NATIONAL PHYSICAL LABORATORY
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Test Report

UKAS TESTING
0002

mCERTS
THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

OXIDES OF NITROGEN (AS NO_2) 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:	**11th October & 5th December 2016**
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:	**21st December 2016**
Report Author	**Matthew Ellison**

Reference: XP3538LD/INTERTEK/SHLNG/OCT2016/SCV/PPC/Q4/V1

Report Approver:	Kevin Blakley	NPL Authorised Signatory
MCERTS Registration:	MM-03-317	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 11th October and 5th December 2016. The report documents the results obtained.

1.2.1 SCV H (Phase One) Monitoring Results

Client: Intertek
Site: South Hook LNG
Emission Point: SCV H (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**	44.4	135	9.3	2.5
Uncertainty (95% Confidence Level)	**Reference Conditions**	13.8	12.4	0.5	N/A
	Units	mg/m^3	mg/m^3	%Vol/Vol	%Vol/Vol
Average Stack Flow	**m^3/s at Reference Conditions**	8.6			
Reference Conditions		273K, 101.3 kPa, 3% Oxygen on a dry gas basis			
Date	**dd/mm/yyyy**	05/12/2016			
Sample Period	**From hh:mm**	12:00			
	To hh:mm	13:00			
Monitoring Method		BS EN 14792	BS EN 15058	BS EN 14789	BS EN 14790
Accreditation		UKAS & MCERTS	UKAS & MCERTS	UKAS & MCERTS	UKAS & MCERTS
Process Status	**Load (Tonnes/Hour)**	150			

1.2.2 SCV A (Phase Two) Monitoring Results

Client: Intertek
Site: South Hook LNG
Emission Point: SCV A (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**	49.4	127	8.8	2.4
Uncertainty (95% Confidence Level)	**Reference Conditions**	13.3	10.8	0.5	N/A
	Units	mg/m^3	mg/m^3	%Vol/Vol	%Vol/Vol
Average Stack Flow	**m^3/s at Reference Conditions**	7.7			
Reference Conditions		273K, 101.3 kPa, 3% Oxygen on a dry gas basis			
Date	**dd/mm/yyyy**	11/10/2016			
Sample Period	**From hh:mm**	12:00			
	To hh:mm	13:00			
Monitoring Method		BS EN 14792	BS EN 15058	BS EN 14789	BS EN 14790
Accreditation		UKAS & MCERTS	UKAS & MCERTS	UKAS & MCERTS	UKAS & MCERTS
Process Status	**Load (Tonnes/Hour)**	160			

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 13284-1. 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.

<table>
<tr><td>Continuous or Batch Process?</td><td colspan="5">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.</td></tr>
<tr><td>What part of the batch process was sampled? (If applicable)</td><td colspan="5">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.</td></tr>
<tr><td>What fuel was used during monitoring? (If applicable)</td><td colspan="5">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.</td></tr>
<tr><td>What feedstock was used during monitoring? (If applicable)</td><td colspan="5">N/A</td></tr>
<tr><td rowspan="3">What was the load during monitoring?</td><td colspan="2">Emission Point</td><td colspan="3">Load (Tonnes per Hour)</td></tr>
<tr><td colspan="2">SCV 1H</td><td colspan="3">150</td></tr>
<tr><td colspan="2">SCV 2A</td><td colspan="3">160</td></tr>
<tr><td>What abatement systems are present? Were they in operation?</td><td colspan="5">Each SCV uses water injection to abate NOx emissions. The system was in operation during the periodic monitoring of each SCV.</td></tr>
<tr><td rowspan="3">Periodic monitoring results and corresponding CEM values</td><td>Emission Point</td><td>Substance Monitored</td><td>CEM Result</td><td>Periodic Monitoring Result</td><td>Units</td></tr>
<tr><td>SCV 1H</td><td>Oxides of Nitrogen</td><td>48.8</td><td>44.4</td><td>mg/Nm^3</td></tr>
<tr><td>SCV 2A</td><td>Oxides of Nitrogen</td><td>54.8</td><td>49.4</td><td>mg/Nm^3</td></tr>
</table>

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 two weeks. 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 – Version 12 - June 2012.

2. Environmental Agency - Manual Stack emission monitoring performance standard for Organisations – Version 8.1 - October 2012.

3. Environmental Agency – M1 Technical Guidance Note – Sampling requirements for stack emission monitoring – Version 6 –January 2010.

4. Environmental Agency – M2 Technical Guidance Note – Monitoring of stack emissions to air – Version 10 – October 2013.

5. Environment Agency - MID 14792 - Stationary source emissions - Determination of mass concentration of nitrogen oxides (NOx) - Reference Method: Chemiluminescence - Version 1.1 - May 2011.

6. Environment Agency - MID 15259 - Stationary source emissions - Requirements for the measurement sections and sites and for the measurement objective, plan and report - Version 1.2 - January 2012.

7. 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	Sep-2018	Sep-2018	Sep-2018	Dec-2018	Sep-2018
Bob Lipscombe	Site Assistant	MM-07-879	Sep-2018	N/A	N/A	N/A	N/A	N/A
Kevin Blakley	Team Leader	MM-03-317	N/A	Sep-2018	Mar-2021	Mar-2021	Sep-2018	May-2019

2.1.2 Emissions Testing Procedures

	Instrumental Methods			Manual Methods		
Determinand	**NOx**	**CO**	**O_2**	**H_2O**	**Stack Flow**	**Temperature**
SRM Standard	BS EN 14792	BS EN 15058	BS EN 14789	BS EN 14790	BS ISO 16911	BS ISO 16911
Instrument	PG-250 SRM	PG-250 SRM	PG-250 SRM	Impingers with DGM	Pitot	Type K Thermocouple
Instrument Serial No.	AS0450	AS0450	AS0450	N/A	AS0638	AS0638
Principle	Chemiluminescence	NDIR	Zirconia & Paramagnetic	Gravimetric	Flow	Temperature
Operational Range	0 - 250 ppm	0 - 200 ppm	0 - 25%	N/A	N/A	N/A
Certified Range	0 - 125 mg/m^3	0 - 75 mg/m^3	0 - 25%	N/A	N/A	N/A
Uncertainty	10%	6%	6%	20%	N/A	N/A
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 SRM. The entire sampling system had been leak tested before testing was carried out to ensure no dilution of the sample gas.

Moisture tests were conducted using a mini impinger setup, a dry gas meter and a small 110v pump. The entire setup was transported to the sampling platform and operated at the same time as the instrumental methods. A flow and temperature profile was carried as well using an S-type pitot and K-type thermocouple, both of which were built into a 2m traversing probe.

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	102400	153.1 ppm	1%
		164171	155.4 ppm	1%
Nitrogen Oxide		242465	149.3 ppm	1%
		164171	151.7 ppm	1%
Oxygen		102488	14.93%	1%
		132170	14.99%	1%

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

The ranges of the Horiba PG-250 SRM 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	153.1 ppm
Oxides of Nitrogen (as NO_2)	0 - 250 ppm	149.3 ppm
Oxygen	0 - 25%	14.93%

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 SRM 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 INTK34OCT16/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:

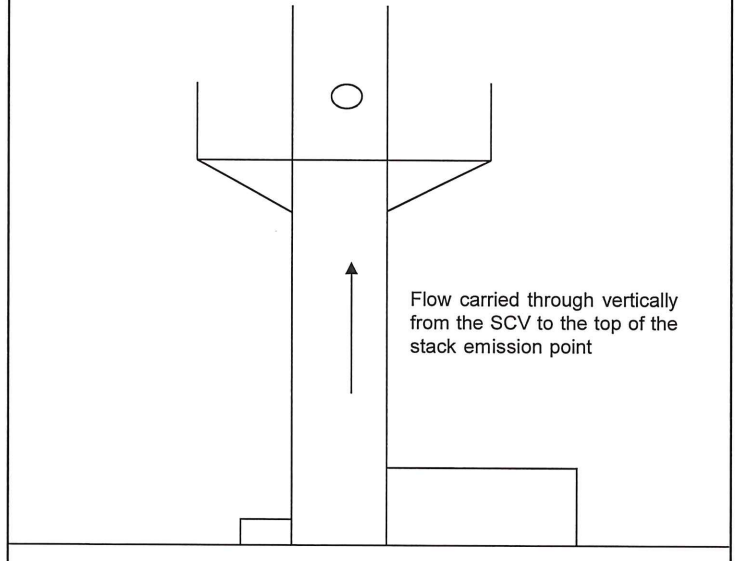
P:\Stack Emissions Team\South Hook LNG - Intertek\INTK34OCT16\7. Monitoring Record Sheets

APPENDIX TWO

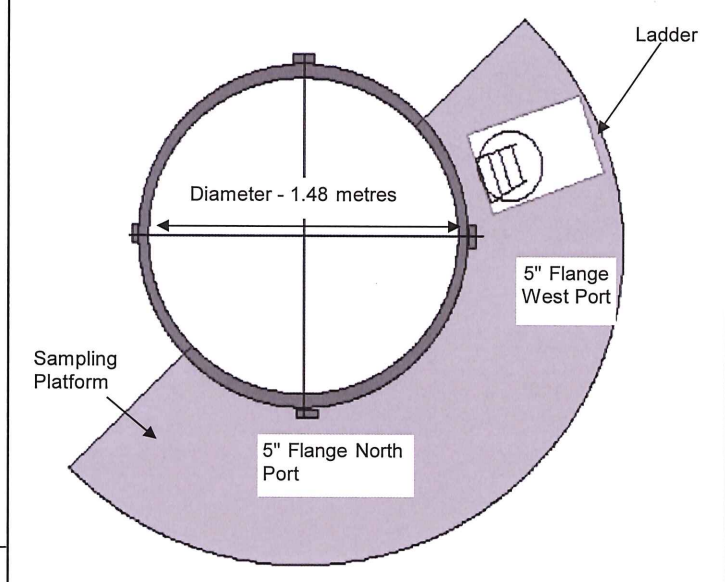
2.2.1 - Stack Diagram

Company	Installation	Stack	Substances Monitored	Permit
Intertek	South Hook LNG	SCVs Phases One & Two	CO, NOx, O_2 and H_2O	XP3538LD

Stack Diagram



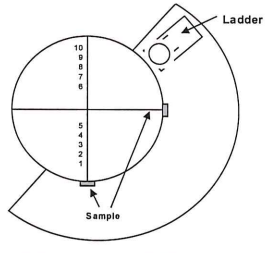
Stack Cross-Section



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

Monitoring Objective	Traverse	Site:	South Hook LNG	Stack ID:	SCV 1H
Date	05/12/2016	Site Team:	RPL/KCB	Time of Survey:	11:30
Tape Measure ID	AS0589	Diagram of Sample Location:			
Laser Measurement Device ID	N/A				
Traverse Pitot Type	S-Type				
Traverse Pitot Tube ID	AS0211				
Pitot Assembly Visual Inspection (Pre)	Pass				
Pitot Leak Check @ ..	Pass				
Traverse Manometer Type	Digital				
Traverse Manometer ID	AS0638				
Damping Device used	No				
Traverse Temp. Readout ID	AS0638				
Traverse Thermocouple ID	AS0451a				
Static Pressure	Δp (mmH20)				
	23.73				
	Pass	Comments/Deviations:			
Swirl Test Conducted	Yes	Velocity & Temperature Measurments			
Protractor ID	AS0626				
Post-Test Blockage Test (L-Type only)					
Post-Test Pitot Leak Check @ ..	Pass				
Pitot Assembly Visual Inspection (Post)	Pass				

Conditions	Value	Units
Stack pressure	754.99	mmHg
Ref O_2 Value	3	%
Moisture Content	2.5	%
CO	135	ppm
CO_2	6.8	%
N_2	83.89	%
O_2	9.30	%
Dry Molecular wt	29.46	
Stack Molecular wt	29.18	
Duct Diameter	1.48	m
Duct Depth		m
Duct Width		m
Area of stack	1.72	m^2
Pbar	1004	mbar
Pbar	753	mmHg
Pitot tube coeft	0.819	
Reference Temp	273	K
Reference Pressure	760	mmHg
Ambient Temperature	12	° C

Duct Dimensions

Port ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Port Depth
A					
B					
C					
D					

Circular Duct

Line ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Diameter
A					
B					

Rectangular Duct

Line ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Depth
A					
B					
C					
D					

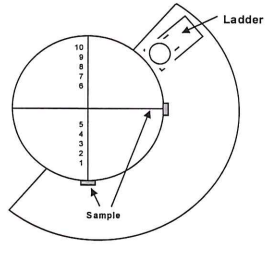
	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Width
Outside Side Division					

			Static Measurement	Δp (mmH20)	
			Measurement Line	Reading 1	Reading 2(180°)
Enter manually from previous visit	Circular Duct	Rectangular Duct	A	23.20	23.30
Duct Diameter (m)	1.48		B	24.10	24.30
Duct Depth (m)			C		
Duct Width (m)			D		

SAMPLING LINE: North										
Traverse Point	Distance into duct (m)	Δp Spot Reading mm H2O	Δp Spot Reading mm H2O	Δp Spot Reading mm H2O	Δp Average mm H_2O	Δp Pa	Stack Temp Ts °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	√Δp
1	1.42	5.2	5.2	5.2	5.2	50.98	21.3	7.55	4	2.28
2	1.26	5.8	5.8	5.8	5.8	56.86	21.3	7.97	4	2.41
3	1.04	7.0	7.0	7.0	7.0	68.62	21.2	8.76	3	2.65
4	0.44	7.9	7.9	7.9	7.9	77.44	21.2	9.30	3	2.81
5	0.22	7.5	7.5	7.5	7.5	73.52	21.1	9.06	4	2.74
6	0.06	6.5	6.5	6.5	6.5	63.72	21.0	8.44	3	2.55
SAMPLING LINE: West										
Traverse Point	Distance into duct (m)	Δp Spot Reading mm H2O	Δp Spot Reading mm H2O	Δp Spot Reading mm H2O	Δp Average mm H_2O	Δp Pa	Stack Temp Ts °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	√Δp
1	1.42	4.8	4.8	4.8	4.8	47.05	20.9	7.25	3	2.19
2	1.26	5.2	5.2	5.2	5.2	50.98	20.9	7.54	4	2.28
3	1.04	6.6	6.6	6.6	6.6	64.70	20.9	8.50	3	2.57
4	0.44	8.2	8.2	8.2	8.2	80.39	20.8	9.47	4	2.86
5	0.22	7.4	7.4	7.4	7.4	72.54	20.6	8.99	4	2.72
6	0.06	9.1	9.1	9.1	9.1	89.21	20.4	9.97	3	3.02
Average values		6.8	6.8	6.8	6.8	66.3	21.0	8.6	3.5	2.6

Duct / Stack Flow Characteristics:	Average	Units
Stack Velocity at stack gas T & P and a wet gas basis	8.57	ms^{-1}
Stack flow @ STP, O_2 (ref) and on a dry gas basis	8.59	m^3s^{-1}
Stack flow @ stack gas T & P and on a wet gas basis	14.73	m^3s^{-1}
Stack flow @ stack gas T & P and on a dry gas basis	14.37	m^3s^{-1}
Stack flow @ STP and on a wet gas basis	13.59	m^3s^{-1}
Stack flow @ STP, O_2 (ref) and on a wet gas basis	8.81	m^3s^{-1}

Flow Criteria Measurements	
Is the Flow Ratio 3:1 or less?	1.4 :1
Any local negative flow?	NO
Flow <15° of duct axis?	YES
Minimum Δp detected > 0.5 mmH2O	YES

Monitoring Objective	Traverse	Site:	South Hook LNG	Stack ID:	SCV 2A
Date	11/10/2016	Site Team:	MRE/KCB	Time of Survey:	10:30
Tape Measure ID	AS0589	Diagram of Sample Location:			
Laser Measurement Device ID	N/A				
Traverse Pitot Type	S-Type				
Traverse Pitot Tube ID	AS0211				
Pitot Assembly Visual Inspection (Pre)	Pass				
Pitot Leak Check @ ..	Pass				
Traverse Manometer Type	Digital				
Traverse Manometer ID	AS0638				
Damping Device used	No				
Traverse Temp. Readout ID	AS0638				
Traverse Thermocouple ID	AS0451a				
Static Pressure	Δp (mmH20)				
	25.75				
	Pass	Comments/Deviations:			
Swirl Test Conducted	Yes				
Protractor ID	AS0626	Velocity & Temperature Measurements			
Post-Test Blockage Test (L-Type only)					
Post-Test Pitot Leak Check @ ..	Pass				
Pitot Assembly Visual Inspection (Post)	Pass				

Conditions	Value	Units
Stack pressure	765.64	mmHg
Ref O_2 Value	3	%
Moisture Content	2.4	%
CO	127	ppm
CO_2	7	%
N_2	84.19	%
O_2	8.80	%
Dry Molecular wt	29.47	
Stack Molecular wt	29.20	
Duct Diameter	1.48	m
Duct Depth		m
Duct Width		m
Area of stack	1.72	m^2
Pbar	1018	mbar
Pbar	764	mmHg
Pitot tube coeft	0.819	
Reference Temp	273	K
Reference Pressure	760	mmHg
Ambient Temperature	8	° C

Duct Dimensions

Port ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Port Depth
A					
B					
C					
D					

Circular Duct

Line ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Diameter
A					
B					

Rectangular Duct

Line ID	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Depth
A					
B					
C					
D					

	Reading 1 (m)	Reading 2 (m)	Reading 3 (m)	Average	Duct Width
Outside Side Division					

			Static Measurement	Δp (mmH20)	
			Measurement Line	Reading 1	Reading 2(180°)
Enter manually from previous visit		Circular Duct	Rectangular Duct	A	25.80	26.00
Duct Diameter (m)		1.48		B	25.60	25.60
Duct Depth (m)				C		
Duct Width (m)				D		

Post-Test Blockage Test (L-Type)	Traverse Point	Δp Reading (mm H_2O)	Δp Reading (mm H_2O)	Δp Reading (mm H_2O)	Δp Average (mm H_2O)
Reading 1					
Reading 2					

SAMPLING LINE: North										
Traverse Point	Distance into duct (m)	Δp Spot Reading mm H2O	Δp Spot Reading mm H2O	Δp Spot Reading mm H2O	Δp Average mm H_2O	Δp Pa	Stack Temp Ts °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	√Δp
1	1.42	3.2	3.2	3.2	3.2	31.37	21.1	5.88	5	1.79
2	1.26	4.8	4.8	4.8	4.8	47.05	21.1	7.20	6	2.19
3	1.04	4.7	4.7	4.7	4.7	46.07	21.0	7.12	6	2.17
4	0.44	6.2	6.2	6.2	6.2	60.78	21.0	8.18	5	2.49
5	0.22	5.3	5.3	5.3	5.3	51.96	21.0	7.56	5	2.30
6	0.06	5.3	5.3	5.3	5.3	51.96	20.8	7.56	6	2.30
SAMPLING LINE: West										
Traverse Point	Distance into duct (m)	Δp Spot Reading mm H2O	Δp Spot Reading mm H2O	Δp Spot Reading mm H2O	Δp Average mm H_2O	Δp Pa	Stack Temp Ts °C	Velocity @ stack gas T&P on wet gas basis m/s	Angle of Swirl °	√Δp
1	1.42	3.9	3.9	3.9	3.9	38.23	20.9	6.49	5	1.97
2	1.26	3.5	3.5	3.5	3.5	34.31	20.0	6.13	4	1.87
3	1.04	3.7	3.7	3.7	3.7	36.27	20.9	6.32	5	1.92
4	0.44	5.6	5.6	5.6	5.6	54.90	20.9	7.77	5	2.37
5	0.22	6.4	6.4	6.4	6.4	62.74	20.8	8.31	6	2.53
6	0.06	6.2	6.2	6.2	6.2	60.78	20.6	8.17	5	2.49
Average values		4.9	4.9	4.9	4.9	48.0	20.8	7.2	5.3	2.2

Duct / Stack Flow Characteristics:	Average	Units
Stack Velocity at stack gas T & P and a wet gas basis	7.22	ms^{-1}
Stack flow @ STP, O_2 (ref) and on a dry gas basis	7.67	m^3s^{-1}
Stack flow @ stack gas T & P and on a wet gas basis	12.42	m^3s^{-1}
Stack flow @ stack gas T & P and on a dry gas basis	12.12	m^3s^{-1}
Stack flow @ STP and on a wet gas basis	11.62	m^3s^{-1}
Stack flow @ STP, O_2 (ref) and on a wet gas basis	7.86	m^3s^{-1}

Flow Criteria Measurements	
Is the Flow Ratio 3:1 or less?	1.4 :1
Any local negative flow?	NO
Flow <15° of duct axis?	YES
Minimum Δp detected > 0.5 mmH2O	YES

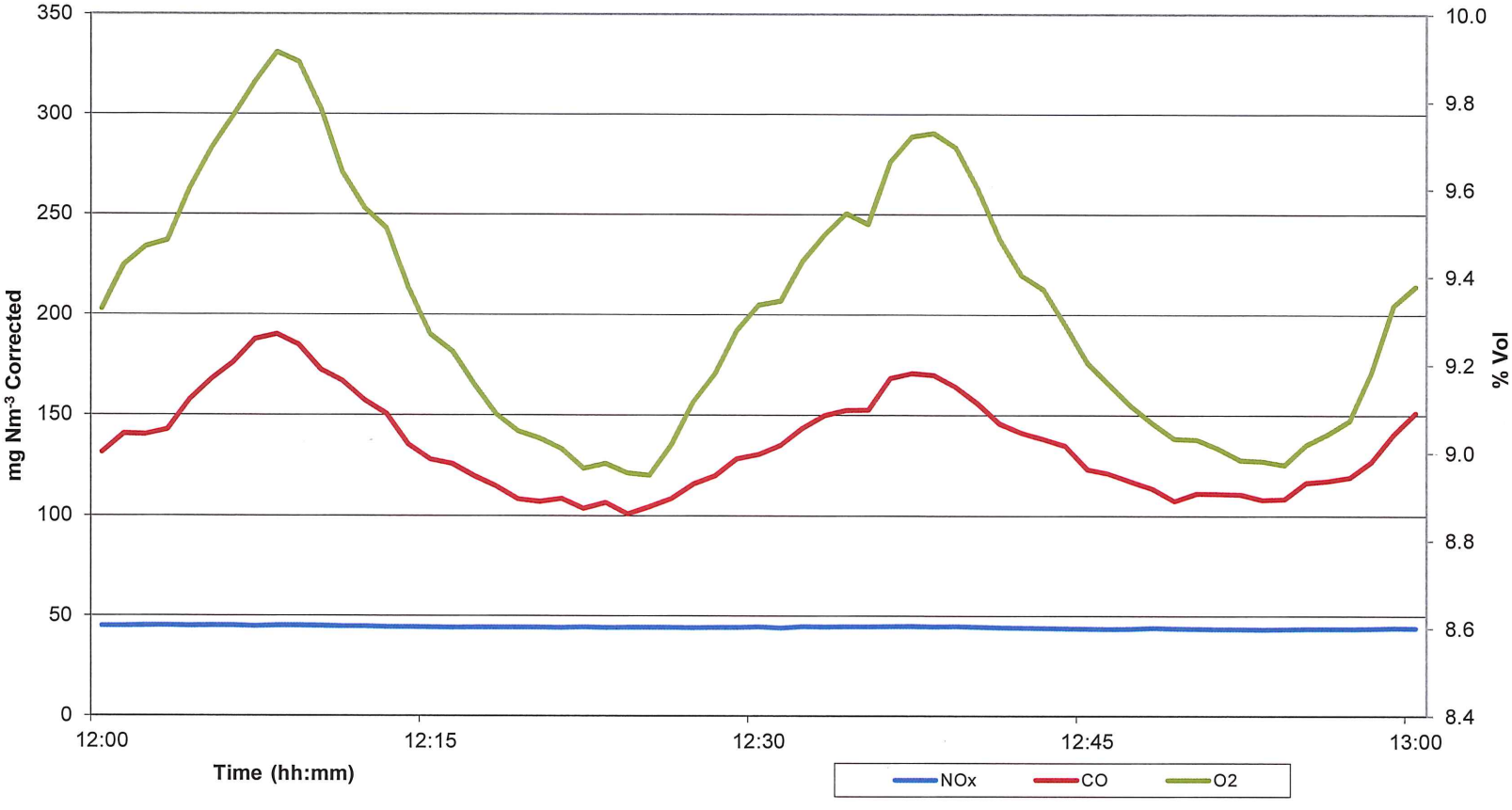
2.2.3 - One Minute Averaged Gaseous Emissions Data

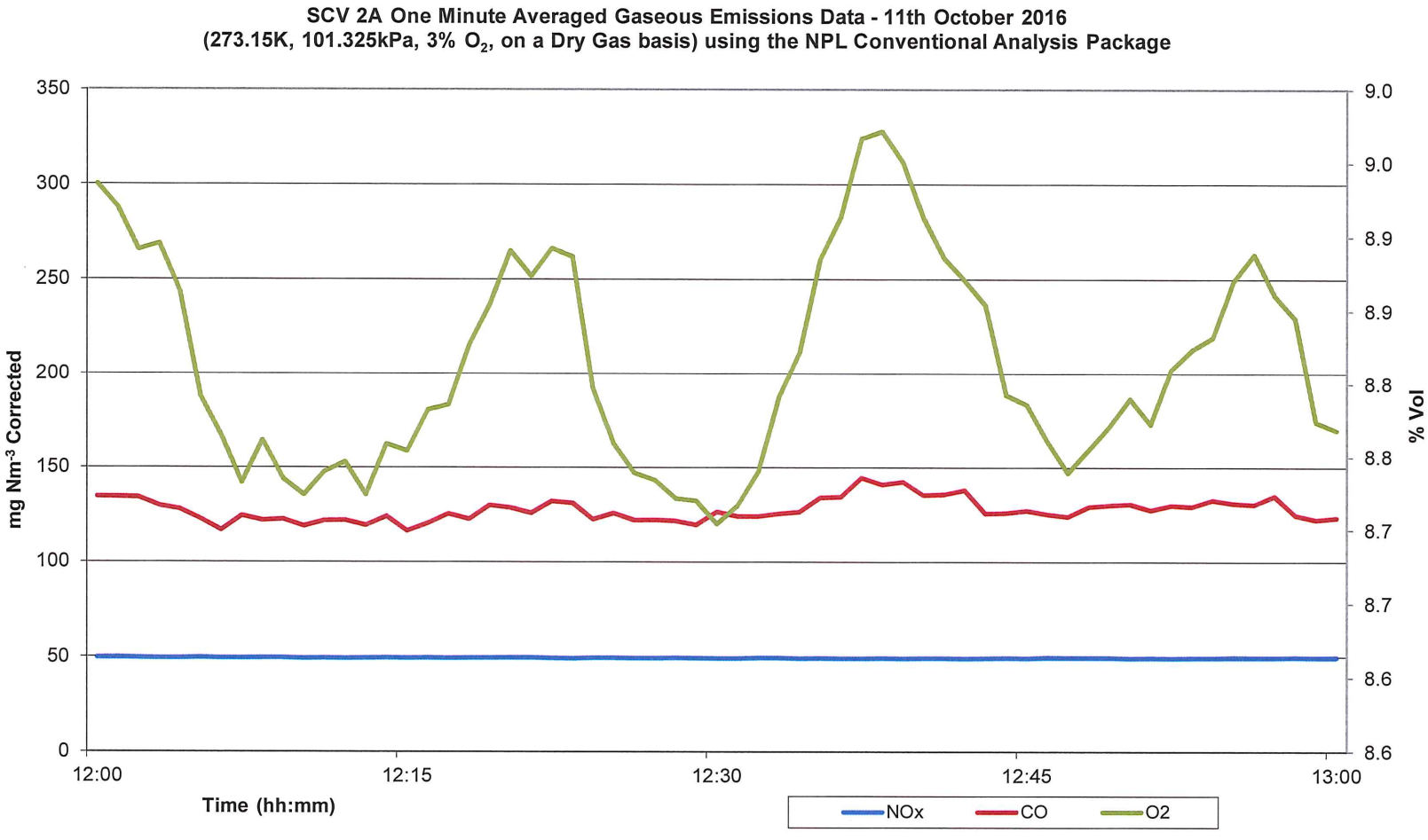
Minute Averaged Gaseous Data from South Hook LNG 5th December 2016 SCV H - Phase One Referenced to 273K, 101.3kPa and 3% Oxygen on a Dry Basis			
Time (hh:mm)	**Carbon Monoxide (mg/Nm^3)**	**Oxides of Nitrogen (mg/Nm^3)**	**Oxygen (%)**
12:00	131	44.9	9.3
12:01	141	44.8	9.4
12:02	140	45.1	9.5
12:03	143	45.2	9.5
12:04	157	45.0	9.6
12:05	168	45.1	9.7
12:06	176	45.1	9.8
12:07	188	44.8	9.8
12:08	190	45.0	9.9
12:09	185	45.1	9.9
12:10	172	45.0	9.8
12:11	167	44.8	9.6
12:12	157	44.8	9.6
12:13	150	44.4	9.5
12:14	135	44.5	9.4
12:15	128	44.3	9.3
12:16	126	44.2	9.2
12:17	120	44.4	9.2
12:18	115	44.4	9.1
12:19	108	44.3	9.1
12:20	107	44.3	9.0
12:21	109	44.2	9.0
12:22	104	44.4	9.0
12:23	107	44.2	9.0
12:24	101	44.3	9.0
12:25	104	44.3	8.9
12:26	109	44.3	9.0
12:27	116	44.3	9.1
12:28	120	44.3	9.2
12:29	128	44.4	9.3
12:30	131	44.6	9.3
12:31	135	44.1	9.3
12:32	144	44.7	9.4
12:33	150	44.6	9.5
12:34	152	44.7	9.5
12:35	153	44.7	9.5
12:36	168	44.9	9.7
12:37	171	44.9	9.7
12:38	170	44.7	9.7
12:39	164	44.8	9.7
12:40	156	44.6	9.6
12:41	146	44.3	9.5
12:42	141	44.2	9.4
12:43	138	44.1	9.4
12:44	135	44.0	9.3
12:45	123	43.8	9.2
12:46	121	43.6	9.2
12:47	117	43.9	9.1
12:48	114	44.2	9.1
12:49	107	44.0	9.0
12:50	111	43.8	9.0
12:51	111	43.7	9.0
12:52	111	43.7	9.0
12:53	108	43.5	9.0
12:54	108	43.7	9.0
12:55	117	43.8	9.0
12:56	117	43.8	9.0
12:57	119	43.8	9.1
12:58	127	44.0	9.2
12:59	141	44.3	9.3
13:00	151	44.0	9.4
Min Value	**101**	**43.5**	**8.9**
Max Value	**190**	**45.2**	**9.9**
Average	**135**	**44.4**	**9.3**

Minute Averaged Gaseous Data from South Hook LNG 11th October 2016 SCV A - 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 (%)**
12:00	134	49.6	8.9
12:01	134	49.6	8.9
12:02	134	49.4	8.9
12:03	130	49.3	8.9
12:04	128	49.2	8.9
12:05	122	49.5	8.8
12:06	117	49.3	8.8
12:07	124	49.2	8.7
12:08	122	49.4	8.8
12:09	122	49.4	8.7
12:10	119	49.2	8.7
12:11	122	49.3	8.7
12:12	122	49.1	8.7
12:13	119	49.3	8.7
12:14	124	49.5	8.8
12:15	116	49.3	8.8
12:16	120	49.4	8.8
12:17	125	49.3	8.8
12:18	122	49.4	8.8
12:19	130	49.3	8.9
12:20	128	49.5	8.9
12:21	126	49.5	8.9
12:22	132	49.2	8.9
12:23	131	49.1	8.9
12:24	122	49.4	8.8
12:25	126	49.4	8.8
12:26	122	49.3	8.7
12:27	122	49.3	8.7
12:28	122	49.4	8.7
12:29	119	49.3	8.7
12:30	126	49.2	8.7
12:31	124	49.2	8.7
12:32	124	49.4	8.7
12:33	125	49.4	8.8
12:34	126	49.2	8.8
12:35	134	49.3	8.9
12:36	134	49.2	8.9
12:37	145	49.2	9.0
12:38	141	49.3	9.0
12:39	142	49.2	9.0
12:40	135	49.3	8.9
12:41	136	49.2	8.9
12:42	138	49.1	8.9
12:43	125	49.3	8.9
12:44	126	49.5	8.8
12:45	127	49.3	8.8
12:46	125	49.6	8.8
12:47	124	49.5	8.7
12:48	129	49.6	8.8
12:49	130	49.5	8.8
12:50	130	49.2	8.8
12:51	127	49.4	8.8
12:52	130	49.3	8.8
12:53	129	49.5	8.8
12:54	133	49.4	8.8
12:55	131	49.6	8.9
12:56	130	49.6	8.9
12:57	135	49.6	8.9
12:58	125	49.7	8.8
12:59	122	49.6	8.8
13:00	123	49.6	8.8
Min Value	**116**	**49.1**	**8.7**
Max Value	**145**	**49.7**	**9.0**
Average	**127**	**49.4**	**8.8**

2.2.4 - Gaseous Emissions Graphical Data

SCV 1H One Minute Averaged Gaseous Emissions Data - 5th December 2016
(273.15K, 101.325kPa, 3% O_2, on a Dry Gas basis) using the NPL Conventional Analysis Package




SCV 2A One Minute Averaged Gaseous Emissions Data - 11th October 2016
(273.15K, 101.325kPa, 3% O2, on a Dry Gas basis) using the NPL Conventional Analysis Package
mg Nm-3 Corrected
% Vol
Time (hh:mm)
350
300
250
200
150
100
50
0
9.0
9.0
8.9
8.9
8.8
8.8
8.7
8.7
8.6
8.6
12:00
12:15
12:30
12:45
13:00
NOx
CO
O2

2.2.5 - Gas Calibration Log

GAS CALIBRATION MEASUREMENTS

Client:	Intertek Ltd	Date:	05/12/2016	Horiba ID:	AS0450
Site:	South Hook LNG	Job Number:	INTK34OCT16	FID ID:	N/A
Stack ID:	SCV 1H	Mobile Lab ID:	VU64 VTY	Sonimix ID:	N/A
Reference oxygen %	3	Nitrogen cylinder ID:	Zero Grade	Initial N_2 pressure bar	150

GAS CALIBRATION LOG - DIRECT CALIBRATION

		SO_2	CO	NOx	O_2	CO_2	VOCs
Gas Cylinder ID:			164171	164171	132170	132170	
Initial Reg. Pressure bar			160	160	30	30	
Cylinder Concentration:			155.4 ppm	151.7 ppm	14.99 % Vol	12.02 % Vol	
Span Value:			155.4 ppm	151.7 ppm	14.99 % Vol	12.02 % Vol	
Analyser Range:0 -			200 ppm	250 ppm	25 % Vol	25 % Vol	
Check Zero	Time		10:41				
	Reading		-1.0 ppm	0.1 ppm	0.23 % Vol	-0.08 % Vol	
	Initial Gain		-1.0	-2.0	-4.00	2.00	
Adjust Zero	Time		10:43				
	Reading		0.0 ppm	0.0 ppm	-0.01 % Vol	0.00 % Vol	
	Final Gain		3	-1	1	0	
Check Span	Time		10:58	10:58	10:47	10:47	
	Reading		134.2 ppm	156.2 ppm	14.75 % Vol	12.48 % Vol	
	Initial Gain		1.251	1.005	0.854	0.954	
Adjust Span	Time		11:01	11:01	10:48	10:48	
	Reading		155.9 ppm	149.3 ppm	14.99 % Vol	12.02 % Vol	
	Final Gain		1.267	1.042	0.872	0.937	
Check Zero	Time		11:05				
	Reading		-0.1 ppm	0.1 ppm	-0.15 % Vol	0.00 % Vol	

GAS CALIBRATION LOG - SYSTEM CAL (Including heated line and chiller unit)

		SO_2	CO	NOx	O_2	CO_2	VOCs
Span Value:			155.4 ppm	151.7 ppm	15.0 % Vol	12.0 % Vol	
Check Zero	Time		11:10				
	Reading		0.4 ppm	0.2 ppm	-0.04 % Vol	0.00 % Vol	
	Pass/fail		PASS	PASS	PASS	PASS	
Check Span	Time		11:20	11:20	11:14	11:14	
	Reading		155.9 ppm	149.6 ppm	14.85 % Vol	11.82 % Vol	
	Response Time/s		81	92	86	102	
	Pass/fail		PASS	PASS	PASS	PASS	

GAS CALIBRATION LOG - POST CAL (Including heated line and chiller unit)

		SO_2	CO	NOx	O_2	CO_2	VOCs
Span Value:			155.4 ppm	151.7 ppm	14.99 % Vol	12.02 % Vol	
Check Zero	Time		17:08				
	Reading		-4.3 ppm	0.1 ppm	-0.11 % Vol	0.06 % Vol	
Check Span	Time		17:16	17:16	17:12	17:12	
	Reading		152.6 ppm	150.8 ppm	14.74 % Vol	11.80 % Vol	
	Reg Pressure		140	140	15	15	
Zero Drift check @2x repeatability zero			-0.05 ppm	0.1 ppm	-0.14 % Vol	0.00 % Vol	
Acceptance			Accept	Accept	Accept	Accept	
Zero Drift (%)			2.8	0.1	0.7	0.5	
Span Drift (%)			1.8	0.6	1.7	1.8	
Acceptance zero			Correct for drift	Accept	Accept	Accept	
Acceptance span			Accept	Accept	Accept	Accept	

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

Name:	Kevin Blakley
MCERTS ID:	MM-03-317

Personnel Present:	KCB/RPL

GAS CALIBRATION MEASUREMENTS

Client:	Intertek	Date:	11/10/2016	Horiba ID:	AS0450
Site:	South Hook LNG	Job Number:	INTK34OCT16	FID ID:	N/A
Stack ID:	SCV 2A	Mobile Lab ID:	VU64 VTY	Sonimix ID:	N/A
Reference oxygen %	3	Nitrogen cylinder ID:	Zero Grade	Initial N_2 pressure bar	150

GAS CALIBRATION LOG - DIRECT CALIBRATION

		SO_2	CO	NOx	O_2	CO_2	VOCs
Gas Cylinder ID:			102400	242465	102488	102488	
Initial Reg. Pressure bar			170	170	60	60	
Cylinder Concentration:			153.1 ppm	149.3 ppm	14.93 % Vol	12.06 % Vol	
Span Value:			153.1 ppm	149.3 ppm	14.93 % Vol	12.06 % Vol	
Analyser Range:0 -			200 ppm	250 ppm	25 % Vol	20 % Vol	
Check Zero	Time		10:00				
	Reading		-1.7 ppm	-0.1 ppm	0.25 % Vol	-0.07 % Vol	
	Initial Gain		-6.0	-2.0	-3.00	1.00	
Adjust Zero	Time		10:02				
	Reading		0.3 ppm	0.0 ppm	0.00 % Vol	0.00 % Vol	
	Final Gain		1	-2	3	0	
Check Span	Time		10:13	10:13	10:22	10:22	
	Reading		156.3 ppm	146.6 ppm	14.84 % Vol	12.53 % Vol	
	Initial Gain		1.142	0.986	0.868	0.950	
Adjust Span	Time		10:15	10:15	10:24	10:24	
	Reading		153.2 ppm	149.3 ppm	14.93 % Vol	12.06 % Vol	
	Final Gain		1.144	1.001	0.873	0.933	
Check Zero	Time		10:27				
	Reading		0.2 ppm	0.1 ppm	0.02 % Vol	0.06 % Vol	

GAS CALIBRATION LOG - SYSTEM CAL (Including heated line and chiller unit)

		SO_2	CO	NOx	O_2	CO_2	VOCs
Span Value:			153.1 ppm	149.3 ppm	14.9 % Vol	12.1 % Vol	
Check Zero	Time		10:34				
	Reading		-0.5 ppm	0.0 ppm	0.01 % Vol	0.04 % Vol	
	Pass/fail		PASS	PASS	PASS	PASS	
Check Span	Time		10:40	10:40	10:46	10:46	
	Reading		155.6 ppm	150.6 ppm	14.84 % Vol	11.97 % Vol	
	Response Time/s		76	82	85	85	
	Pass/fail		PASS	PASS	PASS	PASS	

GAS CALIBRATION LOG - POST CAL (Including heated line and chiller unit)

		SO_2	CO	NOx	O_2	CO_2	VOCs
Span Value:			153.1 ppm	149.3 ppm	14.93 % Vol	12.06 % Vol	
Check Zero	Time		16:04				
	Reading		1.3 ppm	0.1 ppm	-0.12 % Vol	0.09 % Vol	
Check Span	Time		16:10	16:10	16:16	16:16	
	Reading		148.1 ppm	147.9 ppm	14.67 % Vol	11.92 % Vol	
	Reg Pressure		165	165	55	55	
Zero Drift check @2x repeatability zero			-0.10 ppm	0.1 ppm	0.02 % Vol	0.06 % Vol	
Acceptance			Accept	Accept	Accept	Accept	
Zero Drift (%)			0.8	0.1	0.8	0.7	
Span Drift (%)			3.3	0.9	1.7	1.2	
Acceptance zero			Accept	Accept	Accept	Accept	
Acceptance span			Correct for drift	Accept	Accept	Accept	

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

Name:	Matthew Ellison
MCERTS ID:	MM-05-682

Personnel Present:	MRE/KCB

2.2.6 - Uncertainty Calculations

SCV 1H Uncertainty Calculations

Uncertainty calculation for Gaseous Measurement NOx EN14792 - PG-250 (AS0450)- SRM Version

v3.6 Feb-15
SCV 1H

Limit value	107	mg/m^3 (corrected) NOx	**Cal gas conc**	311.44	mg.m^{-3} (NO_2)
Measured concentration	28.79	mg/m3 (101.3kPa, 273K)	**Full Scale**	513.25	mg/m^3 (NO_2)
Measured concentration	44.38	mg/m^3 (Corrected)			

NO/NO2 ratio	100.00

Gas	NO	
Full Scale	250	ppm
Cal gas conc	151.7	ppm
Conversion	2.053	

Correction for reference conditions

		O2, %	Moisture, %	Pressure, KPa	Temperature, K
	ref	3.00	0.00	101.30	273.00
	measured	9.32	0.00	101.30	273.00
	Uncert	0.49	1.00	0.00	0.00
Factors		1.54	1.00	1.00	1.00
Uncertainty in factor		0.06	0.01	0.00	0.00
Correction Factor		**1.54**	uf	**0.07**	

Effect of drift
0.38 mg/m3

Performance characteristics	**Value**			**specification**
Response time	92	seconds		≤200
Logger sampling interval	60	seconds		
Measurement period	61	minutes		
Number of readings in measurement	61			
Repeatability at zero	0.03	% full scale		≤±1 % range
Repeatability at span level	0.09	% full scale		≤±2 % range
Deviation from linearity(lack of fit)	0.56	% full scale		≤±2 % range
Zero drift	0.21	mg/m3		<5% span value
Span drift	1.85	mg/m3		<5% span value
volume or pressure flow dependence	0.36	% full scale		
atmospheric pressure dependence	-0.16	% full scale /2kPa		≤±3 % range/2kPa
ambient temperature dependence	-2.43	% full scale/10K		≤±3 % range/10K
Cross sensitivity	0.5	% full scale		<4 % range
dependence on voltage	-0.1	% full scale/10V		≤±2% range/10V
losses in the line (leak)	0	% value		≤± 2% of value
Converter efficiency	96.1	%		≥95%
Uncertainty of calibration gas	1	% value		≤± 2% of value

	ranges min	max	value at calib	
flow	0.4	0.4	0.4	l/min
pressure	101.0	102	101	kPa
temp	280	285	280	K
Voltage	110	110	110	V

Performance characteristic		**Uncertainty**		**Value of uncertainty quantity**		**mg/m3**
Standard deviation of repeatability at zero		u_{r0}		for mean		use rep at span
Standard deviation of repeatability at span level		u_{rs}		for mean		0.06
Lack of fit		u_{fit}				1.66
Drift		u_{0dr}				0.22
volume or pressure flow dependence		u_{spres}				0.00
atmospheric pressure dependence		u_{apres}				-0.24
ambient temperature dependence		u_{temp}				-3.60
Cross sensitivity		u_{interf}				1.48
Dependence on voltage		u_{volt}				0.00
losses in the line (leak)		u_{leak}				0.00
Uncertainty of calibration gas		u_{cal}				0.17
converter efficiency		u_{conv}				0.65
Uncertainty in factor		uf				1.88

Measurement uncertainty				
Combined uncertainty			4.30	mg/m^3
Expanded uncertainty	k =	2	8.59	mg/m^3
Uncertainty corrected to std conds			**13.77**	**mg/m^3**
Expanded uncertainty	**expressed with a level of confidence of 95%**		**13.77 mg.m^{-3}**	
Expanded uncertainty	**expressed with a level of confidence of 95%**		**31.03 % value**	
Expanded uncertainty	**expressed with a level of confidence of 95%**		**8.03 % ELV**	

Requirement in standard is for uncertainty to be < 10% of ELV (dry before O_2 correction)

Uncertainty calculation for Gaseous Measurement CO EN15058 - PG-250 AS0450 - SRM Version

v4.1 Feb-15

SCV 1H

Limit value	N/A	mg/m^3 (corrected)	**Cal gas conc**	194.25	mg.m^{-3}
Measured concentration	87.83	mg/m3 (101.3kPa, 273K)	**Full Scale**	250.00	mg/m^3
Measured concentration	135.41	mg/m^3 (Corrected)			

Gas	CO	
Full Scale	200	ppm
Cal gas conc	155.4	ppm
Conversion	1.25	

Correction for reference conditions					
		O2, %	**Moisture, %**	**Pressure, KPa**	**Temperature, K**
	ref	3	0.00	101.30	273.00
	measured	9.32	0.00	101.30	273.00
	Uncert	0.49	1.00	0.00	0.00
Factors		1.54	1.00	1.00	1.00
Uncertainty in factor		0.06	0.01	0.00	0.00
Correction Factor		**1.54**	uf	**0.07**	

Performance characteristics	**Value**			**specification**
Response time	81	seconds		≤200
Logger sampling interval	60	seconds		
Measurement period	61	minutes		
Number of readings in measurement	61			
Repeatability at zero	0.09	% full scale		≤±1 % range
Repeatability at span level	0.08	% full scale		≤±2 % range
Deviation from linearity(lack of fit)	0.71	% full scale		≤±2 % range
Zero drift	0	mg/m3		<5% span value
Span drift	0	mg/m3		<5% span value
volume or pressure flow dependence	-0.27	% full scale		
atmospheric pressure dependence	0.09	% full scale /2kPa		≤±3 % range/2kPa
ambient temperature dependence	1.48	% full scale/10K		≤±3 % range/10K
Cross sensitivity	0.1	% full scale		<4 % range
dependence on voltage	0.33	% full scale/10V		≤±2% range/10V
losses in the line (leak)	0	% value		≤± 2% of value
Uncertainty of calibration gas	1	% value		≤± 2% of value

Effect of drift
0.00 mg/m3

	ranges min	max	value at calib	
flow	0.4	0.4	0.4	l/min
pressure	101.0	102	101	kPa
temp	280	285	280	K
Voltage	110	110	110	V

Performance characteristic		**Uncertainty**	**Value of uncertainty quantity**		**mg/m3**
Standard deviation of repeatability at zero		u_{r0}	for mean		use rep at span
Standard deviation of repeatability at span level		u_{rs}	for mean		0.03
Lack of fit		u_{fit}			1.02
Drift		u_{0dr}			0.00
volume or pressure flow dependence		u_{spres}			0.00
atmospheric pressure dependence		u_{apres}			0.06
ambient temperature dependence		u_{temp}			1.07
Cross sensitivity		u_{interf}			0.12
Dependence on voltage		u_{volt}			0.00
losses in the line (leak)		u_{leak}			0.00
Uncertainty of calibration gas		u_{cal}			0.51
Uncertainty in factor		uf			5.73

Measurement uncertainty				
Combined uncertainty			1.57	mg/m^3
Expanded uncertainty	k =	2	3.14	mg/m^3
Uncertainty corrected to std conds			**12.43**	**mg/m^3**
Expanded uncertainty	**expressed with a level of confidence of 95%**		**12.43**	**mg.m^{-3}**
Expanded uncertainty	**expressed with a level of confidence of 95%**		**9.18**	**% value**

Uncertainty calculation for Gaseous Measurement O2 EN14789 - PG-250 AS0450 SRM

v3.0 Feb-15

SCV 1H

Limit value	N/A	**Cal gas conc**	14.99 **% vol**
Measured concentration	9.32 **% vol**	**Full Scale**	25 **% vol**

Performance characteristics	**Value**			**specification**
Response time	86	seconds		≤200
Logger sampling interval	60	seconds		
Measurement period	61	minutes		
Number of readings in measurement	61			
Repeatability at zero	0.03	% range		≤±0.2 % range
Repeatability at span level	0.03	% range		≤±0.4 % range
Deviation from linearity(lack of fit)	-0.05	% vol		<0.3 % vol
Zero drift	0.11	% vol		<5% span value
Span drift	0.25	% vol		<5% span value
volume or pressure flow dependence	0.08	% range		<1% range
atmospheric pressure dependence	0.91	% full scale /kPa		≤±1.5 % range/kPa
ambient temperature dependence	0.19	% vol/10K		≤±0.3 % vol/10K
Cross Sensitivity	0.2	% vol		≤±0.2 % vol
dependence on voltage	0.05	% vol/10V		≤±0.1% vol/10V
losses in the line (leak)	0	% value		≤± 2% of value
Uncertainty of calibration gas	1	% value		≤± 2% of value

Effect of drift
0.27 % vol

	ranges min	max	value at calib	
flow	0.4	0.4	0.4	l/min
pressure	101.0	102	101	kPa
temp	280	285	280	K
Voltage	110	110	110	V

Performance characteristic			**Uncertainty**		**Value of uncertainty quantity**		**% vol**
Standard deviation of repeatability at zero			u_{r0}		for mean		use rep at span
Standard deviation of repeatability at span level			u_{rs}		for mean		0.00
Lack of fit			u_{flt}				-0.03
Drift			u_{0dr}				0.15
volume or pressure flow dependence			u_{spres}				0.00
atmospheric pressure dependence			u_{apres}				0.13
ambient temperature dependence			u_{temp}				0.05
Cross Sensitivity			u_{interf}				0.11
Dependence on voltage			u_{volt}				0.00
losses in the line (leak)			u_{leak}				0.00
Uncertainty of calibration gas			u_{cal}				0.05

Measurement uncertainty				
Combined uncertainty			0.24	% vol
Expanded uncertainty	k =	2	0.49	% vol
Expanded uncertainty	**expressed with a level of confidence of 95%**		**0.49 % vol**	
Expanded uncertainty	**expressed with a level of confidence of 95%**		**5.23 % value**	

Requirement in standard is for uncertainty to be < 6% of value (dry)

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 SCV 1H

Constants

Gas constant	8.314	J/(K.mol)

Velocity meas. during calibration	7.993	m/s
Air density meas. during calibration	1.215	kg/m³
DP meas. during calibration	57.32	Pa
Uncertainty of velocity meas. at calibration	1.1	%
Uncertainty of air density meas. at calibration	0.075	%
Uncertainty of DP meas. at calibration	0.67	%
Pitot coefficient, K	0.819	-
Expanded uncertainty (95%, k=2) as % of value	2.6	%
Expanded uncertainty (95%, k=2)	0.02	

Characteristics of pressure sensor used for Delta P		
Enter uncertainties as (95%,k=2) where relevant		
Repeatability of Delta P transducer	0.05	% of value
Range of Delta P transducer	2500	Pa
Resolution of Delta P transducer	0.098	Pa
Drift of Delta P transducer	0.1	% of range between calibrations
Lack of fit of measurement system	0.1	% of range
Unertainty in Delta P transducer	0.035	Pa
Enter uncertainties as (95%,k=2) where relevant		
Uncertainty in temperature readout system	0.2	°C
Uncertainty in atmospheric pressure transducer	173.4	Pa
Uncertainty in duct area measurement	1.6	%

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	1.72 m2	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 CO, ppm	Dry gas basis CO_2, %	Dry gas basis N_2, %	Dry gas basis O_2, %	dry molecular wt, g/mol	stack molecular wt, g/mol
1	100400	100584.37	184.37	34.31090364					34	21.3	2.47	135	6.8	83.9	9.3	29.46	29.18
2	100400	100584.37	184.37	44.11401896					44	21.3	2.47	135	6.8	83.9	9.3	29.46	29.18
3	100400	100584.37	184.37	44.11401896					44	21.2	2.47	135	6.8	83.9	9.3	29.46	29.18
4	100400	100584.37	184.37	53.91713429					54	21.2	2.47	135	6.8	83.9	9.3	29.46	29.18
5	100400	100584.37	184.37	67.64149574					68	21.1	2.47	135	6.8	83.9	9.3	29.46	29.18
6	100400	100584.37	184.37	63.72024961					64	21	2.47	135	6.8	83.9	9.3	29.46	29.18
7	100400	100584.37	184.37	25.48809985					25	20.9	2.47	135	6.8	83.9	9.3	29.46	29.18
8	100400	100584.37	184.37	48.03526509					48	20.9	2.47	135	6.8	83.9	9.3	29.46	29.18
9	100400	100584.37	184.37	41.17308437					41	20.9	2.47	135	6.8	83.9	9.3	29.46	29.18
10	100400	100584.37	184.37	51.95651122					52	20.8	2.47	135	6.8	83.9	9.3	29.46	29.18
11	100400	100584.37	184.37	59.79900348					60	20.6	2.47	135	6.8	83.9	9.3	29.46	29.18
12	100400	100584.37	184.37	61.75962655					62	20.4	2.47	135	6.8	83.9	9.3	29.46	29.18
Mean	100400	100584	184.4	49.7	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	49.7	21.0	2.5	135.0	6.8	83.9	9.3	29.46	29.18

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

Mean density	1.201 kg/m3

$$Velocity = K.\sqrt{\frac{2.\Delta_p}{\rho}}$$

Mean velocity	7.45 m/sec	
Standard uncertainty of velocity	0.10 m/sec	1.4 % of value
Expanded uncertainty in velocity	0.20 m/sec	2.7 % of value

	Circular duct
Flow rate	46135 m^3/hour
Volume flow rate expanded uncertainty	2086 m^3/hour
Volume flow rate expanded uncertainty	4.5 % of value

SCV 2A Uncertainty Calculations

Uncertainty calculation for Gaseous Measurement NOx EN14792 - PG-250 (AS0450)- SRM Version

v3.6 Feb-15
SCV 2A

Limit value	107	mg/m^3 (corrected) NOx	**Cal gas conc**	306.51	mg.m^{-3} (NO_2)
Measured concentration	33.43	mg/m3 (101.3kPa, 273K)	**Full Scale**	513.25	mg/m^3 (NO_2)
Measured concentration	49.37	mg/m^3 (Corrected)			

NO/NO2 ratio	100.00

Gas	NO	
Full Scale	250	ppm
Cal gas conc	149.3	ppm
Conversion	2.053	

Correction for reference conditions

		O2, %	Moisture, %	Pressure, KPa	Temperature, K
	ref	3.00	0.00	101.30	273.00
	measured	8.81	0.00	101.30	273.00
	Uncert	0.46	1.00	0.00	0.00
Factors		1.48	1.00	1.00	1.00
Uncertainty in factor		0.06	0.01	0.00	0.00
Correction Factor		**1.48**	uf	**0.06**	

Effect of drift
0.52 mg/m3

Performance characteristics	**Value**			**specification**
Response time	165	seconds		≤200
Logger sampling interval	60	seconds		
Measurement period	61	minutes		
Number of readings in measurement	61			
Repeatability at zero	0.03	% full scale		≤±1 % range
Repeatability at span level	0.09	% full scale		≤±2 % range
Deviation from linearity(lack of fit)	0.56	% full scale		≤±2 % range
Zero drift	0.21	mg/m3		<5% span value
Span drift	2.88	mg/m3		<5% span value
volume or pressure flow dependence	0.36	% full scale		
atmospheric pressure dependence	-0.16	% full scale /2kPa		≤±3 % range/2kPa
ambient temperature dependence	-2.43	% full scale/10K		≤±3 % range/10K
Cross sensitivity	0.5	% full scale		<4 % range
dependence on voltage	-0.1	% full scale/10V		≤±2% range/10V
losses in the line (leak)	0	% value		≤± 2% of value
Converter efficiency	96.1	%		≥95%
Uncertainty of calibration gas	1	% value		≤± 2% of value

	ranges min	max	value at calib	
flow	0.4	0.4	0.4	l/min
pressure	101.0	102	101.2	kPa
temp	281	286	281	K
Voltage	110	110	110	V

Performance characteristic			**Uncertainty**		**Value of uncertainty quantity**		**mg/m3**
Standard deviation of repeatability at zero			u_{r0}		for mean		use rep at span
Standard deviation of repeatability at span level			u_{rs}		for mean		0.06
Lack of fit			u_{fit}				1.66
Drift			u_{0dr}				0.30
volume or pressure flow dependence			u_{spres}				0.00
atmospheric pressure dependence			u_{apres}				-0.17
ambient temperature dependence			u_{temp}				-3.60
Cross sensitivity			u_{interf}				1.48
Dependence on voltage			u_{volt}				0.00
losses in the line (leak)			u_{leak}				0.00
Uncertainty of calibration gas			u_{cal}				0.19
converter efficiency			u_{conv}				0.75
Uncertainty in factor			uf				1.88

Measurement uncertainty				
Combined uncertainty			4.32	mg/m^3
Expanded uncertainty	k =	2	8.63	mg/m^3
Uncertainty corrected to std conds			**13.30**	**mg/m^3**
Expanded uncertainty	**expressed with a level of confidence of 95%**		**13.30 mg.m^{-3}**	
Expanded uncertainty	**expressed with a level of confidence of 95%**		**26.94 % value**	
Expanded uncertainty	**expressed with a level of confidence of 95%**		**8.07 % ELV**	

Requirement in standard is for uncertainty to be < 10% of ELV (dry before O_2 correction)

Uncertainty calculation for Gaseous Measurement CO EN15058 - PG-250 AS0450 - SRM Version

v4.1 Feb-15
SCV 2A

Limit value	N/A	mg/m^3 (corrected)	**Cal gas conc**	191.38	mg.m^{-3}
Measured concentration	86.22	mg/m3 (101.3kPa, 273K)	**Full Scale**	250.00	mg/m^3
Measured concentration	127.36	mg/m^3 (Corrected)			

Gas	CO	
Full Scale	200	ppm
Cal gas conc	153.1	ppm
Conversion	1.25	

Correction for reference conditions					
		O2, %	**Moisture, %**	**Pressure, KPa**	**Temperature, K**
	ref	3	0.00	101.30	273.00
	measured	8.81	0.00	101.30	273.00
	Uncert	0.46	1.00	0.00	0.00
Factors		1.48	1.00	1.00	1.00
Uncertainty in factor		0.06	0.01	0.00	0.00
Correction Factor		**1.48**	uf	**0.06**	

Effect of drift
0.00 mg/m3

Performance characteristics	**Value**			**specification**
Response time	76	seconds		≤200
Logger sampling interval	60	seconds		
Measurement period	61	minutes		
Number of readings in measurement	61			
Repeatability at zero	0.09	% full scale		≤±1 % range
Repeatability at span level	0.08	% full scale		≤±2 % range
Deviation from linearity(lack of fit)	0.71	% full scale		≤±2 % range
Zero drift	0	mg/m3		<5% span value
Span drift	0	mg/m3		<5% span value
volume or pressure flow dependence	-0.27	% full scale		
atmospheric pressure dependence	0.09	% full scale /2kPa		≤±3 % range/2kPa
ambient temperature dependence	1.48	% full scale/10K		≤±3 % range/10K
Cross sensitivity	0.1	% full scale		<4 % range
dependence on voltage	0.33	% full scale/10V		≤±2% range/10V
losses in the line (leak)	0	% value		≤± 2% of value
Uncertainty of calibration gas	1	% value		≤± 2% of value

	ranges min	max	value at calib	
flow	0.4	0.4	0.4	l/min
pressure	101.0	102	101.2	kPa
temp	281	286	281	K
Voltage	110	110	110	V

Performance characteristic		**Uncertainty**	**Value of uncertainty quantity**		**mg/m3**
Standard deviation of repeatability at zero		u_{r0}	for mean		use rep at span
Standard deviation of repeatability at span level		u_{rs}	for mean		0.03
Lack of fit		u_{fit}			1.02
Drift		u_{0dr}			0.00
volume or pressure flow dependence		u_{vpres}			0.00
atmospheric pressure dependence		u_{apres}			0.05
ambient temperature dependence		u_{temp}			1.07
Cross sensitivity		u_{interf}			0.12
Dependence on voltage		u_{volt}			0.00
losses in the line (leak)		u_{leak}			0.00
Uncertainty of calibration gas		u_{cal}			0.50
Uncertainty in factor		uf			4.86

Measurement uncertainty				
Combined uncertainty			1.57	mg/m^3
Expanded uncertainty	k =	2	3.13	mg/m^3
Uncertainty corrected to std conds			**10.77**	**mg/m^3**
Expanded uncertainty	**expressed with a level of confidence of 95%**		**10.77**	**mg.m^{-3}**
Expanded uncertainty	**expressed with a level of confidence of 95%**		**8.45**	**% value**

Uncertainty calculation for Gaseous Measurement O2 EN14789 - PG-250 AS0450 SRM

v3.0 Feb-15

SCV 2A

Limit value	N/A	**Cal gas conc**	14.93 **% vol**
Measured concentration	8.81 **% vol**	**Full Scale**	25 **% vol**

Performance characteristics	**Value**			**specification**
Response time	85	seconds		≤200
Logger sampling interval	60	seconds		
Measurement period	61	minutes		
Number of readings in measurement	61			
Repeatability at zero	0.03	% range		≤±0.2 % range
Repeatability at span level	0.03	% range		≤±0.4 % range
Deviation from linearity(lack of fit)	-0.05	% vol		<0.3 % vol
Zero drift	0.12	% vol		<5% span value
Span drift	0.26	% vol		<5% span value
volume or pressure flow dependence	0.08	% range		<1% range
atmospheric pressure dependence	0.91	% full scale /kPa		≤±1.5 % range/kPa
ambient temperature dependence	0.19	% vol/10K		≤±0.3 % vol/10K
Cross Sensitivity	0.2	% vol		≤±0.2 % vol
dependence on voltage	0.05	% vol/10V		≤±0.1% vol/10V
losses in the line (leak)	0	% value		≤± 2% of value
Uncertainty of calibration gas	1	% value		≤± 2% of value

Effect of drift
0.27 % vol

	ranges min	max	value at calib	
flow	0.4	0.4	0.4	l/min
pressure	101.0	102	101.2	kPa
temp	281	286	281	K
Voltage	110	110	110	V

Performance characteristic			**Uncertainty**		**Value of uncertainty quantity**		**% vol**
Standard deviation of repeatability at zero			u_{r0}		for mean		use rep at span
Standard deviation of repeatability at span level			u_{rs}		for mean		0.00
Lack of fit			u_{fit}				-0.03
Drift			u_{0dr}				0.16
volume or pressure flow dependence			u_{spres}				0.00
atmospheric pressure dependence			u_{apres}				0.09
ambient temperature dependence			u_{temp}				0.05
Cross Sensitivity			u_{interf}				0.11
Dependence on voltage			u_{volt}				0.00
losses in the line (leak)			u_{leak}				0.00
Uncertainty of calibration gas			u_{cal}				0.05

Measurement uncertainty				
Combined uncertainty			0.23	% vol
Expanded uncertainty	k =	2	0.46	% vol
Expanded uncertainty	**expressed with a level of confidence of 95%**		**0.46 % vol**	
Expanded uncertainty	**expressed with a level of confidence of 95%**		**5.19 % value**	

Requirement in standard is for uncertainty to be < 6% of value (dry)

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 SCV 2A

Constants

Gas constant	8.314	J/(K.mol)
Velocity meas. during calibration	7.993	m/s
Air density meas. during calibration	1.215	kg/m³
DP meas. during calibration	57.32	Pa
Uncertainty of velocity meas. at calibration	1.1	%
Uncertainty of air density meas. at calibration	0.075	%
Uncertainty of DP meas. at calibration	0.67	%
Pitot coefficient, K	0.819	-
Expanded uncertainty (95%, k=2) as % of value	2.6	%
Expanded uncertainty (95%, k=2)	0.02	

Characteristics of pressure sensor used for Delta P

Enter uncertainties as (95%,k=2) where relevant

Repeatability of Delta P transducer	0.05	% of value
Range of Delta P transducer	2500	Pa
Resolution of Delta P transducer	0.098	Pa
Drift of Delta P transducer	0.1	% of range between calibrations
Lack of fit of measurement system	0.1	% of range
Unertainty in Delta P transducer	0.035	Pa

Enter uncertainties as (95%,k=2) where relevant

Uncertainty in temperature readout system	0.2	°C
Uncertainty in atmospheric pressure transducer	173.4	Pa
Uncertainty in duct area measurement	1.6	%

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	1.72	m2	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: CO, ppm	Dry gas basis: CO_2, %	Dry gas basis: N_2, %	Dry gas basis: O_2, %	dry molecular wt, g/mol	stack molecular wt, g/mol
1	101800	101984.37	184.37	34.31090364					34	21.1	2.4	127	7	84.2	8.8	29.47	29.20
2	101800	101984.37	184.37	44.11401896					44	21.1	2.4	127	7	84.2	8.8	29.47	29.20
3	101800	101984.37	184.37	44.11401896					44	21	2.4	127	7	84.2	8.8	29.47	29.20
4	101800	101984.37	184.37	53.91713429					54	21	2.4	127	7	84.2	8.8	29.47	29.20
5	101800	101984.37	184.37	67.64149574					68	21	2.4	127	7	84.2	8.8	29.47	29.20
6	101800	101984.37	184.37	63.72024961					64	20.8	2.4	127	7	84.2	8.8	29.47	29.20
7	101800	101984.37	184.37	25.48809985					25	20.9	2.4	127	7	84.2	8.8	29.47	29.20
8	101800	101984.37	184.37	48.03526509					48	20	2.4	127	7	84.2	8.8	29.47	29.20
9	101800	101984.37	184.37	41.17308437					41	20.9	2.4	127	7	84.2	8.8	29.47	29.20
10	101800	101984.37	184.37	51.95651122					52	20.9	2.4	127	7	84.2	8.8	29.47	29.20
11	101800	101984.37	184.37	59.79900348					60	20.8	2.4	127	7	84.2	8.8	29.47	29.20
12	101800	101984.37	184.37	61.75962655					62	20.6	2.4	127	7	84.2	8.8	29.47	29.20
Mean	101800	101984	184.4	49.7	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	49.7	20.8	2.4	127.0	7.0	84.2	8.8	29.47	29.20

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

Mean density	1.219 kg/m3

$$Velocity = K.\sqrt{\frac{2.\Delta_P}{\rho}}$$

Mean velocity	7.39 m/sec	
Standard uncertainty of velocity	0.10 m/sec	1.4 % of value
Expanded uncertainty in velocity	0.20 m/sec	2.7 % of value

	Circular duct
Flow rate	45792 m^3/hour
Volume flow rate expanded uncertainty	2070 m^3/hour
Volume flow rate expanded uncertainty	4.5 % of value

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:

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

$$DH = K \times Dp$$

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.

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

Where the Constant = 0.6071 Metric

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

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

Where Km =Orifice meter coefficient

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

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

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

Oxygen Concentration Correction C_{oxy} to Particulate concentration

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

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

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

Mass Emission Rate M_R

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

IsoKinicity

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

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
Vs = Velocity of stack gas m/s
C_M = measured concentration of particulate matter (mg/m^3)
T_m = average temperature at dry gas meter (^oC)
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 (^oC)
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)