

EMISSIONS MONITORING SURVEY

Prepared for:
Engie
Barry Cogeneration Plant
Barry Silicon Based Manufacturing Installation
Wimbourne Road
Barry
CF63 3DH

Permit Number	: EPR/JP3632ZH
Variation Number	: EPR/JP3632ZH/V002
Installation	: MP Boilers – Dow Corning CHP
Visit Details	: A4 & A5 Annual Compliance
Job Number	: P3276
Report Number	: R001
Report Issue Date	: 11 th September 2017
Survey Dates	: 24 th August & 7 th September 2017

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Report Issue:		FINAL	
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		MCERTS No:	MM 06 775
		Signature:	
Date:	08/09/2017	Date:	11/09/2017

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MCERTS requirements mean that comparison of results with emissions limit values is not permitted within this report.

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PART 1 - EXECUTIVE SUMMARY

1 Monitoring Objectives

Environmental Compliance Ltd (ECL) was commissioned by **Engie** to undertake an emission monitoring survey at their **Dow Corning CHP Plant**. This report presents the findings of the study.

The monitoring at this installation was carried out in accordance with our quotation reference **DHFB/P3276/Q001**, for compliance check monitoring of emissions to air. The substances requested for monitoring at each emissions point are listed below:

Substances to be monitored	Emission Point Identification	
	A4	A5
Oxides of Nitrogen (as NO ₂)	● U	● U
Carbon Monoxide	● U	● U
Oxygen	● U	● U

● Denotes the substances to be monitored.

U Denotes UKAS accreditation is held for monitoring that substance, but does not mean that it has been claimed which will depend on whether the testing could be completed in accordance with the Standard Reference Method.

Special Requirements: *"Under normal operating conditions."*

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1.1 Monitoring Results

Emission Point Reference	Substance to be Monitored	Emission Limit Value	Periodic Monitoring Result	Units	Uncertainty %	Reference Conditions 273 K, 101.3 kPa	Date of Sampling	Start and End Times	Monitoring Method Reference	Accreditation for use of Method	Tick if non-conforming test (see Sections 2 & 5)	Operating Status
A4	Oxides of Nitrogen (as NO ₂)	135	95.08	mg/m ³	4	Dry Gas, 3% Oxygen	24/08/2017	14:30 – 15:29	BS EN 14792: 2017	UKAS / MCERTS		Normal
	Carbon Monoxide	200	1.17	mg/m ³	6				BS EN 15058: 2017	UKAS / MCERTS		
	Oxygen	...	9.45	%	3	Dry Gas			BS EN 14789: 2017	UKAS / MCERTS		

Emission Point Reference	Substance to be Monitored	Emission Limit Value	Periodic Monitoring Result	Units	Uncertainty %	Reference Conditions 273 K, 101.3 kPa	Date of Sampling	Start and End Times	Monitoring Method Reference	Accreditation for use of Method	Tick if non-conforming test (see Sections 2 & 5)	Operating Status
A5	Oxides of Nitrogen (as NO ₂)	135	97.97	mg/m ³	3	Dry Gas, 3% Oxygen	07/09/2017	10:48 – 11:47	BS EN 14792: 2017	UKAS / MCERTS		Normal
	Carbon Monoxide	200	2.15	mg/m ³	3				BS EN 15058: 2017	UKAS / MCERTS		
	Oxygen	...	5.76	%	1	Dry Gas			BS EN 14789: 2017	UKAS / MCERTS		

Notes

The uncertainty figures presented in Table 1.1 for NO_x, CO &, O₂ are “measurement uncertainty” figures, which do not take into account the variability of the measured sample values. The “uncertainty of measurement results” figures, which do include this contribution, are presented in the appendices of the report for these determinands.

Emission Limit Value
 Periodic Monitoring Result
 Uncertainty
 Reference Conditions
 Monitoring Method Reference
 Accreditation for use of Method
 Operating Status

The emission limit value is that stated in the permit and will be expressed as a concentration or a mass emission.
 The result given is expressed in the same terms and units as the emission limit value.
 The uncertainty associated with the quoted result is at the 95% confidence interval. The Uncertainty results **DO NOT** take into account the effect of the sample location limitations.
 All results are expressed at 273 K and 101.3kPa. The oxygen and moisture corrections are stated.
 The method stated is in accordance with the Environment Agency Technical Guidance Note M2, or other method approved by the Environment Agency.
The details indicate the accreditation for the use of the complete monitoring method, e.g. MCERTs, UKAS. If use of the method is not accredited " NA" is stated.
 The details indicate the feedstock and the loading rate of the plant during monitoring.
 Chemical Analysis on sample reagents was performed by an External Laboratory as detailed in Section 4
 UKAS Accreditation Held but UKAS Accreditation cannot be claimed for the test as sampling did not comply with the Standard Reference Method (SRM), see section 2 & 5
Method is NOT UKAS Accredited.

NU
 NA

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1.2 Operating Information

Emission Point Reference	Process Type	Process Duration	Fuel	Feedstock	Abatement	Load	Comparison of Operator CEMS and Periodic Monitoring Results					
							Parameter	Date	Time	CEMS Results	Periodic Monitoring Results	Units
A4	Continuous	NA	Gas	NA	None	Low fire	...	...	...	NP	...	...
A5	Continuous	NA	Gas	NA	None	20% Fire	...	...	...	NP	...	...

Notes:

Process Type
 Process Duration
 Fuel
 Feedstock
 Abatement
 Load
 CEMS Data

State whether the process is a continuous or batch process.
 If a batch process, state the duration, frequency and details of the portion of the batch sampled. If continuous state "NA"
 If applicable, state the fuel type If not applicable state "NA"
 State the feedstock type
 State the type and whether operational during monitoring. If not applicable state "NA"
 State the normal load, throughput or rating of the plant
 Enter this data for each CEM installed if it has been provided by operator otherwise state "NP" (NOT PROVIDED)

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2 Monitoring Deviations

The objective of the survey was to measure the concentrations of pollutants from the processes / locations as detailed in Section 1. This survey meets the requirements of the site's **PPC Permit Number: EPR/JP3632ZH** where UKAS and MCERTS accreditation has and could be claimed for the testing in the monitoring results table.

There were no modifications to the sampling procedures (TPDs) listed in Section 4.

There were no substance deviations from the original and agreed emissions monitoring schedule.

There were no non-conforming tests.

Homogeneity tests have not been completed for pollutants at the following locations:

- A4 – Not applicable to this location as the duct area is <1m² and not requested by client.
- A5 – Not applicable to this location as the duct area is <1m² and not requested by client.

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PART 2 – SUPPORTING INFORMATION

3 SAMPLING STAFF DETAILS

Site Sampling Team

Names of Site Team	Dates on Site	MCERTS No.	LEVEL	Technical Endorsements
Sam Brookes	24 th August & 7 th September 2017	MM 06 775	2	TE1, TE2, TE3, TE4
Ben Jones	7 th September 2017	MM 16 1401	1	...

Report Reviewer

Name	MCERTS No.	LEVEL	Technical Endorsements
Sam Brookes	MM 06 775	2	TE1, TE2, TE3, TE4

Technical Endorsement Key: -

TE1 – Isokinetic Particulates, Temperature & Velocity Profiles, Oxygen.

TE2 – Isokinetic Extractive Pollutants: - Metals, Dioxin & Furans, PAHs, PCBs, HCl, HF.

TE3 – Non-Isokinetic Extractive Pollutants: - Speciated VOCs, HF, HCl, Cyanide.

TE4 – Continuous Analysers (Combustion Gases): - TVOC, CO, NO_x, SO₂.

4 SAMPLING PROTOCOLS / METHODOLOGIES

Any required modifications to the Technical Procedure Documents (TPDs) specified below will be detailed in section 2 of this report.

Stand alone velocity measurements and those made to support isokinetic sampling are conducted using BS EN 16911-1:2013 & MID.

Combustion Gases (NO_x, CO & O₂)

Measurements of combustion gases were carried out using an MCERTS Certified **Horiba PG 350** stack gas analyser. Continuous monitoring of emissions was undertaken over each test period recording minute averaged data (one measurement every 60 seconds). The measurement techniques for each determinand are as follows:

<u>Determinand</u>	<u>Technique</u>	<u>SRM</u>
• NO _x	Chemiluminescence	BS EN 14792: 2017
• CO	Non-dispersive infrared	BS EN 15058: 2017
• O ₂	Paramagnetic Sensor	BS EN 14789: 2017

The analyser was set up with reference to the manufacturer's operator handbook and the in-house technical procedure **ECL/TPD/033d**. The analyser was calibrated on site using certified gases which are traceable to ISO 17025 (with uncertainty < 2%). Zero measurements were performed using Nitrogen. The analyser was calibrated directly into the sample inlet and then checked through the entire sampling system (including sampling probe, heated & unheated gas transport lines and gas drying/ conditioning system).

Data is presented graphically in the Figures Section, and the minute averaged data is given in the Tables Section.

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5 SAMPLE POINT DESCRIPTIONS

The homogeneity test is applicable to combustion processes. This includes but is not restricted to, those regulated under the Waste Incineration Directive (**WID**) and the Large Combustion Plant Directive (**LCPD**).

Homogeneity testing has not been completed at these locations in accordance with the mandatory requirements of the regulatory authority.

The test is not usually required for stacks with sampling plane areas of < 1m² (below 1.13m in diameter for circular ducts).

The sample locations that were monitored are detailed below: -

A4 & A5

The sampling platform does not currently meet the requirements detailed in *Technical Guidance Note (Monitoring) M1" Sampling requirements for stack-emission monitoring"* Environment Agency, and BS EN 13284-1 due to the small platform dimensions. However, the platform is suitable for the sampling of combustion gases.

Stack diameter is 1.08m.

The sample platform is approximately 1m in width, measured from the wall of the common flue wind shield, at a height of approximately 14m.

Two sample ports are located on each stack at 90 degrees to each other and are located on the same plane. Only a single port is available for sampling on each stack due to the placement of the AMS units on the other available port.

The sample ports are located at a height of approximately 1.5m from the working sample platform.

Access to the sample platform was attained by means of fixed hooped ladders accessed from the base of the stack.

The Uncertainty of the reported concentrations for these pollutant results DOES NOT take into account the effect of non-conformities or sample location limitations.

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EQUIPMENT IDs
(Pre-site checklist from SSP)

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PRE-SITE EQUIPMENT CHECKLIST/ EQUIPMENT USED

(Completed before departure to site and when on site in full)

Equipment	Equip. Type	ID No:	ID No:	ID No:	ID No:	ID No:	ID No:	ID No:	ID No:
MST console/pump	E001								
MST Nozzle set									
MST "S" Type Pitot									
MST Probe									
MST Hot Box									
MST Impinger Arm									
Barometer		352							
Site Balance									
Site Check weights									
Horiba	E002	1065							
Heated Probe / Filter		920							
Chiller		970							
Sonimix / MFC		752	754						
Heated Line		354	355	854	855				
FID	E003								
Heated Line									
Heated Probe / Filter									
Testo	E004								
FTIR	E005								
Heated Probe / Filter									
Heated Line									
Stackmite	E006								
"L" Type Pitot									
Digital Manometer									
Stack Thermocouple									
Thermocouple Reader									
Nozzle Set									
Workhorse Pumps	E007								
Low Flow Pumps									

Quantity of Ice Required / Used for Survey	N/A	Bags (2kg bags)
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FIGURES

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Figure 1

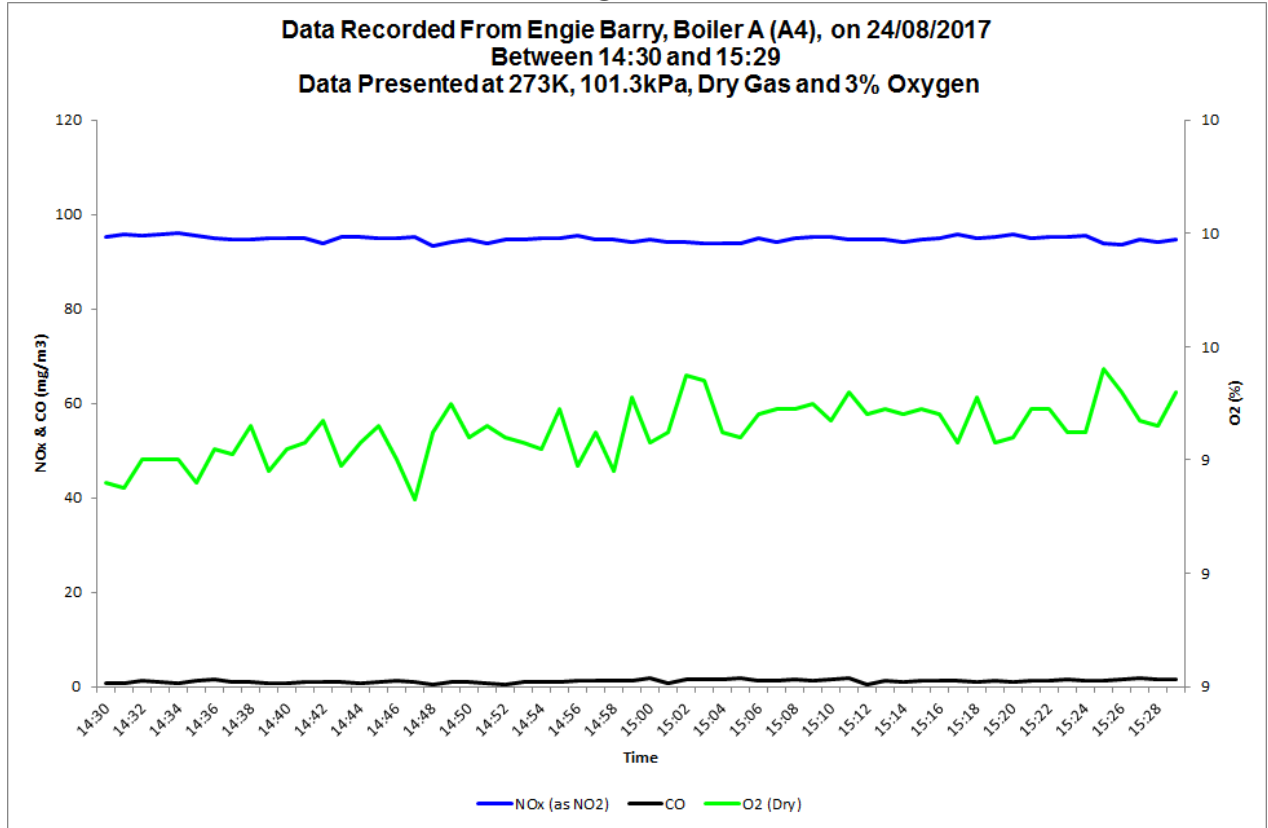
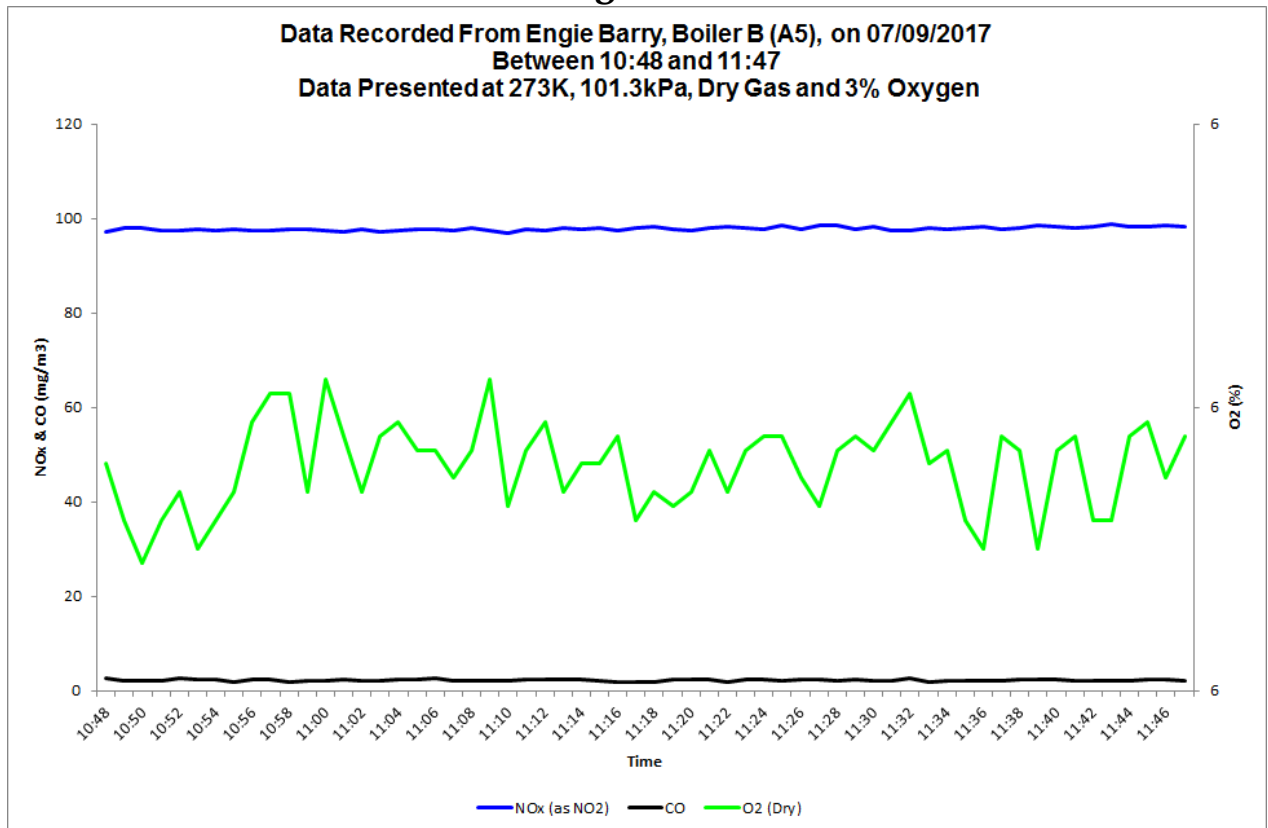


Figure 2



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TABLES

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Table 1 – NO_x, CO & O₂
Data Recorded from A4 – MP Boiler
Sample Period: 14:30 – 15:29 on the 24th August 2017

Volumetric Flowrate (Reference Conditions) = **Not Measured**

	Average	Emission Rate
	mg/m ³	Kg/hr
Oxides of Nitrogen (as NO ₂) *	95.08	...
Carbon Monoxide *	1.17	...
Oxygen (%)	9.45	...

* Reference Conditions (273K, 101.3 kPa, 3% Oxygen & Dry Gas)

Table 2 – NO_x, CO & O₂
Data Recorded from A5 – MP Boiler
Sample Period: 10:48 – 11:47 on the 7th September 2017

Volumetric Flowrate (Reference Conditions) = **Not Measured**

	Average	Emission Rate
	mg/m ³	Kg/hr
Oxides of Nitrogen (as NO ₂) *	97.97	...
Carbon Monoxide *	2.15	...
Oxygen (%)	5.76	...

* Reference Conditions (273K, 101.3 kPa, 3% Oxygen & Dry Gas)

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FIELD CALIBRATION

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A4 Field Calibration

Units

Mean Initial Direct Zero
 Mean Confirmation Direct Zero
 Difference in Direct Zero
 Repeatability at Zero
 <2 x Repeatability at Zero?

Mean Pre Test Zero
 % of Measurement Range?
 Detection Limit (LOD)

Actual Applied Span Concentration

Mean Pre Test System Zero
 Difference $\leq \pm 2\%$ of Span Value (5% for SO₂)?

Mean Post Test Zero
 % of Certified Range?
 Zero Drift $\leq \pm 5\%$ of Applied Span?

Mean Pre Test System Span
 Difference $\leq \pm 2\%$ of Span Value (5% for SO₂)?

Mean Post Test System Span
 Span Drift $\leq \pm 5\%$ Span Value?

Horiba PG 350 Measurement Ranges:		
NO as NO ₂	CO	O ₂
512.5	250	25
mg/m ³	mg/m ³	%Vol
Zero Values (Direct)		
0.08	0.20	-0.07
-0.05	-0.22	0.00
0.13	0.42	0.07
4.10	2.50	0.20
YES	YES	YES
Pre Zero Values (System)		
-0.15	-0.09	0.16
-0.03%	-0.04%	0.65%
0.15	0.26	0.20

Applied Span:		
NO	CO	O ₂
256.50	125.48	15.06
Pre Test System Zero Values		
-0.15	-0.09	0.16
0.06%	0.07%	1.07%
Post Zero Values (System)		
-0.08	-0.29	-0.09
-0.02%	-0.12%	-0.37%
0.03%	0.16%	1.68%
Pre Test System Span Values		
257.79	126.25	15.10
0.50%	0.62%	0.27%
Post Test System Span Values		
260.86	122.63	15.00
1.19%	2.87%	0.66%

1.19% 2.87% 1.68%

See Note 3 See Note 2 See Note 3

NOTE 1: Data Invalid! Contact Quality Manager!

NOTE 2: Correct test data for drift!

NOTE 3: No drift correction required.

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A5 Field Calibration

Units

Mean Initial Direct Zero
 Mean Confirmation Direct Zero
 Difference in Direct Zero
 Repeatability at Zero
 <2 x Repeatability at Zero?

Mean Pre Test Zero
 % of Measurement Range?
 Detection Limit (LOD)

Actual Applied Span Concentration

Mean Pre Test System Zero
 Difference $\leq \pm 2\%$ of Span Value (5% for SO₂)?

Mean Post Test Zero
 % of Certified Range?
 Zero Drift $\leq \pm 5\%$ of Applied Span?

Mean Pre Test System Span
 Difference $\leq \pm 2\%$ of Span Value (5% for SO₂)?

Mean Post Test System Span
 Span Drift $\leq \pm 5\%$ Span Value?

Horiba PG 350 Measurement Ranges:		
NO as NO ₂	CO	O ₂
512.5	250	25
mg/m ³	mg/m ³	%Vol
Zero Values (Direct)		
0.05	-0.04	-0.01
0.06	0.20	-0.08
0.01	0.25	0.07
4.10	2.50	0.20
YES	YES	YES
Pre Zero Values (System)		
0.18	0.03	-0.02
0.03%	0.01%	-0.09%
0.15	0.47	0.20

Applied Span:		
NO	CO	O ₂
256.95	125.05	14.89
Pre Test System Zero Values		
0.18	0.03	-0.02
0.07%	0.02%	0.16%
Post Zero Values (System)		
0.11	0.40	-0.17
0.02%	0.16%	-0.67%
0.03%	0.30%	0.97%
Pre Test System Span Values		
255.23	123.78	14.90
0.67%	1.01%	0.07%
Post Test System Span Values		
253.69	124.71	14.90
0.60%	0.75%	0.00%

0.60% 0.75% 0.97%

See Note 3 See Note 3 See Note 3

NOTE 1: Data Invalid! Contact Quality Manager!

NOTE 2: Correct test data for drift!

NOTE 3: No drift correction required.

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UNCERTAINTY CALCULATIONS

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A4 Measurement Uncertainty

Measurement Uncertainty Calculations Part 1

Horiba PG 350 Performance Characteristics	Standard Uncertainty (% of Range)	Distributioun	Minimum Certified Range (R)		
			NO 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Lack of fit ⁽¹⁾	u_{lof}	Rectangular (Divisor = $\sqrt{3}$)	0.75	0.61	0.10
Span drift ⁽²⁾	$u_{d,s}$	Rectangular (Divisor = $\sqrt{3}$)	0.094	0.056	0.0057
Repeatability Standard Deviation (span) ⁽³⁾	u_r	Normal (Divisor = 1)	1.42	2.60	0.21
Losses / leakage in the sample system ⁽⁴⁾	u_{loss}	Rectangular (Divisor = $\sqrt{3}$)	0.96	1.03	0.16
Temperature dependant span drift ⁽⁵⁾	u_t	Rectangular (Divisor = $\sqrt{3}$)	1.80	2.00	0.15
Interferents ⁽¹⁾	u_i	Rectangular (Divisor = $\sqrt{3}$)	0.52	0.87	
Uncertainty of Reference Gas ⁽⁶⁾	u_{ref}	Rectangular (Divisor = $\sqrt{3}$)	4.44	2.17	0.15
Effect of Voltage Fluctuation ⁽⁷⁾	u_v	Rectangular (Divisor = $\sqrt{3}$)	0.40	0.50	0.020
Effect of Sample Gas Flow/ Pressure ⁽⁷⁾	u_{sg}	Rectangular (Divisor = $\sqrt{3}$)	0.10	0.10	0.10

Note:

$$\text{when } \left(x_{i,\max} - x_{i,\text{adj}} \right) = \left(x_{i,\min} - x_{i,\text{adj}} \right), \text{ then } u(x_i) = \frac{\Delta x_i}{\sqrt{3}}$$

- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range as maximum drift per 24hr period
- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range per one degree centigrade
- Expressed as standard uncertainty in units of measurement i.e. mg/m³ / %Vol inc additional uncertainty of 2% for gas blending
- Expressed as a percentage of the certified range

Measurement Uncertainty Calculations Part 2

Horiba PG 350 Performance Characteristics	Uncertainty	Value of Standard Uncertainty	NO 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Lack of fit	u_{lof}	$u(x_i) = \frac{u_{lof} \times R_i}{\sqrt{3}} =$	0.58	0.26	0.014
Span drift	$u_{d,s}$	$u(x_i) = \frac{u_{d,s} \times R_i}{\sqrt{3}} =$	0.073	0.024	0.00082
Repeatability Standard Deviation (span)	u_r	$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} =$	1.42	2.60	0.21
Losses / leakage in the sample system	u_{loss}	$u(x_i) = \frac{u_{loss} \times R_i}{\sqrt{3}} =$	0.75	0.45	0.023
Temperature dependant span drift	u_t	$u(x_i) = \frac{u_t}{100} \times R_i \times \sqrt{\frac{(x_{i,\max} - x_{i,\text{adj}})^2 + (x_{i,\min} - x_{i,\text{adj}})(x_{i,\max} - x_{i,\text{adj}}) + (x_{i,\min} - x_{i,\text{adj}})^2}{3}} =$	3.55	2.21	0.055
Interferents	u_i	$u(x_i) = \frac{u_i \times R_i}{\sqrt{3}} =$	0.40	0.38	
Uncertainty of Reference Gas	u_{ref}	$u(x_i) = \frac{u_{ref}}{\sqrt{3}} =$	2.56	1.25	0.087
Effect of Voltage Fluctuation ⁽⁷⁾	u_v	$u(x_i) = \frac{u_v \times R_i}{\sqrt{3}} =$	0.23	0.29	0.012
Effect of Sample Gas Flow / Pressure ⁽⁷⁾	u_{sg}	$u(x_i) = \frac{u_{sg} \times R_i}{\sqrt{3}} =$	0.058	0.058	0.058
Combined Standard Uncertainty			4.72	3.70	0.25
Expanded measurement uncertainty (at 95% confidence)			9.45	7.40	0.49
Applied Span Concentration			256.50	125.48	15.06
Measured Span Concentration, STP Dry Gas			259.33	124.44	15.05
Expanded measurement uncertainty as % of Applied Span			4%	6%	3%

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Permit No : EPR/JP3632ZH
Variation No : EPR/JP3632ZH/V002
Report Ref : P3276 : R001

Installation Name : MP Boilers – Dow Corning CHP
Visit Details : A4 & A5 Annual Compliance
Survey Dates : 24th August & 7th September 2017
Report Issue Date : 11th September 2017

A4 Uncertainty of Measurement

Uncertainty of Measurement Results - Calculations Part 1

Horiba PG 350 Performance Characteristics	Standard Uncertainty (% of Range)	Distribution	Divisor	Minimum Certified Range (R _i)		
				NO 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Lack of fit ⁽¹⁾	u_{lof}	Rectangular	$\sqrt{3}$	0.75	0.61	0.10
Span drift ⁽²⁾	$u_{d,s}$			0.094	0.056	0.0057
Losses / leakage in the sample system ⁽⁴⁾	u_{loss}			0.96	1.03	0.16
Temperature dependant span drift ⁽⁵⁾	u_t			1.80	2.00	0.15

Notes:

For rectangular distributions, $u(x_i) = \frac{u \times R_i}{\sqrt{3}}$

For $u(x_i) = \Delta x_i \sqrt{\frac{(x_{i,max} - x_{i,adj})^2 + (x_{i,min} - x_{i,adj})(x_{i,max} - x_{i,adj}) + (x_{i,min} - x_{i,adj})^2}{3}}$, when $|(x_{i,max} - x_{i,adj})| = |(x_{i,min} - x_{i,adj})|$, then $u(x_i) = \frac{\Delta x_i}{\sqrt{3}}$

Where $u(x_i) = \frac{\sigma}{\sqrt{n}}$ (See note 6 below), $\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$

Horiba PG 350 Performance Characteristics	Uncertainty (Units of final measurement)	Distribution	Divisor	NO 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Lack of fit	u_{lof}	Rectangular	$\sqrt{3}$	0.58	0.26	0.014
Span drift	$u_{d,s}$			0.073	0.024	0.00082
Temperature dependant span drift	u_t			3.25	2.02	0.051
Interferents	u_i			0.40	0.38	

Uncertainty of Measurement Results - Calculations Part 2

Horiba PG 350 Performance Characteristics	Uncertainty (Units of final measurement)	Date & Time	NO 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Losses / leakage in the sample system	u_{loss}	24/08/17 14:30 - 15:29	0.92	0.012	0.015
Standard Error of Measured Value	u_{SE}	24/08/17 14:30 - 15:29	0.049	0.027	0.0065

Effect on Uncertainty Caused by Oxygen

$$u_{Corr_{O_2}} = \frac{20.9\% - O_{2,ref}}{(20.9\% - O_{2,measured}) \times (20.9\% - O_{2,measured})} \times \text{Uncertainty of } O_2 \text{ Measurement} = 0.025$$

$$f_{O_2} = \frac{20.9\% - O_{2,ref}}{20.9\% - O_{2,measured}} = 1.8939 \quad u_{f_{O_2}} = \frac{u_{Corr_{O_2}} \times f_{O_2}}{f_{O_2}} \times 100 = 1.30 \%$$

The effect of oxygen on the overall uncertainties (below) is incorporated using the following equation:-

$$u_{combined} = \sqrt{\sum (u_{f_{O_2}})^2 + (\text{Uncertainty of Measurement of Determinand})^2}$$

Where oxygen or moisture correction is required, uncertainty based on the standard error of the measured peripheral value is converted to units of final measurement using a sensitivity coefficient C,

$$\therefore u(x_i) = C_i u_i \text{ where } C_i = \frac{\partial f}{\partial x_i}$$

Uncertainty of Measurement Results - Calculations Part 3

Horiba PG 350 Uncertainty	Date & Time	NOx (as NO2) 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Measured Concentration	24/08/17 14:30 - 15:29	95.08	1.17	9.45
Expanded Uncertainty as Percentage of Measured Concentration		7%	> 100%	2%

Combined Standard Uncertainty

$$u_c = \sqrt{u_{lof}^2 + u_{d,s}^2 + u_t^2 + u_{loss}^2 + u_i^2 + u_{f_{O_2}}^2 + u_{f_{CO_2}}^2 + u_{f_{H_2O}}^2 + u_{f_{SE}}^2}$$

Expanded uncertainty (at 95% confidence)

$$U_{Exp} = 2 \times u_c$$

- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range as maximum drift per 24hr period
- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range per one degree centigrade
- Where the uncertainty of Moisture is taken as the standard error of the time averaged value used to correct to Dry Conditions
- If no value for uncertainty is presented above, the uncertainty is considered to be > 100%

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Visit Details : A4 & A5 Annual Compliance
Survey Dates : 24th August & 7th September 2017
Report Issue Date : 11th September 2017

A5 Measurement Uncertainty

Measurement Uncertainty Calculations Part 1

Horiba PG 350 Performance Characteristics	Standard Uncertainty (% of Range)	Distributioun	Minimum Certified Range (R _i)		
			NO 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Lack of fit ⁽¹⁾	u_{lof}	Rectangular (Divisor = $\sqrt{3}$)	0.75	0.61	0.10
Span drift ⁽²⁾	$u_{d,s}$	Rectangular (Divisor = $\sqrt{3}$)	0.094	0.056	0.0057
Repeatability Standard Deviation (span) ⁽³⁾	u_r	Normal (Divisor = 1)	0.98	0.70	7.67E-15
Losses / leakage in the sample system ⁽⁴⁾	u_{loss}	Rectangular (Divisor = $\sqrt{3}$)	1.29	1.69	0.040
Temperature dependant span drift ⁽⁵⁾	u_t	Rectangular (Divisor = $\sqrt{3}$)	1.80	2.00	0.15
Interferents ⁽¹⁾	u_i	Rectangular (Divisor = $\sqrt{3}$)	0.52	0.87	
Uncertainty of Reference Gas ⁽⁶⁾	u_{ref}	Rectangular (Divisor = $\sqrt{3}$)	4.45	2.17	0.15
Effect of Voltage Fluctuation ⁽⁷⁾	u_v	Rectangular (Divisor = $\sqrt{3}$)	0.40	0.50	0.020
Effect of Sample Gas Flow/ Pressure ⁽⁷⁾	u_{sg}	Rectangular (Divisor = $\sqrt{3}$)	0.10	0.10	0.10

Note:

$$\text{when } |(x_{i,max} - x_{i,adj})| = |(x_{i,min} - x_{i,adj})|, \text{ then } u(x_i) = \frac{\Delta x_i}{\sqrt{3}}$$

- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range as maximum drift per 24hr period
- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range per one degree centigrade
- Expressed as standard uncertainty in units of measurement i.e. mg/m³ / %Vol inc additional uncertainty of 2% for gas blending
- Expressed as a percentage of the certified range

Measurement Uncertainty Calculations Part 2

Horiba PG 350 Performance Characteristics	Uncertainty	Value of Standard Uncertainty	NO 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Lack of fit	u_{lof}	$u(x_i) = \frac{u_{lof} \times R_i}{\sqrt{3}} =$	0.58	0.26	0.014
Span drift	$u_{d,s}$	$u(x_i) = \frac{u_{d,s} \times R_i}{\sqrt{3}} =$	0.073	0.024	0.00082
Repeatability Standard Deviation (span)	u_r	$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} =$	0.98	0.70	7.67E-15
Losses / leakage in the sample system	u_{loss}	$u(x_i) = \frac{u_{loss} \times R_i}{\sqrt{3}} =$	0.99	0.73	0.0058
Temperature dependant span drift	u_t	$u(x_i) = \frac{u_t}{100} \times R_i \times \sqrt{\frac{(x_{i,max} - x_{i,adj})^2 + (x_{i,min} - x_{i,adj})^2 + (x_{i,max} - x_{i,adj})(x_{i,min} - x_{i,adj})}{3}} =$	1.39	0.87	0.022
Interferents	u_i	$u(x_i) = \frac{u_i \times R_i}{\sqrt{3}} =$	0.40	0.38	
Uncertainty of Reference Gas	u_{ref}	$u(x_i) = \frac{u_{ref}}{\sqrt{3}} =$	2.57	1.25	0.086
Effect of Voltage Fluctuation ⁽⁷⁾	u_v	$u(x_i) = \frac{u_v \times R_i}{\sqrt{3}} =$	0.23	0.29	0.012
Effect of Sample Gas Flow / Pressure ⁽⁷⁾	u_{sg}	$u(x_i) = \frac{u_{sg} \times R_i}{\sqrt{3}} =$	0.058	0.058	0.058
Combined Standard Uncertainty		$u_c = \sqrt{u_{lof}^2 + u_{d,s}^2 + u_r^2 + u_{loss}^2 + u_t^2 + u_i^2 + u_{ref}^2 + u_v^2 + u_{sg}^2} =$	3.32	1.91	0.11
Expanded measurement uncertainty (at 95% confidence)		$U_{EXP} = 2 \times u_c$	6.65	3.82	0.22
Applied Span Concentration			256.95	125.05	14.89
Measured Span Concentration, STP Dry Gas			254.46	124.18	14.90
Expanded measurement uncertainty as % of Applied Span			3%	3%	1%

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A5 Uncertainty of Measurement

Uncertainty of Measurement Results - Calculations Part 1

Horiba PG 350 Performance Characteristics	Standard Uncertainty (% of Range)	Distribution	Divisor	Minimum Certified Range (R _i)		
				NO 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Lack of fit ⁽¹⁾	u_{lof}	Rectangular	$\sqrt{3}$	0.75	0.61	0.10
Span drift ⁽²⁾	$u_{d,s}$			0.094	0.056	0.0057
Losses / leakage in the sample system ⁽⁴⁾	u_{loss}			1.29	1.69	0.040
Temperature dependant span drift ⁽⁵⁾	u_t			1.80	2.00	0.15

Notes:

For rectangular distributions, $u(x_i) = \frac{u \times R_i}{\sqrt{3}}$

For $u(x_i) = \Delta x_i \sqrt{\frac{(x_{i,max} - x_{i,adj})^2 + (x_{i,min} - x_{i,adj})(x_{i,max} - x_{i,adj}) + (x_{i,min} - x_{i,adj})^2}{3}}$, when $|(x_{i,max} - x_{i,adj})| = |(x_{i,min} - x_{i,adj})|$, then $u(x_i) = \frac{\Delta x_i}{\sqrt{3}}$

Where $u(x_i) = \frac{\sigma}{\sqrt{n}}$ (See note 6 below), $\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$

Horiba PG 350 Performance Characteristics	Uncertainty (Units of final measurement)	Distribution	Divisor	NO 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Lack of fit	u_{lof}	Rectangular	$\sqrt{3}$	0.58	0.26	0.014
Span drift	$u_{d,s}$			0.073	0.024	0.00082
Temperature dependant span drift	u_t			1.39	0.87	0.022
Interferents	u_i			0.40	0.38	

Uncertainty of Measurement Results - Calculations Part 2

Horiba PG 350 Performance Characteristics	Uncertainty (Units of final measurement)	Date & Time	NO 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Losses / leakage in the sample system	u_{loss}	07/09/17 10:48 - 11:47	1.26	0.036	0.0023
Standard Error of Measured Value	u_{SE}	07/09/17 10:48 - 11:47	0.046	0.025	0.0040

Effect on Uncertainty Caused by Oxygen

$$u_{Corr_{O_2}} = \frac{20.9\% - O_{2,ref}}{(20.9\% - O_{2,measured}) \times (20.9\% - O_{2,measured})} \times \text{Uncertainty of } O_2 \text{ Measurement} = 0.014$$

$$f_{O_2} = \frac{20.9\% - O_{2,ref}}{20.9\% - O_{2,measured}} = 3.1084 \quad u_{f_{O_2}} = \frac{u_{Corr_{O_2}} \times n_{O_2}}{f_{O_2}} \times 100 = 0.45 \%$$

The effect of oxygen on the overall uncertainties (below) is incorporated using the following equation:-

$$u_{combined} = \sqrt{\sum (u_{f_{O_2}})^2 + (\text{Uncertainty of Measurement of Determinand})^2}$$

Where oxygen or moisture correction is required, uncertainty based on the standard error of the measured peripheral value is converted to units of final measurement using a sensitivity coefficient C,

$$\therefore u(x_i) = C_i u_i \text{ where } C_i = \frac{\partial f}{\partial x_i}$$

Uncertainty of Measurement Results - Calculations Part 3

Horiba PG 350 Uncertainty	Date & Time	NOx (as NO2) 0 - 134 mg/m ³	CO 0 - 75 mg/m ³	O ₂ 0 - 25 %Vol
Measured Concentration	07/09/17 10:48 - 11:47	97.97	2.15	5.76
Expanded Uncertainty as Percentage of Measured Concentration		4%	92%	1%

Combined Standard Uncertainty

$$u_c = \sqrt{u_{lof}^2 + u_{d,s}^2 + u_t^2 + u_{loss}^2 + u_i^2 + u_{f_{O_2}}^2 + u_{f_{H_2O}}^2 + u_{f_{SG}}^2}$$

Expanded uncertainty (at 95% confidence)

$$U_{Exp} = 2 \times u_c$$

- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range as maximum drift per 24hr period
- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range
- Expressed as a percentage of the certified range per one degree centigrade
- Where the uncertainty of Moisture is taken as the standard error of the time averaged value used to correct to Dry Conditions
- If no value for uncertainty is presented above, the uncertainty is considered to be > 100%