	4.5	82.7	12.8	29.23	28.99
2	100310	100490.614	180.614	16.7	16.7	16.7	16.7	16.7	16.7	19.0	2.18	178	4.5	82.7	12.8	29.23	28.99
3	100310	100490.614	180.614	19.6	19.6	19.6	19.6	19.6	19.6	18.7	2.18	178	4.5	82.7	12.8	29.23	28.99
4	100310	100490.614	180.614	16.7	16.7	16.7	16.7	16.7	16.7	18.6	2.18	178	4.5	82.7	12.8	29.23	28.99
5	100310	100490.614	180.614	19.6	19.6	19.6	19.6	19.6	19.6	18.6	2.18	178	4.5	82.7	12.8	29.23	28.99
6	100310	100490.614	180.614	19.6	19.6	19.6	19.6	19.6	19.6	19.0	2.18	178	4.5	82.7	12.8	29.23	28.99
7	100310	100490.614	180.614	16.7	16.7	16.7	16.7	16.7	16.7	18.8	2.18	178	4.5	82.7	12.8	29.23	28.99
8	100310	100490.614	180.614	15.7	15.7	15.7	15.7	15.7	15.7	19.0	2.18	178	4.5	82.7	12.8	29.23	28.99
9	100310	100490.614	180.614	14.7	14.7	14.7	14.7	14.7	14.7	19.0	2.18	178	4.5	82.7	12.8	29.23	28.99
10	100310	100490.614	180.614	20.6	20.6	20.6	20.6	20.6	20.6	18.8	2.18	178	4.5	82.7	12.8	29.23	28.99
11	100310	100490.614	180.614	25.5	25.5	25.5	25.5	25.5	25.5	18.9	2.18	178	4.5	82.7	12.8	29.23	28.99
12	100310	100490.614	180.614	33.3	33.3	33.3	33.3	33.3	33.3	19.6	2.18	178	4.5	82.7	12.8	29.23	28.99
Mean	100310	100491	180.6	19.7	19.7	19.7	19.7	19.7	19.7	18.9	2.2	178.0	4.5	89.6	12.8	28.74	28.59

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

Mean density	1.184 kg/m <sup>3</sup>
--------------	-------------------------

$$Velocity = K \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$

Mean velocity	4.76 m/sec	
Standard uncertainty of velocity	0.26 m/sec	5.5 % of value
Expanded uncertainty in velocity	0.52 m/sec	10.9 % of value

	Circular duct	Rectangular duct
Flow rate	29482 m <sup>3</sup> /hour	0 m <sup>3</sup> /hour
Volume flow rate expanded uncertainty	3271 m <sup>3</sup> /hour	#DIV/0! m <sup>3</sup> /hour
Volume flow rate expanded uncertainty	11.1 % of value	#DIV/0! % of value

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

## **2.2.7 - Calculations Used in Reporting Results**

### 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 ( $8.038 \times 10^{-5}$  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<sup>-1</sup>

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

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



### 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  $M_R$

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

**IsoKinicity**

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

- $W_t$  = 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<sup>3</sup>)
- $T_m$  = average temperature at dry gas meter (°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<sub>2</sub>O)
- $DH$  = mean orifice pressure drop (mm H<sub>2</sub>O)
- $D_s$  = diameter of stack (m)
- $D_n$  = Nozzle diameter (mm)
- $T_s$  = stack temperature (°C)
- $M_d$  = molecular weight of dry stack gas
- $B_w$  = moisture fraction
- $P_s$  = stack pressure (mmHg)
- $A$  = duct c.s.a. (m<sup>2</sup>)
- $M_s$  = molecular weight of wet stack gas
- $M_d$  = molecular weight of dry stack gas
- $W_t$  = total weight of particulate matter (g)