

EMISSIONS MONITORING SURVEY

Prepared for:

Bryn Power Limited
Gelliargwellt Farm
Gelligaer
Hengoed
Caerphilly
CF82 8FY

Permit Number	: EPR/AB3092ZE
Variation Number	: ...
Installation	: CHP 1 & 2
Visit Details	: Annual Compliance
Job Number	: P3155
Report Number	: R001
Report Issue Date	: 24th March 2017
Survey Dates	: 9th March 2017

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Report Issue:		FINAL	
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		Signature:	
Date:	24/03/2017	Date:	24/03/2017

This report is not to be used for contractual or engineering purposes unless this approval sheet is signed where indicated by the approver and the report is designated "FINAL".



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Opinions and Interpretation expressed within this report are outside the scope of the UKAS accreditation.

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 **Bryn Power Limited** to undertake an emission monitoring survey at their **Hengoed facility**. This report presents the findings of the study.

The monitoring at this installation was carried out in accordance with our quotation reference **PC/P3155/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	
	A1 CHP1 - Clarke	CHP2 - Edina
Velocity / Flowrate	● U	● U
Oxides of Nitrogen (as NO ₂)	● U	● U
Sulphur Dioxide	● U	● U
Carbon Monoxide	● U	● U
Oxygen	● U	● U
Total Organic Carbon (TVOC)	● 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
A1 CHP1 Clarke	Volumetric Flowrate	...	1.13	m³/sec	5	Stack Conditions	09/03/2017	10:14 – 10:25	BS EN 16911-1	UKAS / MCERTS		Normal - 350KW
	Volumetric Flowrate	...	0.47	m³/sec	10	5% Oxygen & Dry Gas ^{Note 1}				UKAS / MCERTS		
	TVOC as Carbon	1000	1699.02	mgC/m³	3			15:42 – 16:41	BS EN 12619:2013	UKAS / MCERTS		
	Oxides of Nitrogen (as NO ₂)	500	80.52	mg/m³	2				BS EN 14792: 2005	UKAS / MCERTS		
	Carbon Monoxide	1400	1163.39	mg/m³	3				BS EN 15058: 2006	UKAS / MCERTS		
	Carbon Dioxide	...	11.19	%	5				ISO 12039:2001	UKAS / MCERTS		
	Oxygen	...	7.68	%	6				BS EN 14789: 2005	UKAS / MCERTS		
	Sulphur Dioxide ^{\$}	350	115.45	mg/m³	13	15:16 – 16:16		BS EN 14791	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
CHP2 Edina ^{Note 2}	Volumetric Flowrate	...	0.76	m³/sec	9	Stack Conditions	09/03/2017	13:15 – 13:27	BS EN 16911-1	UKAS / MCERTS		Normal - 500KW
	Volumetric Flowrate	...	0.35	m³/sec	14	5% Oxygen & Dry Gas ^{Note 1}				UKAS / MCERTS		
	TVOC as Carbon	1000	996.70	mgC/m³	3			13:09 – 14:08	BS EN 12619:2013	UKAS / MCERTS		
	Oxides of Nitrogen (as NO ₂)	500	499.46	mg/m³	2				BS EN 14792: 2005	UKAS / MCERTS		
	Carbon Monoxide	1400	820.85	mg/m³	3				BS EN 15058: 2006	UKAS / MCERTS		
	Carbon Dioxide	...	11.56	%	5				ISO 12039:2001	UKAS / MCERTS		
	Oxygen	...	7.85	%	6				BS EN 14789: 2005	UKAS / MCERTS		
	Sulphur Dioxide ^{\$}	350	88.15	mg/m³	13	12:59 – 13:59		BS EN 14791	UKAS / MCERTS			

Note 1: 5% oxygen correction used as per Environment Agency Standard Rules document SR2010No15 (Version 3.0) "Anaerobic digestion facility including use of the resultant biogas".

Note 2: CHP2 does not have a permit reference and therefore has no emission limit values (ELVs) but for the purposes of this report the same ELVs as those for permit reference A1 (CHP1) are used.

Further notes are on page 6.

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Notes

The volumetric flowrate shown above is that from the initial pitot traverse.

Any other flow measurements made during isokinetic sampling and / or repeat traverses are shown later in the tables section.

The uncertainty figures presented in Table 1.1 for NO_x, CO, CO₂, O₂ & TVOC 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	The emission limit value is that stated in the permit and will be expressed as a concentration or a mass emission.
Periodic Monitoring Result	The result given is expressed in the same terms and units as the emission limit value.
Uncertainty	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.
Reference Conditions	All results are expressed at 273 K and 101.3kPa. The oxygen and moisture corrections are stated.
Monitoring Method Reference	The method stated is in accordance with the Environment Agency Technical Guidance Note M2, or other method approved by the Environment Agency.
Accreditation for use of Method	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.
Operating Status	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
NU	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
NA	Method is NOT UKAS Accredited.

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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
A1 CHP1 Clarke	Continuous	When required	Biogas	N/A	N/A	350KW	No CEMS					
CHP2 Edina	Continuous	When required	Biogas	N/A	N/A	500KW	No CEMS					

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/AB3092ZE** 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.

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

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

- A1 CHP1 – Clarke – Not applicable to this location as the duct area is < 1m²
- CHP2 – Edina – Not applicable to this location as the duct area is < 1m²

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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	09/03/2017	MM 06 775	2	TE1, TE2, TE3, TE4
Christopher Pickford		MM 14 1301	2	TE1, TE4
Ben Jones		MM 16 1401	Trainee	...

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, NOx, SO2.

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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.

Pressure, Temperature and Velocity

Testing was carried out using a sampling system in accordance with BS EN ISO 16911-1 & MID and In-house technical procedure ECL/TPD/022.

Temperature was recorded using a thermocouple and digital temperature reader.

Velocity and pressure were recorded using an "L" type pitot and digital manometer, data being recorded in Pascals.

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Combustion Gases (NO_x, CO, O₂ & CO₂)

Measurements of combustion gases were carried out using an MCERTS Certified **Horiba PG 250** 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: 2005
• CO	Non-dispersive infrared	BS EN 15058: 2006
• O ₂	Galvanic / Zirconia	BS EN 14789: 2005
• CO ₂	Non-dispersive infrared	ISO 12039

The analyser was set up with reference to the manufacturer's operator handbook and the in-house technical procedure **ECL/TPD/033c**. 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.

Sulphur Dioxide

Testing was carried out non-isokinetically using a Universal Stack Sampling system in accordance with **BS EN 14791** and In-house technical procedure **ECL/TPD/039**. Non-isokinetic sampling can only take place if there are no droplets present in the stack gas.

In this method, the stack gases are filtered to remove particulate matter then the gases are passed through a series of impingers. The first three impingers each contain 140ml of 3% Hydrogen Peroxide (3% H₂O₂). The fourth impinger is left empty and the final impinger contains a measured quantity of silica gel.

The first three impingers containing the 3% Hydrogen Peroxide are analysed for concentrations of Sulphur Dioxide by IC (Ion Chromatography).

Scientific Analysis Laboratories Ltd (SAL) who are situated in Manchester carried out the analysis of the samples. **SAL** are UKAS accredited for this analysis. In addition to the survey samples, appropriate field blanks and efficiency checks are submitted as part of the technical procedure.

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TVOC as Carbon

Testing was carried out using an MCERTS Certified Signal 3030PM FID and heated gas sample line, with reference to the manufacturer's operation handbook, **BS EN 12619:2013** and in-house technical procedure **ECL/TPD/032A**.

The analyser was calibrated on site using certified propane span gases, (made up in synthetic air) which are traceable to ISO 17025 standard. (with uncertainty < 2%).

Zero measurements were performed using synthetic air zero gas, with TVOC content less than 0.2 mg/m³ (or purity greater than 99.998%).

The analyser was calibrated directly into the sample inlet and then checked through the entire sampling system (including sampling probe, heated filter and heated gas transport lines). Data was corrected by molecular weight to TVOCs as total carbon.

Data was recorded as minute averages over each test period. The data is presented in the Figures Section and the minute averaged data is detailed in the Tables Section.

Water Vapour

Testing was carried out using a Universal Stack Sampling system in accordance with **BS EN 14790** and In-house technical procedure **ECL/TPD/082**.

In this method, the stack gases are filtered (out-stack **heated filter**) to remove particulate matter. The gases are then passed through a **heated line** and then to a cooled moisture trapping unit. All unheated parts of the sample train (outside the sample port) which come into contact with stack gas are weighed pre and post sampling in order to determine the weight gain.

After each test, a visual inspection of the last impinger is made to confirm that at least 50% of the silica gel column has not changed colour. This indicates satisfactory collection of water vapour.

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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 $< 1\text{m}^2$ (below 1.13m in diameter for circular ducts).

The sample locations that were monitored are detailed below: -

A1 CHP1 – Clarke

The sampling location 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 health and safety restrictions and the lack of a sampling platform.

The stack diameter is 0.35m and the sample platform width back from the sample port is $> 5\text{m}$ (please note that there is no platform).

Two sample ports are located on the stack at 90 degrees to each other and are not located on the same plane. However, as stack diameter is 0.357m only one sampling point and therefore one sampling ports is required.

These sample ports are located at a height of approximately 5m from ground level and were access via a crane lift operated by trained and competent Bryn Power staff, and were used to insert probe into the stack only (test equipment kept at ground level).

Recommend that access to the sample ports is attained by means of scaffold accessed from outside the Clarke engine room in the next survey.

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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CHP2 – Edina

The sampling platform does currently meet the requirements detailed in *Technical Guidance Note (Monitoring) M1 "Sampling requirements for stack-emission monitoring"* Environment Agency, and BS EN 13284-1.

The stack diameter is 0.24m and the sample platform width back from the sample port is 1.8m.

Two sample ports are located on the stack at 90 degrees to each other and are located on the same plane.

These sample ports are located at a height of approximately 0.5m from the working sample platform.

Access to the sample platform was attained by means of scaffold accessed from outside the Edina engine room.

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	U006							
MST Nozzle set									
MST “S” Type Pitot									
MST Probe									
MST Hot Box									
MST Impinger Arm		657							
Barometer		351							
Site Balance		088							
Site Check weights		276							
	277								
Horiba	E002	096							
Heated Probe / Filter		631							
Chiller		972							
Sonimix / MFC		752	754						
Heated Line		1009	1010	1011	1012				
FID	E003	301							
Heated Line		517	518	1011	1012				
Heated Probe / Filter		919	631						
Testo	E004								
FTIR	E005								
Heated Probe / Filter									
Heated Line									
Stackmite	E006								
“L” Type Pitot		1095							
Digital Manometer		506							
Stack Thermocouple		860							
Thermocouple Reader		431							
Nozzle Set									
Workhorse Pumps	E007								
Low Flow Pumps									

Quantity of Ice Required / Used for Survey	3	Bags (2kg bags)
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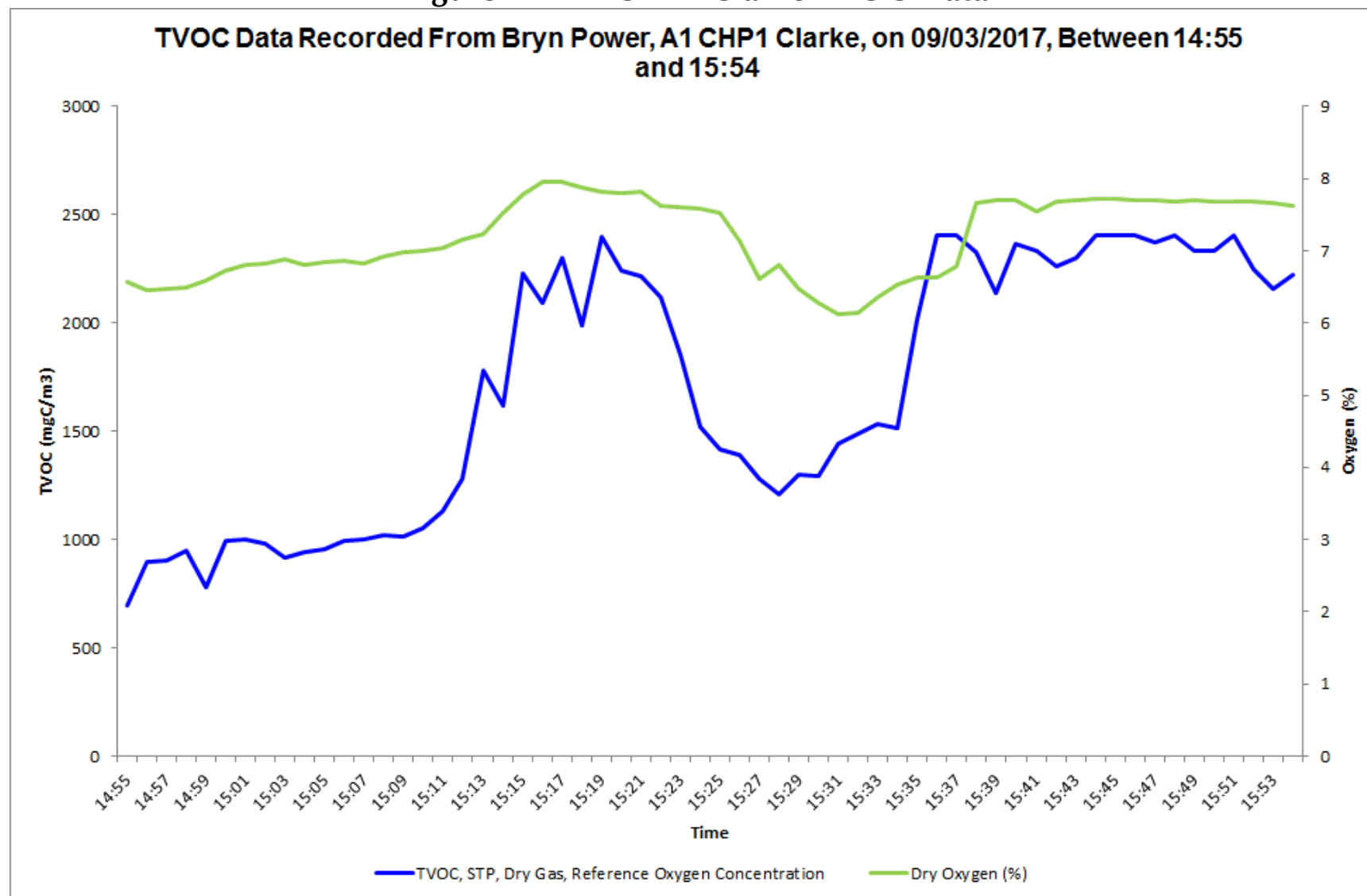
FIGURES

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Figure 1 – A1 CHP1 Clarke TVOC Data

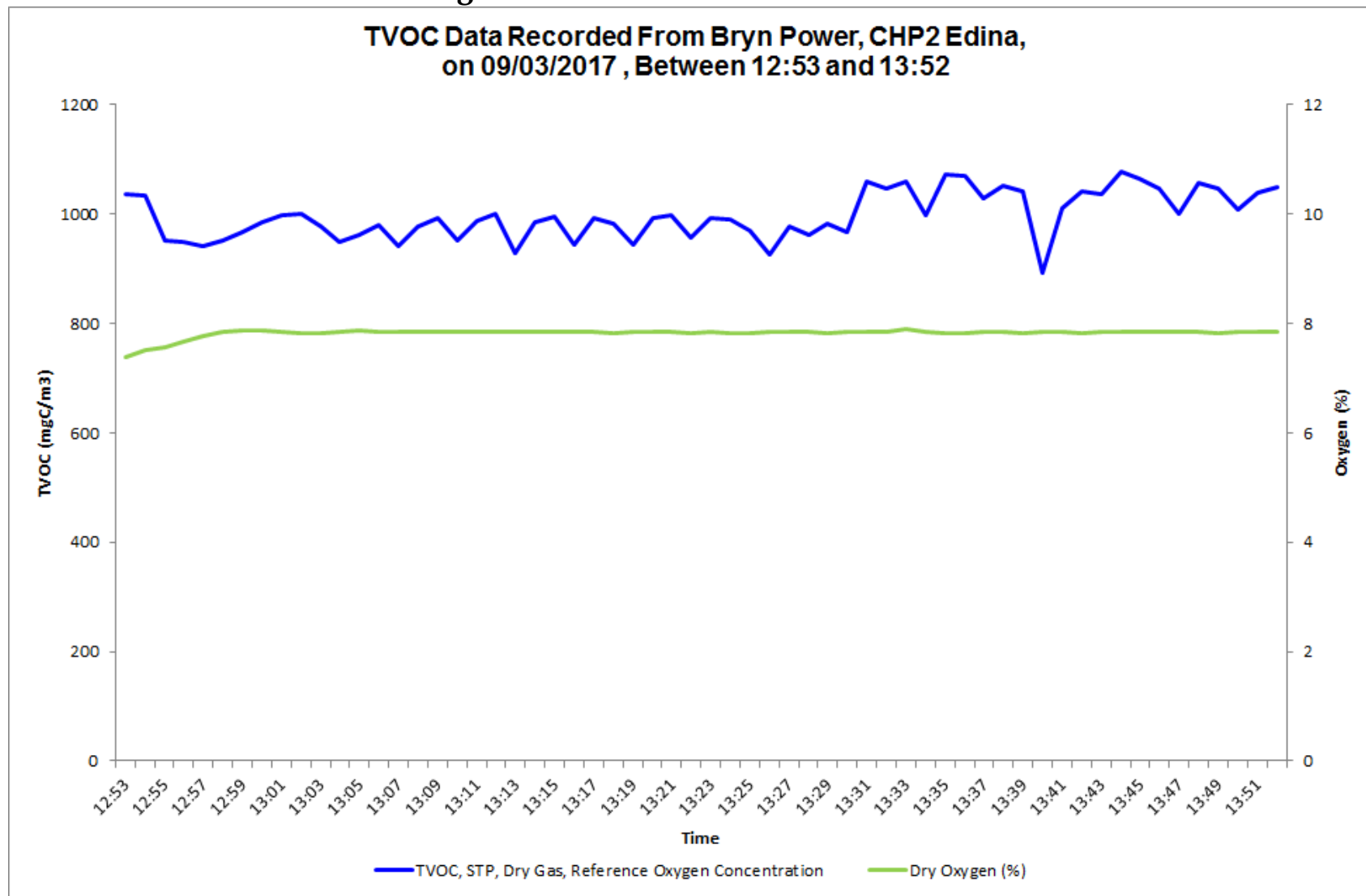


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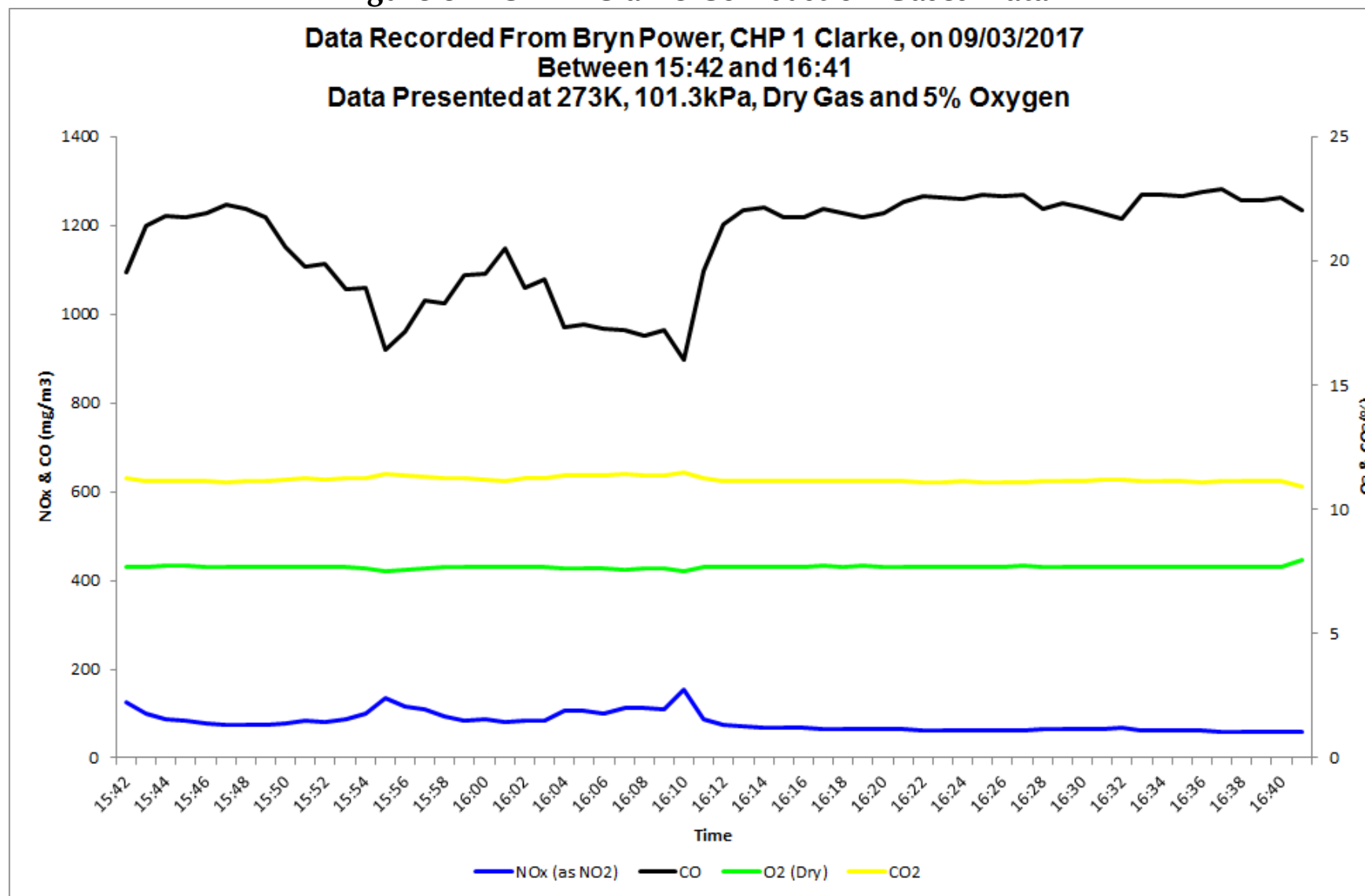
Figure 2 – CHP2 Edina TVOC Data



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Figure 3 – CHP1 Clarke Combustion Gases Data



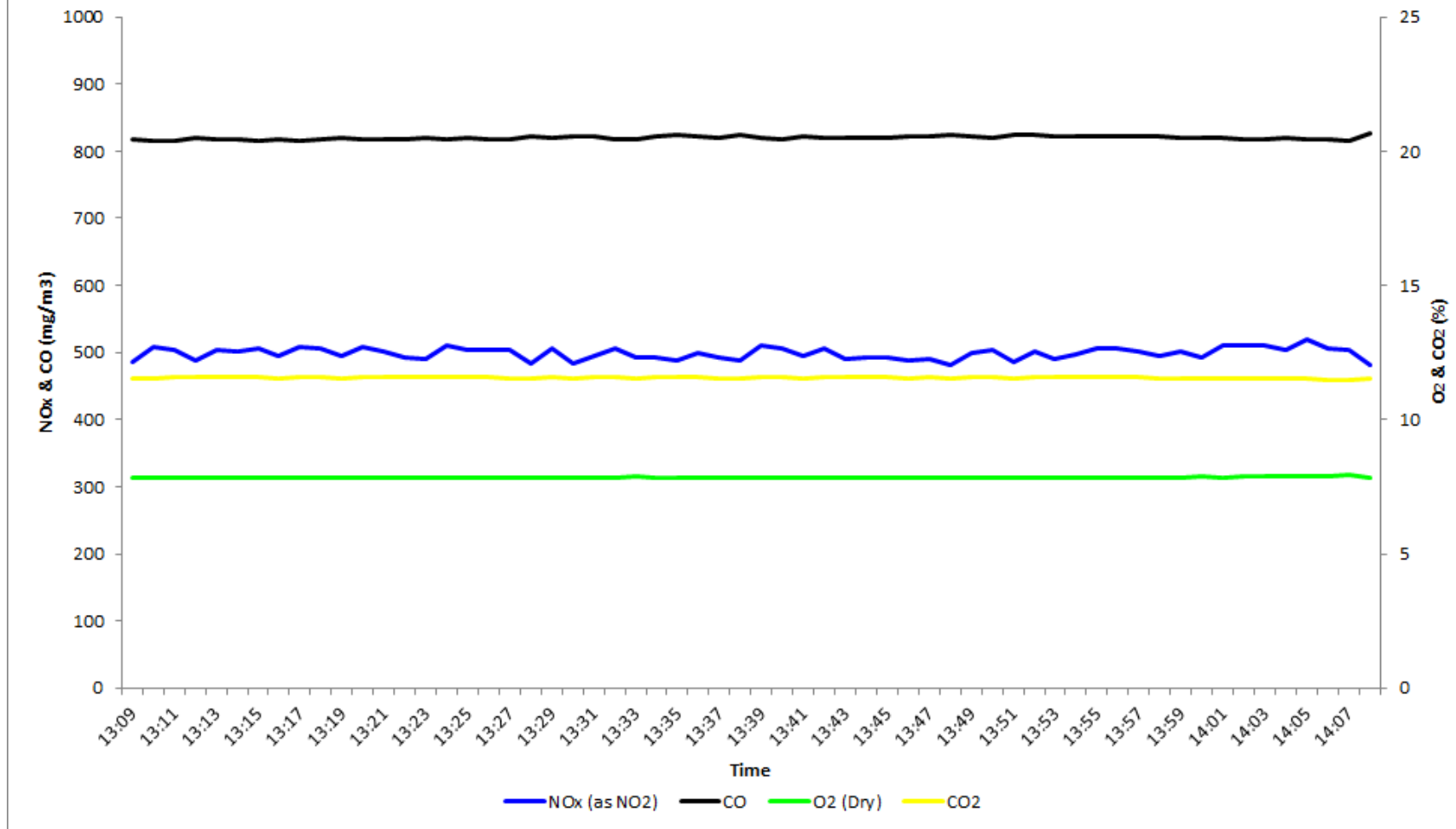
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Figure 4 – CHP2 Edina Combustion Gases Data

**Data Recorded From Bryn Power, CHP 2 Edina, on 09/03/2017
 Between 13:09 and 14:08
 Data Presented at 273K, 101.3kPa, Dry Gas and 5% Oxygen**



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TABLES

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Table 1 – TVOCs
Data Recorded from A1 CHP1 Clarke
Sample Period: 14:55 – 15:54 on the 9th March 2017

Volumetric Flowrate (Reference Conditions) = **0.47 m³/sec ***

	Average	Emission Rate
	mgC/m³	Kg/hr
TVOC (as carbon)*	1699.02	2.87

* Reference Conditions (273K, 101.3 kPa, 5% Oxygen & Dry Gas)

Table 2 – TVOCs
Data Recorded from CHP2 Edina
Sample Period: 12:53 – 13:52 on the 9th March 2017

Volumetric Flowrate (Reference Conditions) = **0.35 m³/sec ***

	Average	Emission Rate
	mgC/m³	Kg/hr
TVOC (as carbon)*	996.70	1.26

* Reference Conditions (273K, 101.3 kPa, 5% Oxygen & Dry Gas)

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Table 3 – NO_x, CO, CO₂ & O₂
Data Recorded from A1 CHP1 Clarke
Sample Period: 15:42 – 16:41 on the 9th March 2017

Volumetric Flowrate (Reference Conditions) = 0.47 m³/sec *

	Average	Emission Rate
	mg/m ³	Kg/hr
Oxides of Nitrogen (as NO ₂) *	80.52	0.14
Carbon Monoxide *	1163.39	1.97
Oxygen (%) **	7.68	...
Carbon Dioxide (%) **	11.19	...

* Reference Conditions (273K, 101.3 kPa, 5% Oxygen & Dry Gas)

** Dry Gas

Table 4 – NO_x, CO, CO₂ & O₂
Data Recorded from CHP2 Edina
Sample Period: 13:09 – 14:08 on the 9th March 2017

Volumetric Flowrate (Reference Conditions) = 0.35 m³/sec *

	Average	Emission Rate
	mg/m ³	Kg/hr
Oxides of Nitrogen (as NO ₂) *	499.46	0.63
Carbon Monoxide *	820.85	1.03
Oxygen (%) **	7.85	...
Carbon Dioxide (%) **	11.56	...

* Reference Conditions (273K, 101.3 kPa, 5% Oxygen & Dry Gas)

** Dry Gas

Bryn Power Limited
 Permit No : EPR/AB3092ZE
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Installation Name : CHP 1 & 2
 Visit Details : Annual Compliance
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Table 5 – A1 CHP1 Clarke SO₂

Data Recorded from A1 - Clarke

Emission Parameter	Units	One - SO ₂	Blank
Stack Diameter	metres	0.35	
Area of Sample Plane	m ²	0.096	
Moisture Content	%	9.50	
Oxygen Content	%	7.46	
Stack Temperature	°C	209	
Gas Velocity (as Measured)	m/sec	11.54	
Gas Velocity (Reference Conditions)	m/sec*	4.92	
Volumetric Flowrate (as Measured)	m ³ /sec	1.11	
Volumetric Flowrate (Reference Conditions)	m ³ /sec*	0.47	
Dry Gas Molecular Weight	g/gmole	30.12556	
Sample Date	...	09/03/2017	
Sample Period	...	15:16 - 16:16	
Sample Volume (reference Conditions)	m ³ *	0.515	0.515
Sample Reference	ECL/17/	1012 & 1013	1014
Mass of Sulphur Dioxide Collected	mg	59.42	0.20
Concentration of Sulphur Dioxide	mg/m ³ *	115.45	0.38
Emission Rate of Sulphur Dioxide	kg/hr	0.20	...
Expanded Uncertainty (% Relative)	%	13	...
Emission Limit Value (ELV)	mg/m ³ *	350	...
Impinger Collection Efficiency	%	100	...
Blank Concentration as Percentage of ELV	%	...	<1.00%

*Reference Conditions (273K, 101.3kPa, 5% Oxygen, Dry Gas)

Environmental Compliance Limited

Bryn Power Limited
 Permit No : EPR/AB3092ZE
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 Report Ref : P3155 : R001

Installation Name : CHP 1 & 2
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Table 6 – CHP2 Edina SO₂

Data Recorded from Edina - CHP 2

Emission Parameter	Units	One - SO ₂	Blank
Stack Diameter	metres	0.24	
Area of Sample Plane	m ²	0.045	
Moisture Content	%	8.69	
Oxygen Content	%	7.84	
Stack Temperature	°C	150	
Gas Velocity (as Measured)	m/sec	16.61	
Gas Velocity (Reference Conditions)	m/sec*	7.71	
Volumetric Flowrate (as Measured)	m ³ /sec	0.75	
Volumetric Flowrate (Reference Conditions)	m ³ /sec*	0.35	
Dry Gas Molecular Weight	g/gmole	30.1638	
Sample Date	...	09/03/2017	
Sample Period	...	12:59 - 13:59	
Sample Volume (reference Conditions)	m ³ *	0.346	0.346
Sample Reference	ECL/17/	1015 & 1016	1017
Mass of Sulphur Dioxide Collected	mg	30.53	0.12
Concentration of Sulphur Dioxide	mg/m ³ *	88.15	0.34
Emission Rate of Sulphur Dioxide	kg/hr	0.11	...
Expanded Uncertainty (% Relative)	%	13	...
Emission Limit Value (ELV)	mg/m ³ *	350	...
Impinger Collection Efficiency	%	100	...
Blank Concentration as Percentage of ELV	%	...	<1.00%

(Conc < 30% ELV)

*Reference Conditions (273K, 101.3kPa, 5% Oxygen, Dry Gas)

Environmental Compliance Limited

Bryn Power Limited

Permit No : EPR/AB3092ZE

Variation No : ...

Report Ref : P3155 : R001

Installation Name

: CHP 1 & 2

Visit Details

: Annual Compliance

Survey Dates

: 9th March 2017

Report Issue Date

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VELOCITY TRAVERSE PROFILES

Installation Name : CHP 1 & 2
Visit Details : Annual Compliance
Survey Dates : 9th March 2017
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Installation Name : CHP 1 & 2
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Static Pressure Readings (Pascals)			
Port A	Port B	Port C	Port D
-10.30			

[illegible]

Post - Traverse Checks Carried Out		Time	Pass/ Fail
Post - Traverse Visual Inspection		13:27:00	Pass

Stagnation Check (S-type Pitot Only)	Time	Reading
Static Pressure Via Positive Leg (Pa)	...	...
Static Pressure Via Negative Leg (Pa)	...	...
Difference (Pa) < 10Pa }		#VALUE!

Average temp (K)	434.400
--------------------	---------

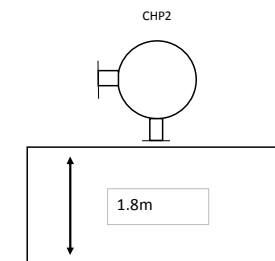
Suitability of Sampling Position	Actual Stack Conditions
Highest:lowest flow pressure ratio < 9:1?	1.05:1
Maximum deviation of flow from axis < 15°?	5
X-sectional area for stacks = πr^2	0.05 m ²
X-sectional area for ducts = L x B	m ²
Suitability of Position for Sampling	OK

Stack Moisture	8.69	%	Gas Velocity (as Measured) Adjusted for Smooth Walls	16.90963	m/sec
Measured Oxygen	7.85	%	Gas Velocity (Reference Conditions) Adjusted for Smooth Walls	7.83754	m/sec*
Measured Carbon Dioxide	11.56	%	Volumetric Flowrate (as Measured) Adjusted for Smooth Walls	0.76497	m ³ /sec
Dry Gas Molecular Weight	30.16360	g/g mole	Volumetric Flowrate (Ref Cond) Adjusted for Smooth Walls	0.35456	m ³ /sec*

*Reference Conditions: 273K, 101.3kPa, 5% Oxygen, Dry Gas

NOTE: Velocity / volume flowrate calculations exclude contributions from the measurement point(s) where swirl $> 15^\circ$

Diagram/ Description of Cross Section of Stack/Duct



Notes

Including expected or actual deviations from procedures / non-conformities

Narrow ports

Compliance With Positional Requirements?

Height of sample ports from Platform

Number of sample ports

Width of platform (port back to handrail)

Nearest downstream disturbance	Exit	0.5m
--------------------------------	------	------

Nearest upstream disturbance	Bend	0.5m
------------------------------	------	------

Disturbances are classed as bends, fans or diameter variations.

Environmental Compliance Limited

Bryn Power Limited

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Installation Name

: CHP 1 & 2

Visit Details

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: 9th March 2017

Report Issue Date

: 24th March 2017

FIELD CALIBRATION AND SAMPLING DATA

Environmental Compliance Limited

Bryn Power Limited
Permit No : EPR/AB3092ZE
Variation No : ...
Report Ref : P3155 : R001

Installation Name : CHP 1 & 2
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CHP2 Edina SO2 Sampling Data

Environmental Compliance Limited		NON ISOKINETIC SAMPLING PROFORMA		Date of Measurement		09/03/2017		If moisture was not measured see detailed notes below.	
ECU/PPD		39		Time taken to change Parts		0		Start Time	
								End Time	
								60 mins	
								12:59	
								13:59	
								Additional Moisture Weighings	
								Impinger 1	
								3% H2O2	
								Item Name	
								Start Weight (g)	
								End Weight (g)	
								Total weight (g)	
								0	
								Impinger 2	
								3% H2O2	
								Item Name	
								Start Weight (g)	
								End Weight (g)	
								Total weight (g)	
								0	
								Impinger 3	
								3% H2O2	
								Item Name	
								Start Weight (g)	
								End Weight (g)	
								Total weight (g)	
								0	
								Impinger 4	
								Empty	
								Item Name	
								Start Weight (g)	
								End Weight (g)	
								Total weight (g)	
								0	
								Impinger 5	
								Silica	
								Item Name	
								Start Weight (g)	
								End Weight (g)	
								Total weight (g)	
								0	
								Impinger 6	
								Empty	
								Item Name	
								Start Weight (g)	
								End Weight (g)	
								Total weight (g)	
								0	
								Impinger 7	
								Empty	
								Item Name	
								Start Weight (g)	
								End Weight (g)	
								Total weight (g)	
								0	
								Impinger 8	
								Empty	
								Item Name	
								Start Weight (g)	
								End Weight (g)	
								Total weight (g)	
								0	
								Total (g)	
								32.20	
								Total weight (g)	
								0	
								Silica < 50% used at End of Test? Y/N	
								YES	
								If moisture was not measured and gas was dried before entering the gas meter, impinger weights must be included to produce the moisture concentration used in the isokinetic calculations. If the gas was not dried before it entered the gas meter then impinger weights may be included to produce a nominal 0.1% moisture value.	
								Rinse Solutions used	
								Solution	
								DI Water	
								3147	
								Acetone	
								3% H2O2	
								3163	
								Total weight (g)	
								0	

Environmental Compliance Limited

Bryn Power Limited
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Installation Name : CHP 1 & 2
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 Report Issue Date : 24th March 2017

TVOC FID Field Calibration

Calibration Summary		TVOC ppm
Analyser Range		1000
Repeatability at Zero		2
Span Gas Concentration Applied		936.9
Zero Gas Concentration Applied		0
Direct Cal	Zero	0.00
	Span	936.9
	Zero	2.29
Difference (Zero)		2.2936
< 2 × Repeatability @ Zero?		YES
Pre Test (System)	Zero	1.67
	Span	951.5
	Difference (Zero)	1.6681
< 2% Relative to Direct Span		YES
Difference (Span)		14.6272
< 2% Relative to Direct Span		YES
Post Test (System)	Zero	1.40
	Span	923.8
	Difference (Zero)	0.2711
Zero Drift < 2% of Applied Span?		YES
Difference (Span)		27.7635
Span Drift < 2% of Applied Span?		NO
Zero and Span Drift < 5% of Applied Span?		YES

Environmental Compliance Limited

Bryn Power Limited
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TVOC FID Site Log

TVOC - FIELD DATA SHEET

Client	Bryn Power	Barometric Pressure mb	992
Site	Hengoed	Barometer ID	ECL/ID/351
Date	09/03/2017	Analyser ID	ECL/ID/301
Location	CHP's	Sonimix/ MFC ID	ECL/ID/752 + 754
Stack ID	A1 CHP1 & CHP2	Heated Line/ Controller ID	ECL/ID/1011 + 1012
Stack Temp °C	480	Heated Line Set Temp °C	180 YES
Ambient Temp (sampling)	1 = 17.9 2 = 18.2 3 = 19.5	Heated Line Length	10 m
Ambient Temp (sampling)	4 = 17.4 5 = 16.9 6 = 19.2	Heated Probe Filter ID	ECL/ID/631
Job No	P3155	Heated Filter Set Temp °C	180 YES
Operators	CP + SEB + BJ	Logger ID	926

Calibration Gas Details

Calibration Gas	Gas Bottle ID	Gas Value	Uncertainty of Gas (k=2)
Zero Gas (Synthetic Air)	Gas/1674	...	...
Hydrogen / Helium	Gas/1582	...	...
Propane (In Air)	Gas/1582	936.9ppm	1ppm

Propane	Analyser Range	Span Gas value used
	1000ppm	936.9ppm

Analyser Range should be not less than the expected peak emissions.

Span Gas Values should be either approximately the half-hourly ELV OR 50% to 90% of the Selected Analyser Range.

Direct Calibration (Rear of Analyser)						
Zero Cal		Span Gas Cal		Zero Check		
Start Time	End Time	Start Time	End Time	Start Time	End Time	
ZERO /SPAN/ ZERO	09:42 09:47	09:55 10:00		10:34 10:39		

NOTE: RESPONSE TIME

Response Time to be carried out at the same time as "Span Check" on system verification (via the sample probe)
 Start Time = when gas turned on. 90% Time = when analyser displays 90% of span gas value used. Response must be within 200 seconds.

Pre-Cal Ambient Temp °C	PRE System Verification Check (Down Line)			
Max Min	Zero Check		Span Check	
19.8 17.5	Start Time	End Time	Start Time	End Time
ZERO / SPAN	10:47	10:52	10:53	10:58

Response Time SYSTEM Span Gas Cal		
Start Time	90% Time	less than 200s (Y/N)
10:51:00	10:51:30	Y

Start Time	End Time	Location	Production Details
Sample Period	11:02 12:01	Fail? ~ 800ppm	CHP 1 - Clarke 500 - 250KW
Sample Period	12:30 14:09	Ok ~ 500ppm	CHP 2 - Edina 500KW
Sample Period	15:38 16:38	CHP 1	CHP 1 - Clarke 350 KW
Sample Period			
Sample Period			
Sample Period			

Post-Cal Ambient Temp °C	POST System Verification Check (Down Line)			
Max Min	Zero Check		Span Check	
17.6 17.6	Start Time	End Time	Start Time	End Time
ZERO / SPAN	16:40	16:45	16:46	16:51

Process Details / Comments

Bryn Power Limited
 Permit No : EPR/AB3092ZE
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 Visit Details : Annual Compliance
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Combustion Gases 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 250 Measurement Ranges:

NO as			
NO ₂	CO	O ₂	CO ₂
1025	2500	25	20
mg/m ³	mg/m ³	%Vol	%Vol
Zero Values (Direct)			
0.48	0.00	-0.11	0.02
0.55	1.11	-0.10	0.07
0.06	1.11	0.01	0.05
4.10	2.50	0.20	0.20
YES	YES	YES	YES
Pre Zero Values (System)			
0.62	0.59	0.04	0.04
0.06%	0.02%	0.17%	0.20%
0.02	0.48	0.20	0.00

Applied Span:

NO	CO	O ₂	CO ₂
536.08	252.13	15.12	17.99
Pre Test System Zero Values			
0.62	0.59	0.04	0.04
0.12%	0.23%	0.27%	0.23%
Post Zero Values (System)			
0.98	1.25	0.05	0.07
0.10%	0.05%	0.21%	0.35%
0.07%	0.26%	0.07%	0.16%
Pre Test System Span Values			
533.88	253.19	15.33	17.88
0.41%	0.42%	1.39%	0.60%
Post Test System Span Values			
533.01	252.60	15.08	17.92
0.16%	0.23%	1.67%	0.19%

0.16% 0.26% 1.67% 0.19%

See Note 3 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.

Environmental Compliance Limited

Bryn Power Limited

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Installation Name

: CHP 1 & 2

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LABORATORY ANALYSIS RESULTS

Environmental Compliance Limited

Bryn Power Limited
Permit No : EPR/AB3092ZE
Variation No : ...
Report Ref : P3155 : R001

Installation Name : CHP 1 & 2
Visit Details : Annual Compliance
Survey Dates : 9th March 2017
Report Issue Date : 24th March 2017



Concept Life Sciences
Certificate of Analysis

Hadfield House
Hadfield Street
Combrook
Manchester
M16 9FE
Tel : 0161 874 2400
Fax : 0161 874 2404

Report Number: 639334-1

Date of Report: 20-Mar-2017

Customer: Environmental Compliance Ltd
Unit G1
Main Avenue
Treforest Industrial Estate
Pontypridd
CF37 5BF

Customer Contact: Mr. Chris Pickford

Customer Job Reference: P3155
Customer Purchase Order: E6354
Date Job Received at Concept: 13-Mar-2017
Date Analysis Started: 13-Mar-2017
Date Analysis Completed: 20-Mar-2017

The results reported relate to samples received in the laboratory and may not be representative of a whole batch.

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation

This report should not be reproduced except in full without the written approval of the laboratory

Tests covered by this certificate were conducted in accordance with Concept SOPs



Report checked
and authorised by :
Emma Spear
Project Manager

Issued by :
Emma Spear
Project Manager

Validity unknown
Digitally signed by Emma Spear
Date: 2017.03.20 12:08:59 GMT
Reason: Issued
Location: Salford

Page 1 of 2

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639334-1

Environmental Compliance Limited

Bryn Power Limited
 Permit No : EPR/AB3092ZE
 Variation No : ...
 Report Ref : P3155 : R001

Installation Name : CHP 1 & 2
 Visit Details : Annual Compliance
 Survey Dates : 9th March 2017
 Report Issue Date : 24th March 2017

Concept Reference: 639334						
Customer Reference: P3155						
Impinger(peroxide) Analysed as Impinger(peroxide)						
Sulphur Dioxide & Volume						
Concept Reference	639334 001	639334 002	639334 003	639334 004	639334 005	639334 006
Customer Sample Reference	ECL/17/1012	ECL/17/1013	ECL/17/1014	ECL/17/1015	ECL/17/1016	ECL/17/1017
Test Sample	AR	AR	AR	AR	AR	AR
Date Sampled	09-MAR-2017	09-MAR-2017	09-MAR-2017	09-MAR-2017	09-MAR-2017	09-MAR-2017
Determinand	Method	LOD	Units	Symbol		
Sulphur Dioxide	IC	0.05	mg/l	U	(195,13) 160	(13) 1.4
Volume	Vol	1	ml	U	370	160

Index to symbols used in 639334-1

Value	Description
AR	As Received
195	Due to levels found in the sample that are outside of the normal calibration range of the instrument, analysis was conducted on a diluted sample
13	Results have been blank corrected.
U	Analysis is UKAS accredited

Environmental Compliance Limited

Bryn Power Limited

Permit No : EPR/AB3092ZE

Variation No : ...

Report Ref : P3155 : R001

Installation Name

: CHP 1 & 2

Visit Details

: Annual Compliance

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UNCERTAINTY CALCULATIONS

Bryn Power Limited
 Permit No : EPR/AB3092ZE
 Variation No : ...
 Report Ref : P3155 : R001

Installation Name : CHP 1 & 2
 Visit Details : Annual Compliance
 Survey Dates : 9th March 2017
 Report Issue Date : 24th March 2017

Volumetric Flowrate Uncertainty – A1 CHP1 Clarke

Stack Reference A1

Measurement Uncertainty Calculations - Velocity at Stack Conditions

Contribution From	Standard u/c (Pa)	
Pitot Calibration Uncertainty Contribution	0.25	A
Manometer Calibration Uncertainty Contribution	0.251833333	B
Variation in Actual Pitot reading at sample points	1.05	C
Combined u/c (Pa) = SQRT $(A/\sqrt{3})^2 + (B/\sqrt{3})^2 + (C/\sqrt{3})^2$	0.64	
Expanded Uncertainty of Flow Measurements Pa	1.28	
	Standard u/c (K)	
Temperature Calibration (K)	2.41	D
Variation in Actual Temp reading at sample points	0.50	E
Combined u/c of Temp (K) SQRT $((D/\sqrt{3})^2 + (E/\sqrt{3})^2)$	1.42	
Expanded Uncertainty of Temp Measurements (K)	2.84	
Measured Average Velocity (m/s) at Stack Conds	11.83	
Maximum Average Velocity (m/s) at Stack Conds	12.01	
Standard Uncertainty Velocity at Stack Conditions (%)	1.56	
Expanded Uncertainty Velocity (at Stack Conditions)	3.12 (%)	

Measurement Uncertainty Calculations - Flowrate at Stack Conditions

Contribution From	Standard u/c (m ³)
Area (m ²)	0.00096
Measured Average Flowrate (m ³ /s) at Stack Conds	1.14
Maximum Average Flowrate (m ³ /s) at Stack Conds	1.17
Standard Uncertainty Flowrate (m ³ /s) at Stack Conditions (%)	2.58
Expanded Uncertainty Flowrate (m³/s) at Stack Conditions	5.15 (%)

Measurement Uncertainty Calculations - Flowrate at STP & Wet Gas

Contribution From	Standard u/c (%)
Temperature Calibration (K)	0.5
Barometer Calibration	0.5
Measured Average Flowrate (m ³ /s) at STP Wet	0.63
Maximum Average Flowrate (m ³ /s) at STP Wet	0.65
Standard Uncertainty Flowrate (m ³ /s) at STP Wet	2.87
Expanded Uncertainty Flowrate (m³/s) at STP Wet	5.73 (%)

Measurement Uncertainty Calculations - Flowrate at STP & Dry Gas

Contribution From	Standard u/c (%)
Moisture Uncertainty (% v/v)	0.17
Measured Average Flowrate (m ³ /s) at STP Dry	0.57
Maximum Average Flowrate (m ³ /s) at STP Dry	0.59
Standard Uncertainty Flowrate (m ³ /s) at STP Dry	3.06
Expanded Uncertainty Flowrate (m³/s) at STP Dry	6.12 (%)

Measurement Uncertainty Calculations - Flowrate at STP, Dry Gas & Ref Oxygen

Contribution From	Standard u/c (%)
Oxygen Uncertainty (% v/v)	0.230
Measured Average Flowrate (m ³ /s) at STP Dry & Ref Oxygen	0.48
Maximum Average Flowrate (m ³ /s) at STP Dry & Ref Oxygen	0.50
Standard Uncertainty Flowrate (m ³ /s) at STP Dry & Ref Oxygen	4.84
Expanded Uncertainty Flowrate (m³/s) at STP Dry & Ref O₂	9.68 (%)

Bryn Power Limited
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 Report Ref : P3155 : R001

Installation Name : CHP 1 & 2
 Visit Details : Annual Compliance
 Survey Dates : 9th March 2017
 Report Issue Date : 24th March 2017

Volumetric Flowrate Uncertainty – CHP2 Edina

Stack Reference Edina

Measurement Uncertainty Calculations - Velocity at Stack Conditions

Contribution From	Standard u/c (Pa)	
Pitot Calibration Uncertainty Contribution	0.58	A
Manometer Calibration Uncertainty Contribution	0.580333333	B
Variation in Actual Pitot reading at sample points	6.50	C
Combined u/c (Pa) = SQRT (A/ $\sqrt{3}$) ² + (B/ $\sqrt{3}$) ² + (C/ $\sqrt{3}$) ²	3.78	
Expanded Uncertainty of Flow Measurements Pa	7.57	
	Standard u/c (K)	
Temperature Calibration (K)	2.17	D
Variation in Actual Temp reading at sample points	0.00	E
Combined u/c of Temp (K) SQRT ((D/ $\sqrt{3}$) ² + (E/ $\sqrt{3}$) ²)	1.25	
Expanded Uncertainty of Temp Measurements (K)	2.51	
Measured Average Velocity (m/s) at Stack Conds	16.99	
Maximum Average Velocity (m/s) at Stack Conds	17.59	
Standard Uncertainty Velocity at Stack Conditions (%)	3.51	
Expanded Uncertainty Velocity (at Stack Conditions)	7.01 (%)	

Measurement Uncertainty Calculations - Flowrate at Stack Conditions

Contribution From	Standard u/c (m ²)
Area (m ²)	0.00045
Measured Average Flowrate (m ³ /s) at Stack Conds	0.77
Maximum Average Flowrate (m ³ /s) at Stack Conds	0.80
Standard Uncertainty Flowrate (m ³ /s) at Stack Conditions (%)	4.54
Expanded Uncertainty Flowrate (m³/s) at Stack Conditions	9.08 (%)

Measurement Uncertainty Calculations - Flowrate at STP & Wet Gas

Contribution From	Standard u/c (%)
Temperature Calibration (K)	0.5
Barometer Calibration	0.5
Measured Average Flowrate (m ³ /s) at STP Wet	0.48
Maximum Average Flowrate (m ³ /s) at STP Wet	0.50
Standard Uncertainty Flowrate (m ³ /s) at STP Wet	4.87
Expanded Uncertainty Flowrate (m³/s) at STP Wet	9.74 (%)

Measurement Uncertainty Calculations - Flowrate at STP & Dry Gas

Contribution From	Standard u/c (%)
Moisture Uncertainty (% v/v)	0.20
Measured Average Flowrate (m ³ /s) at STP Dry	0.43
Maximum Average Flowrate (m ³ /s) at STP Dry	0.46
Standard Uncertainty Flowrate (m ³ /s) at STP Dry	5.10
Expanded Uncertainty Flowrate (m³/s) at STP Dry	10.20 (%)

Measurement Uncertainty Calculations - Flowrate at STP, Dry Gas & Ref Oxygen

Contribution From	Standard u/c (%)
Oxygen Uncertainty (% v/v)	0.236
Measured Average Flowrate (m ³ /s) at STP Dry & Ref Oxygen	0.36
Maximum Average Flowrate (m ³ /s) at STP Dry & Ref Oxygen	0.38
Standard Uncertainty Flowrate (m ³ /s) at STP Dry & Ref Oxygen	6.98
Expanded Uncertainty Flowrate (m³/s) at STP Dry & Ref O₂	13.96 (%)

Environmental Compliance Limited

Bryn Power Limited
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SO2 Uncertainty – A1 CHP1 Clarke

Site: Hengoed
Location: A1

$$u_{mass} = \sqrt{(u_{filter})^2 + (u_{solution})^2}$$

Determinand	Filter mg	Solution mg	Recovered Mass mg	LAB Method Uncert (%) K=2 Filter mg	Solution mg	Standard Uncertainty Filter mg	Solution mg	Combined Uncertainty mg
One - SO2								
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
Sulphur Dioxide	...	59.42	59.42	...	7.73	...	3.86	3.86
...	...	...	...	...	...	...	...	...

...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

	One - SO2		Standard Uncertainty @ 95%
Sampled Volume (V _m)	0.67	m ³	uV _m 0.001 m ³
Meter Correction Factor (Y _d)	0.99	...	...
Meter Temperature (T _m)	292.50	k	uT _m 1.5 k
Average Differential Pressure (ΔH)	10.00	mmH ₂ O	uΔH 0.25 mmH ₂ O
Barometric Pressure (p _b)	747.81	mmHg	uP _b 3.8 mmHg
ΔH + p _s (p _m)	99.80	kPa	...
Oxygen content (O _{2,m})	7.46	% by volume	uO _{2,m} = σ/√n 0.00
Moisture Content (H ₂ O)	9.50	% by volume	uH ₂ O 0.34

Note: In the following calculations, the sensitivity coefficient (C) is estimated using:

$$C_i = \frac{\partial f}{\partial x_i}$$

For each factor, uncertainty is then calculated by $C_i u_i$ where C is the sensitivity coefficient, u is the standard uncertainty and i is the index identifying the contributing factor e.g. $i = uV_m$, uT_m etc.

Where results are required at wet conditions, the following correction factor is used to convert the data from the dry gas meter:

One - SO2:

$$f_{s, wet} = \frac{100}{(100 - H_2O)} = 1.00$$

Uncertainty in correction factor to STP due to measured ΔH uncertainty component (uΔH), measured stack pressure uncertainty component (uP_b) & measured temperature of dry gas uncertainty component (uT_{m Dry})

One - SO2:

$$f_s = \frac{273}{760} \times \frac{P_b + \frac{\Delta H}{13.6}}{T_m} \times Y_d = 0.908$$

	Maximum	Minimum	Sensitivity	u _{STP}
uΔH	0.91	0.91	0.0000892	0.0000223
uP _b	0.91	0.90	0.00121	0.00455
uT _m	0.91	0.90	0.00310	0.00466
H ₂ O	...	...	...	...

$$\frac{u f_s}{f_s} = \sqrt{\left(\frac{(u\Delta H)^2 + (uP_b)^2}{(P_m/101.3)} \right)^2 + \left(\frac{uT_m}{(T_m/273.15)} \right)^2 + \left(\frac{uH_2O}{100/(100-H_2O)} \right)^2} = 0.00576$$

Uncertainty in volume @ STP due to volume correction factor uncertainty component (uV_{std}) & volume uncertainty component (uV_m)

One - SO2:

$$V_{std} = V_{measured} \times f_s = 0.608$$

	Maximum m ³	Minimum m ³	Sensitivity	Standard Uncertainty (m ³)
Effect of uV _{std}	0.61	0.60	0.67	0.00386
Effect of uV _m	0.61	0.61	0.91	0.000908

Combined Standard Uncertainty

$$\frac{uV_{std}}{V_{std}} = \sqrt{\left(\frac{uV_{std}}{f_s} \right)^2 + \left(\frac{uV_m}{V_m} \right)^2} = 0.00271$$

Uncertainty of Oxygen Correction Factor (%):-

One - SO2:

$$f_{O_2} = \frac{20.9\% - O_{2, ref}}{20.9\% - O_{2, measured}} = 1.18$$

$$u_{Corr_{O_2}} = \frac{20.9\% - O_{2, ref}}{(20.9\% - O_{2, measured})(20.9\% - O_{2, measured})} \times \text{Uncertainty of } O_2 \text{ Measurement} = 0.0264$$

$$u f_{O_2} = \frac{u_{Corr_{O_2}}}{f_{O_2}} \times 100 = 2.23 \%$$

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Uncertainty in final measurement @ reference conditions due to mass uncertainty component (uM)

Determinand	One - SO ₂ :			
	Maximum mg/Nm ³	Minimum mg/Nm ³	Sensitivity	uM mg/Nm ³
...	...	...	...	...
...	...	...	...	...
Sulphur Dioxide	123.10	108.07	1.95	7.51
...	...	...	...	...

Uncertainty in final measurement @ reference conditions due to uncertainty component arising from leak and/or loss (assumed 2% max) in the sample system (uL)

Determinand	One - SO ₂ :	
	uL mg/Nm ³	
...	...	
...	...	
Sulphur Dioxide	1.33	
...	...	

Uncertainty in final measurement @ Reference Conditions due to uVstp

Determinand	One - SO ₂ :			
	Maximum mg/Nm ³	Minimum mg/Nm ³	Sensitivity	uVstp mg/Nm ³
...	...	...	...	...
...	...	...	...	...
Sulphur Dioxide	116.10	115.07	190.11	0.52
...	...	...	...	...

Combined Uncertainty excluding oxygen contribution

$$u_{combined} = \sqrt{\sum (u_M)^2 + (u_L)^2 + (u_{V_{stp}})^2}$$

Determinand	One - SO ₂ :			
	Combined Uncertainty mg/Nm ³	Expanded Uncertainty mg/Nm ³	Measured Concentration mg/Nm ³	Percent of Measured Concentration
...	...	...	...	...
...	...	...	...	...
Sulphur Dioxide	7.65	15.30	115.58	13.23
...	...	...	...	...

Combined Uncertainty including oxygen contribution

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

Determinand	Measurement Uncertainty of Determinand	Measurement Uncertainty of Oxygen Corr'n Factor	Overall Measurement Uncertainty inc O ₂ Corr' factor (U _{combined})
...	...	...	...
...	...	...	...
Sulphur Dioxide	13.23	2.23	13.42
...	...	...	...

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SO2 Uncertainty – CHP2 Edina

Site: Hengoed
Location: Edina

$$u_{\text{mass}} = \sqrt{\sum (u_{\text{filter}})^2 + (u_{\text{solution}})^2}$$

Determinand	Filter mg	Solution mg	Recovered Mass mg	LAB Method Uncert (%) K=2 Filter mg	Solution mg	Standard Uncertainty Filter mg	Solution mg	Combined Uncertainty mg
One - SO2								
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
Sulphur Dioxide	...	30.53	30.53	...	3.97	...	1.98	1.98
...	...	...	...	...	...	...	...	...

...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

	One - SO2		Standard Uncertainty @ 95%
Sampled Volume (V _m)	0.46	m ³	uV _m 0.001 m ³
Meter Correction Factor (Y _d)	0.99	...	...
Meter Temperature (T _m)	292.50	k	uT _m 1.5 k
Average Differential Pressure (ΔH)	10.00	mmH ₂ O	uΔH 0.25 mmH ₂ O
Barometric Pressure (p _b)	747.81	mmHg	up _b 3.8 mmHg
ΔH + p _s (p _m)	99.80	kPa	...
Oxygen content (O _{2,m})	7.84	% by volume	uO _{2,m} = σ/√n 0.00 % by volume
Moisture Content (H ₂ O)	8.69	% by volume	uH ₂ O 0.40 % by volume

Note: In the following calculations, the sensitivity coefficient (C) is estimated using:

$$C_i = \frac{\partial f}{\partial x_i}$$

For each factor, uncertainty is then calculated by C_iu_i where C is the sensitivity coefficient, u is the standard uncertainty and i is the index identifying the contributing factor e.g. i = uV_m, uT_m etc.

Where results are required at wet conditions, the following correction factor is used to convert the data from the dry gas meter:

One - SO2:

$$f_{s, \text{wet}} = \frac{100}{(100 - H_2O)} = 1.00$$

Uncertainty in correction factor to STP due to measured ΔH uncertainty component (uΔH), measured stack pressure uncertainty component (up_b) & measured temperature of dry gas uncertainty component (uT_{m DRY})

One - SO2:

$$f_s = \frac{273}{760} \times \frac{P_b + \frac{\Delta H}{13.6}}{T_m} \times Y_d = 0.908$$

	Maximum	Minimum	Sensitivity	u _{fstp}
uΔH	0.91	0.91	0.0000892	0.0000223
up _b	0.91	0.90	0.00121	0.00455
uT _m	0.91	0.90	0.00310	0.00466
H ₂ O	...	...	...	...

$$\frac{u_{f_s}}{f_s} = \sqrt{\left(\frac{u_{\Delta H}}{P_m/101.3}\right)^2 + \left(\frac{u_{T_m}}{T_m/273.15}\right)^2 + \left(\frac{u_{H_2O}}{100/(100-H_2O)}\right)^2} = 0.00576$$

Uncertainty in volume @ STP due to volume correction factor uncertainty component (uV_{std}) & volume uncertainty component (uV_m)

One - SO2:

$$V_{std} = V_{measured} \times f_s = 0.421$$

	Maximum m ³	Minimum m ³	Sensitivity	Standard Uncertainty (m ³)
Effect of uV _{std}	0.42	0.42	0.46	0.00267
Effect of uV _m	0.42	0.42	0.91	0.000908

Combined Standard Uncertainty

$$\frac{uV_{std}}{V_{std}} = \sqrt{\left(\frac{uV_{std}}{f_s}\right)^2 + \left(\frac{uV_m}{V_m}\right)^2} = 0.00149$$

Uncertainty of Oxygen Correction Factor (%):-

One - SO2:

$$f_{O_2} = \frac{20.9\% - O_{2, \text{ref}}}{20.9\% - O_{2, \text{measured}}} = 1.22$$

$$u_{\text{Corr } O_2} = \frac{20.9\% - O_{2, \text{ref}}}{(20.9\% - O_{2, \text{measured}}) \times (20.9\% - O_{2, \text{measured}})} \times \text{Uncertainty of } O_2 \text{ Measurement} = 0.0280$$

$$u_{f_{O_2}} = \frac{u_{\text{Corr } O_2}}{f_{O_2}} \times 100 = 2.30 \%$$

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Uncertainty in final measurement @ reference conditions due to mass uncertainty component (uM)

Determinand	One - SO ₂ :			
	Maximum mg/Nm ³	Minimum mg/Nm ³	Sensitivity	uM mg/Nm ³
...	...	...	...	...
...	...	...	...	...
Sulphur Dioxide	94.00	82.53	2.89	5.74
...	...	...	...	...

Uncertainty in final measurement @ reference conditions due to uncertainty component arising from leak and/or loss (assumed 2% max) in the sample system (uL)

Determinand	One - SO ₂ :
	uL mg/Nm ³
...	...
...	...
Sulphur Dioxide	1.02
...	...

Uncertainty in final measurement @ Reference Conditions due to uVstp

Determinand	One - SO ₂ :			
	Maximum mg/Nm ³	Minimum mg/Nm ³	Sensitivity	uVstp mg/Nm ³
...	...	...	...	...
...	...	...	...	...
Sulphur Dioxide	88.58	87.95	209.56	0.31
...	...	...	...	...

Combined Uncertainty excluding oxygen contribution

$$u_{combined} = \sqrt{\sum (u_M)^2 + (u_L)^2 + (u_{Vstp})^2}$$

Determinand	One - SO ₂ :			
	Combined Uncertainty mg/Nm ³	Expanded Uncertainty mg/Nm ³	Measured Concentration mg/Nm ³	Percent of Measured Concentration
...	...	...	...	...
...	...	...	...	...
Sulphur Dioxide	5.84	11.67	88.27	13.22
...	...	...	...	...

Combined Uncertainty including oxygen contribution

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

Determinand	Measurement Uncertainty of Determinand	Measurement Uncertainty of Oxygen Corr Factor	Overall Measurement Uncertainty inc O ₂ Corr ² factor (Ucombined)
...	...	...	...
...	...	...	...
Sulphur Dioxide	13.22	2.30	13.42
...	...	...	...

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TVOC Measurement Uncertainty

A1 CHP1 & CHP2 - TVOC - Measurement Uncertainty - Uncertainty Calculations Table 1

Performance Characteristics	Standard Uncertainty (% of Range)	Distribution	Min Certified Ranges
			TVOC 0 - 15 mgC/m ³
Lack of fit ⁽¹⁾	u_{lof}	Rectangular (Divisor = $\sqrt{3}$)	0.73
Span drift ⁽²⁾	$u_{d,s}$	Rectangular (Divisor = $\sqrt{3}$)	0.35
Repeatability Standard Deviation (span) ⁽³⁾	u_r	Normal (Divisor = 1)	131.32
Losses / leakage in the sample system ⁽⁴⁾	u_{loss}	Rectangular (Divisor = $\sqrt{3}$)	97.51
Temperature dependant span drift ⁽⁵⁾	u_t	Rectangular (Divisor = $\sqrt{3}$)	0.30
Interferents ⁽¹⁾	u_i	Rectangular (Divisor = $\sqrt{3}$)	4.39
Uncertainty of Reference Gas ⁽⁶⁾	u_{ref}	Rectangular (Divisor = $\sqrt{3}$)	26.08
Effect of Voltage Fluctuation ⁽⁷⁾	u_v	Rectangular (Divisor = $\sqrt{3}$)	1.80
Effect of Oxygen Synergism ⁽⁷⁾	u_{syn}	Rectangular (Divisor = $\sqrt{3}$)	4.60

Note:

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

- Expressed as a percentage of the certified range
- Expressed as maximum drift per 24hr period as percentage of the certified range
- 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 taking account of an additional uncertainty of 2% for gas blending
- Expressed as a percentage of the certified range

A1 CHP1 & CHP2 - TVOC - Measurement Uncertainty - Uncertainty Calculations Table 2

Performance Characteristics	Uncertainty	Value of Standard Uncertainty	*TVOC 0 - 15 mgC/m ³
Lack of fit	u_{lof}	$u(x_i) = \frac{u_{lof} \times R_i}{\sqrt{3}} =$	0.064
Span drift	$u_{d,s}$	$u(x_i) = \frac{u_{d,s} \times R_i}{\sqrt{3}} =$	0.031
Repeatability Standard Deviation (span)	u_r	$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} =$	19.70
Losses / leakage in the sample system	u_{loss}	$u(x_i) = \frac{u_{loss} \times R_i}{\sqrt{3}} =$	8.45
Temperature dependant span drift	u_t	$u(x_i) = \frac{u_t}{100} \times R_i \times \sqrt{\frac{(x_{i,\max} - x_{adj})^2 + (x_{i,\min} - x_{adj})(x_{i,\max} - x_{adj}) + (x_{i,\min} - x_{adj})^2}{3}}$	0.030
Interferents	u_i	$u(x_i) = \frac{u_i \times R_i}{\sqrt{3}} =$	0.38
Uncertainty of Reference Gas	u_{ref}	$u(x_i) = \frac{u_{ref}}{\sqrt{3}} =$	15.06
Effect of Voltage Fluctuation	u_v	$u(x_i) = \frac{u_v \times R_i}{\sqrt{3}} =$	0.16
Effect of Oxygen Synergism	u_{syn}	$u(x_i) = \frac{u_{syn} \times R_i}{\sqrt{3}} =$	0.40
Combined Standard Uncertainty		$u_c = \sqrt{u_{lof}^2 + u_{d,s}^2 + u_r^2 + u_{loss}^2 + u_t^2 + u_i^2 + u_{ref}^2}$	26.20
Expanded measurement uncertainty (at 95% confidence)		$U_{EXP} = 2 \times u_c$	52.40
Applied Span Concentration			1505.60
Measured Span Concentration, STP Dry Gas			1510.53
Expanded measurement uncertainty as % of Applied Span			3 %

* Signal 3030 FID

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TVOC Uncertainty of Measurement – CHP1 Clarke

A1 CHP1 - TVOC - Uncertainty of Measurement Results - Calculations Part 1

Performance Characteristics	Standard Uncertainty (% of Range)	Distribution	Divisor	Min Certified Range	
				O ₂ 0 - 25 %Vol	TVOC 0 - 15 mgC/m ³
Lack of fit ⁽¹⁾	u_{lof}	Rectangular	$\sqrt{3}$	0.13	0.73
Span drift ⁽²⁾	$u_{d,s}$			0.029	0.35
Losses / leakage in the sample system ⁽⁴⁾	u_{loss}			1.00	1.56
Temperature dependant span drift ⁽⁵⁾	u_t			0.070	0.30
Interferents ⁽¹⁾	u_i			0.56	4.39
Effect of Voltage Fluctuation ⁽⁷⁾	u_v			...	1.80
Effect of Oxygen Synergism ⁽⁷⁾	u_{syn}			...	

Notes:

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

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

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

Performance Characteristics	Uncertainty (Units of final measurement)	Distribution	Divisor	O ₂ 0 - 25 %Vol	TVOC 0 - 15 mgC/m ³
Lack of fit	u_{lof}	Rectangular	$\sqrt{3}$	0.019	0.064
Span drift	$u_{d,s}$			0.0041	0.031
Temperature dependant span drift	u_t			0.015	0.039
Interferents	u_i			0.081	0.38
Effect of Voltage Fluctuation (See Note)	u_v			...	0.16

A1 CHP1 - TVOC - Uncertainty of Measurement Results - Calculations Part 2

Performance Characteristics	Uncertainty (Units of final measurement)	Date & Time	O ₂ 0 - 25 %Vol	TVOC 0 - 15 mgC/m ³
Losses / leakage in the sample system	u_{loss}	09/03/17 14:55 - 15:54	0.072	26.53
Standard Error of Measured Value	u_{SE}	09/03/17 14:55 - 15:54	0.070	59.73
Uncertainty due to Moisture Correction ⁽⁶⁾	u_{H2O}	09/03/17 14:55 - 15:54	0.083	17.84

Effect on Uncertainty Caused by Oxygen

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

0.03

$$f_{O_2} = \frac{20.9\% - O_{2,ref}}{20.9\% - O_{2,measured}} = 1.1595$$

$$uf_{O_2} = \frac{u_{Corr_{O_2}}}{f_{O_2}} \times 100 = 2.19 \%$$

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

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

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,

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

A1 CHP1 - TVOC - Uncertainty of Measurement Results - Calculations Part 3

Uncertainty	Date & Time	O ₂ 0 - 25 %Vol	*TVOC 0 - 15 mgC/m ³
Measured Concentration	09/03/17 14:55 - 15:54	7.19	1699.02
Expanded Uncertainty as Percentage of Measured Concentration		4 %	8 %

$$\text{Combined Standard Uncertainty } u_c = \sqrt{u_{lof}^2 + u_{d,s}^2 + u_{loss}^2 + u_t^2 + u_i^2 + u_{v}^2 + u_{syn}^2}$$

$$\text{Expanded uncertainty (at 95\% confidence)} U_{exp} = 2 \times u_c$$

- 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 applied span concentration
- Expressed as a percentage of the certified range per one degree centigrade
- Where the uncertainty of moisture is taken from the manual extract test calculations.
- Expressed as a percentage of the certified range
- Where no uncertainty is presented above, the uncertainty is > 100%

Environmental Compliance Limited

Bryn Power Limited
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TVOC Uncertainty of Measurement – CHP2 Edina

CHP2 - TVOC - Uncertainty of Measurement Results - Calculations Part 1

Performance Characteristics	Standard Uncertainty (% of Range)	Distribution	Divisor	Min Certified Range	
				O ₂ 0 - 25 %Vol	TVOC 0 - 15 mgC/m ³
Lack of fit ⁽¹⁾	u_{lof}	Rectangular	$\sqrt{3}$	0.13	0.73
Span drift ⁽²⁾	u_{ds}			0.029	0.35
Losses / leakage in the sample system ⁽⁴⁾	u_{loss}			1.00	1.56
Temperature dependant span drift ⁽⁵⁾	u_t			0.070	0.30
Interferents ⁽¹⁾	u_i			0.56	4.39
Effect of Voltage Fluctuation ⁽⁷⁾	u_v			...	1.80
Effect of Oxygen Synergism ⁽⁷⁾	u_{syn}			...	

Notes:

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

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

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

Performance Characteristics	Uncertainty (Units of final measurement)	Distribution	Divisor	O ₂ 0 - 25 %Vol	TVOC 0 - 15 mgC/m ³
Lack of fit	u_{lof}	Rectangular	$\sqrt{3}$	0.019	0.064
Span drift	u_{ds}			0.0041	0.031
Temperature dependant span drift	u_t			0.015	0.039
Interferents	u_i			0.081	0.38
Effect of Voltage Fluctuation (See Note)	u_v			...	0.16

CHP2 - TVOC - Uncertainty of Measurement Results - Calculations Part 2

Performance Characteristics	Uncertainty (Units of final measurement)	Date & Time	O ₂ 0 - 25 %Vol	TVOC 0 - 15 mgC/m ³
Losses / leakage in the sample system	u_{loss}	09/03/17 12:53 - 13:52	0.078	15.56
Standard Error of Measured Value	u_{SE}	09/03/17 12:53 - 13:52	0.011	4.20
Uncertainty due to Moisture Correction ⁽⁶⁾	u_{H2O}	09/03/17 12:53 - 13:52	0.082	9.49

Effect on Uncertainty Caused by Oxygen

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

0.03

$$f_{O_2} = \frac{20.9\% - O_{2,ref}}{20.9\% - O_{2,measured}} = 1.2157$$

$$u_{f_{O_2}} = \frac{u_{Corr_{O_2}}}{f_{O_2}} \times 100 = 2.29 \%$$

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,

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

CHP2 - TVOC - Uncertainty of Measurement Results - Calculations Part 3

Uncertainty	Date & Time	O ₂ 0 - 25 %Vol	*TVOC 0 - 15 mgC/m ³
Measured Concentration	09/03/17 12:53 - 13:52	7.82	996.70
Expanded Uncertainty as Percentage of Measured Concentration		4 %	4 %

$$\text{Combined Standard Uncertainty } u_c = \sqrt{u_{lof}^2 + u_{ds}^2 + u_{loss}^2 + u_t^2 + u_{SE}^2 + u_{H2O}^2 + u_{f_{O_2}}^2 + u_{syn}^2}$$

$$\text{Expanded uncertainty (at 95\% confidence)} U_{exp} = 2 \times u_c$$

- 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 applied span concentration
- Expressed as a percentage of the certified range per one degree centigrade
- Where the uncertainty of moisture is taken from the manual extract test calculations.
- Expressed as a percentage of the certified range
- Where no uncertainty is presented above, the uncertainty is > 100%

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Combustion Gases Measurement Uncertainty

Measurement Uncertainty Calculations Part 1

Horiba PG 250 Performance Characteristics	Standard Uncertainty (% of Range)	Distributioun	Minimum Certified Range (R _i)			
			NO 0 - 125 mg/m ³	CO 0 - 95 mg/m ³	O ₂ 0 - 25 %Vol	CO ₂ 0 - 20 %Vol
Lack of fit ⁽¹⁾	u_{lof}	Rectangular (Divisor = $\sqrt{3}$)	0.40	0.40	0.13	0.60
Span drift ⁽²⁾	$u_{d,s}$	Rectangular (Divisor = $\sqrt{3}$)	0.27	0.29	0.029	0.24
Repeatability Standard Deviation (span) ⁽³⁾	u_r	Normal (Divisor = 1)	0.82	0.84	0.60	0.36
Losses / leakage in the sample system ⁽⁴⁾	u_{loss}	Rectangular (Divisor = $\sqrt{3}$)	1.76	1.13	0.84	0.54
Temperature dependant span drift ⁽⁵⁾	u_t	Rectangular (Divisor = $\sqrt{3}$)	0.18	0.050	0.070	0.040
Interferents ⁽¹⁾	u_i	Rectangular (Divisor = $\sqrt{3}$)	1.20	2.90	0.56	0.010
Uncertainty of Reference Gas ⁽⁶⁾	u_{ref}	Rectangular (Divisor = $\sqrt{3}$)	9.29	4.37	0.15	0.31

Note:

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

- 1 Expressed as a percentage of the certified range
- 2 Expressed as a percentage of the certified range as maximum drift per 24hr period
- 3 Expressed as a percentage of the certified range
- 4 Expressed as a percentage of the certified range
- 5 Expressed as a percentage of the certified range per one degree centigrade
- 6 Expressed as standard uncertainty in units of measurement i.e. mg/m³ / %Vol inc additional uncertainty of 2% for gas blending
- 7 Applies to TVOC only

Measurement Uncertainty Calculations Part 2

Horiba PG 250 Performance Characteristics	Uncertainty	Value of Standard Uncertainty	NO 0 - 125 mg/m ³	CO 0 - 95 mg/m ³	O ₂ 0 - 25 %Vol	CO ₂ 0 - 20 %Vol
Lack of fit	u_{lof}	$u(x_i) = \frac{u_{lof} \times R_i}{\sqrt{3}} =$	0.29	0.22	0.019	0.07
Span drift	$u_{d,s}$	$u(x_i) = \frac{u_{d,s} \times R_i}{\sqrt{3}} =$	0.20	0.16	0.0041	0.0280
Repeatability Standard Deviation (span)	u_r	$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} =$	0.82	0.84	0.60	0.36
Losses / leakage in the sample system	u_{loss}	$u(x_i) = \frac{u_{loss} \times R_i}{\sqrt{3}} =$	1.27	0.62	0.12	0.06
Temperature dependant span drift	u_t	$u(x_i) = \frac{u_t}{100} \times R_i \times \sqrt{\frac{(x_{i,\max} - x_{i,\text{adj}})^2 + (x_{i,\min} - x_{i,\text{adj}})(x_{i,\max} - x_{i,\text{adj}}) + (x_{i,\min} - x_{i,\text{adj}})^2}{3}}$	0.25	0.053	0.020	0.009
Interferents	u_i	$u(x_i) = \frac{u_i \times R_i}{\sqrt{3}} =$	0.87	1.59	0.081	0.01
Uncertainty of Reference Gas	u_{ref}	$u(x_i) = \frac{u_{ref}}{\sqrt{3}} =$	5.36	2.52	0.087	0.18
Combined Standard Uncertainty		$u_c = \sqrt{u_{lof}^2 + u_{d,s}^2 + u_r^2 + u_{loss}^2 + u_t^2 + u_i^2 + u_{ref}^2}$	5.65	3.17	0.62	0.42
Expanded measurement uncertainty (at 95% confidence)		$U_{EXP} = 2 \times u_c$	11.31	6.34	1.25	0.83
Applied Span Concentration			536.08	252.13	15.12	17.99
Measured Span Concentration, STP Dry Gas			533.44	252.90	15.20	17.90
Expanded measurement uncertainty as % of Applied Span			2%	3%	8%	5%

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Combustion Gases Uncertainty of Measurement – CHP1 Clarke

Uncertainty of Measurement Results - Calculations Part 1

Horiba PG 250 Performance Characteristics	Standard Uncertainty (% of Range)	Distribution	Divisor	Minimum Certified Range (R _i)			
				NO 0 - 125 mg/m ³	CO 0 - 95 mg/m ³	O ₂ 0 - 25 %Vol	CO ₂ 0 - 20 %Vol
Lack of fit ⁽¹⁾	u_{lof}	Rectangular	$\sqrt{3}$	0.40	0.40	0.13	0.60
Span drift ⁽²⁾	$u_{d,s}$			0.27	0.29	0.029	0.24
Losses / leakage in the sample system ⁽⁴⁾	u_{loss}			1.76	1.13	0.61	0.54
Temperature dependant span drift ⁽³⁾	u_t			0.18	0.050	0.070	0.040

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 250 Performance Characteristics	Uncertainty (Units of final measurement)	Distribution	Divisor	NO 0 - 125 mg/m ³	CO 0 - 95 mg/m ³	O ₂ 0 - 25 %Vol	CO ₂ 0 - 20 %Vol
Lack of fit	u_{lof}	Rectangular	$\sqrt{3}$	0.29	0.22	0.019	0.069
Span drift	$u_{d,s}$			0.20	0.16	0.0041	0.028
Temperature dependant span drift	u_t			0.086	0.018	0.0067	0.0092
Interferents	u_i			0.87	1.59	0.081	...

Uncertainty of Measurement Results - Calculations Part 2

Horiba PG 250 Performance Characteristics	Uncertainty (Units of final measurement)	Date & Time	NO 0 - 125 mg/m ³	CO 0 - 95 mg/m ³	O ₂ 0 - 25 %Vol	CO ₂ 0 - 20 %Vol
Losses / leakage in the sample system	u_{loss}	09/03/17 15:42 - 16:41	1.42	13.10	0.047	0.060
Standard Error of Measured Value	u_{SE}	09/03/17 15:42 - 16:41	2.31	12.20	0.0073	0.013

Effect on Uncertainty Caused by Oxygen

$$u_{Corr_{O_2}} = \frac{20.9\% - O_{2,ref}}{(20.9\% - O_{2,measured})(20.9\% - O_{2,measured})} \times \text{Uncertainty of } O_2 \text{ Measurement} = 0.027$$

$$f_{O_2} = \frac{20.9\% - O_{2,ref}}{20.9\% - O_{2,measured}} = 2.0698 \quad u_{f_{O_2}} = \frac{u_{Corr_{O_2}} \times n_{O_2}}{f_{O_2}} \times 100 = 1.32 \%$$

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 250 Uncertainty	Date & Time	NOx (as NO2) 0 - 125 mg/m ³	CO 0 - 95 mg/m ³	O ₂ 0 - 25 %Vol	CO ₂ 0 - 20 %Vol
Measured Concentration	09/03/17 15:42 - 16:41	80.52	1163.39	7.68	11.19
Expanded Uncertainty as Percentage of Measured Concentration		7%	3%	3%	2%

Combined Standard Uncertainty

$$u_c = \sqrt{u_{lof}^2 + u_{d,s}^2 + u_{loss}^2 + u_t^2 + u_i^2 + u_{ref}^2 + u_{syn}^2}$$

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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Combustion Gases Uncertainty of Measurement – CHP2 Edina

Uncertainty of Measurement Results - Calculations Part 1

Horiba PG 250 Performance Characteristics	Standard Uncertainty (% of Range)	Distribution	Divisor	Minimum Certified Range (R _i)			
				NO 0 - 125 mg/m ³	CO 0 - 95 mg/m ³	O ₂ 0 - 25 %Vol	CO ₂ 0 - 20 %Vol
Lack of fit ⁽¹⁾	u_{lof}	Rectangular	$\sqrt{3}$	0.40	0.40	0.13	0.60
Span drift ⁽²⁾	$u_{d,s}$			0.27	0.29	0.029	0.24
Losses / leakage in the sample system ⁽⁴⁾	u_{loss}			1.76	1.13	0.61	0.54
Temperature dependant span drift ⁽³⁾	u_t			0.18	0.050	0.070	0.040

Notes:

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

For $u(x_i) = \Delta x_i \sqrt{\frac{(x_{i,max} - x_{i,adj})^2 + (x_{i,min} - x_{i,adj})^2 + (x_{i,max} - x_{i,adj}) + (x_{i,min} - x_{i,adj})^2}{3}}$, 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 250 Performance Characteristics	Uncertainty (Units of final measurement)	Distribution	Divisor	NO 0 - 125 mg/m ³	CO 0 - 95 mg/m ³	O ₂ 0 - 25 %Vol	CO ₂ 0 - 20 %Vol
Lack of fit	u_{lof}	Rectangular	$\sqrt{3}$	0.29	0.22	0.019	0.069
Span drift	$u_{d,s}$			0.20	0.16	0.0041	0.028
Temperature dependant span drift	u_t			0.086	0.018	0.0067	0.0092
Interferents	u_i			0.87	1.59	0.081	...

Uncertainty of Measurement Results - Calculations Part 2

Horiba PG 250 Performance Characteristics	Uncertainty (Units of final measurement)	Date & Time	NO 0 - 125 mg/m ³	CO 0 - 95 mg/m ³	O ₂ 0 - 25 %Vol	CO ₂ 0 - 20 %Vol
Losses / leakage in the sample system	u_{loss}	09/03/17 13:09 - 14:08	8.78	9.24	0.048	0.062
Standard Error of Measured Value	u_{SE}	09/03/17 13:09 - 14:08	0.92	0.27	0.0028	0.0026

Effect on Uncertainty Caused by Oxygen

$$u_{Corr_{O_2}} = \frac{20.9\% - O_{2,ref}}{(20.9\% - O_{2,measured})(20.9\% - O_{2,measured})} \times \text{Uncertainty of } O_2 \text{ Measurement} = 0.028$$

$$f_{O_2} = \frac{20.9\% - O_{2,ref}}{20.9\% - O_{2,measured}} = 2.0261 \quad uf_{O_2} = \frac{u_{Corr_{O_2}} \times f_{O_2}}{f_{O_2}} \times 100 = 1.38 \%$$

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

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

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 250 Uncertainty	Date & Time	NOx (as NO2) 0 - 125 mg/m ³	CO 0 - 95 mg/m ³	O ₂ 0 - 25 %Vol	CO ₂ 0 - 20 %Vol
Measured Concentration	09/03/17 13:09 - 14:08	499.46	820.85	7.85	11.56
Expanded Uncertainty as Percentage of Measured Concentration		4%	3%	3%	2%

Combined Standard Uncertainty

$$u_c = \sqrt{u_{lof}^2 + u_{d,s}^2 + u_{loss}^2 + u_t^2 + u_i^2 + u_{ref}^2 + u_{syn}^2}$$

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%