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Test Report

UKAS TESTING
0002

MCERTS
THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

BS EN 14181 QAL2 TESTING FOR INTERTEK LIMITED AT SOUTH HOOK LNG TERMINAL

SCV 2A

15TH - 17TH NOVEMBER 2021

Permit Number:	XP3538LD
Operator Name:	South Hook LNG
Installation Name:	South Hook LNG Terminal
Client Name:	Intertek Limited
Client Address:	Unit 14 - Waterston Industrial Estate Main Road Waterston, Milford Haven SA73 3SL
Monitoring Organisation Name:	National Physical Laboratory
Monitoring Organisation Address:	Hampton Road Teddington Middlesex TW11 0LW

Reference: XP3538LD/INTERTEK/SHLNG/OCT2021/SCV2A/QAL2/01/V1
Date of Issue: 21st December 2021

MCERTS Level 2 Approval
Name: Chris Dimopoulos
Signature:

MCERTS ID & TEs: MM-07-812, Level 2 with TEs 1 - 4
Position: Project Manager

NPL Authorised Signature
Name: Mr Rod Robinson (for NPLML)
Signature:

CONTENTS PAGE

1.1 Summary of Results

Stack Designation:	SCV 2A		Testing:	QAL2	
Species Monitored	Calibration Function	Valid Calibration Range	Extrapolated Range	Test of Variability	Test of Calibration
Oxides of Nitrogen (as NO2)	y = 0.88 -2.93	0 - 65 mg/m³	0 - 145.2 mg/m³	PASS	N/A
Oxygen	y = 1.02 + 0.01	0 - 12.8 %	N/A	PASS	N/A

Recommendations:	None

Note that once the calibration function has been calculated and applied to the CEM, it will only remain valid for as long as the QAL3 data remains within the control limits, and that no manual adjustments are made to the CEMs other than those allowed to bring the settings back within the QAL3 control limits.

1.2 Deviations

Were there any deviations from the SRM?	No
Were there any deviations from BS EN 14181?	The parallel measurements were postponed by approximately one month as SCV 2A was offline when it was due to be monitored. The oxygen linearity checks could not be repeated and therefore it was outside the one month requirement to be carried out prior to the parallel measurements.
Do any deviations have an impact on the results?	The linearity checks exceeded the required timeframe by a few weeks so should have minimal/no impact on results.
Are any actions required?	None

1.3 Introduction

NPL were awarded a contract by Intertek Limited to perform a QAL2 at South Hook LNG Terminal on the CEMs (Continuous Emission Monitoring Systems) installed on SCV 2A. This was carried out to ensure compliance to BS EN 14181.

NPL achieved this by carrying out a series of parallel measurements using the relevant SRMs (Standard Reference Method), and comparing the findings against the site CEM. This data was then used to investigate whether the QAL2 calibration was valid, and that any variability still remains within acceptable limits.

NPL carried out the testing between the 15th and 17th November 2021.

Section 2 - Information about the Regulated Installation

2.1 Regulatory Information

2.1.1 - Name of the Installation	South Hook LNG Terminal
2.1.2 - Address of the Installation	Unit 14 - Waterston Industrial Estate
	Main Road
	Waterston, Milford Haven
	SA73 3SL
2.1.3 - Sector for the Installation	LNG Regassification
2.1.4 - Date of the last QAL2/AST	September 2020

2.1.5 - Regulated Determinands and Emission Limit Values				
Determinand	Emission Point	Short Term ELV (Half Hourly Average)	Daily Average ELV	Uncertainty Requirements
Oxides of Nitrogen (as NO2)	SCV 2A	-	107 mg/m³	20%
Oxygen	SCV 2A	-	21 %	10%
Reference Conditions - 273K, 101.3kPa, 3% Oxygen on a Dry Gas Basis				

There are no actual emission limit values set out in the permit for oxygen and moisture, a virtual ELV as well as a virtual uncertainty requirement is set in order to carry out the variability tests (see TGN M20 Section 3.5.17).

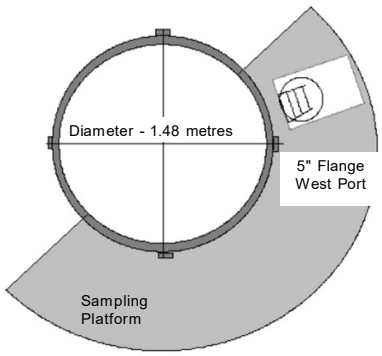
2.2 Operational Information and Site Monitoring Provisions

2.2.1 - Type of Process	The SCVs operate as batch processes and are turned on and off depending upon the current regasification demand. As a result the process loading can vary.
	The oxides of nitrogen and oxygen emissions are not expected to vary much during the monitoring. Historical data indicates emission levels will be suitable to carry out a QAL2, however there will be little variation.
	No species under test are expected to have emissions near zero.
2.2.2 - Type of Fuel	A small amount of LNG is used as fuel during the regasification process. The load typically varies from 140-160 tonnes per hour.
2.2.3 - Abatement	There is a water injection system which is used to reduce oxides of nitrogen emissions. This was in operation during the monitoring visit.

2.3 Monitoring Provisions at the Installation - Periodic Monitoring

2.3.1 Stack & Sampling Ports

Type of Stack	Circular	
Dimensions	Area - 1.72 m³	Diameter - 1.48 m
Location of Ports	Sampling platform	
Number of Sampling Ports	2	
Number of Sample Lines	2	



2.3.2 Monitoring Platform and Site Provisions

Requirement	Compliant?	Notes
A safe and clean working environment with sufficient space and weather protection	Yes	There is a suitably sized platform to carry out the monitoring on both SCVs, however there is minimal weather protection.
Easy and safe access to the CEM	Yes	The CEMs are located in an air conditioned container between SCV phases one and two.
Adequate supplies of reference materials, tools and spare parts	Yes	The site has some materials in the CEM container as well as their stores.
Facilities to introduce the reference materials for gaseous-monitoring systems both at the inlet of the sampling line (where present), and the inlet of the CEM	Yes	Reference gases can be introduced straight into the CEM system as well as down a separate line that connects to the inlet of the sampling system.
Compliance with MID 15259?	Yes	The sampling platform is of a sufficient size to use the sampling equipment required to perform extractive gaseous analysis.

2.3.3 Sample - How Representative is it?

Homogeneity testing to BS EN 15259 has been carried out on SCV 2A and all species passed. Report reference - INTK11JUL11.

Highest/Lowest Flow Ratio: N/A (Ratio must be to 3:1 or lower)

2.4 Continuous Emission Monitoring Systems (CEMs) at the Installation

2.4.1 CEMs Details

Species	Type	Brand & Model	MCERTs Certificate	Certified Range	Principle	Sampling Location	QAL1 Compliance
Oxides of Nitrogen	Extractive	Siemens Ultramat 23	MC 040033	NO-100 mg/m³	NDIR	Sampling platform	Yes
Oxygen	Extractive	Siemens Oxymat 6F	MC 040032	0 - 5% & 0 - 25%	Paramagnetic	Sampling platform	Yes

No moisture measurements are carried out.

2.4.2 Peripheral Measurements

No temperature and pressure corrections are required. As the sampled gas is dried before measurement no moisture data is required. Oxygen is measured by the Oxymat.

Section 3 - Information about the Monitoring Campaign

3.1 Test Laboratory Staff

Name	MCERTS Number	Certification Level and Expiry Date (if applicable)					
		Level 1	Level 2	TE1	TE2	TE3	TE4
Matthew Ellison	MM-05-682	N/A	Jul - 2023	Sep - 2023	Sep - 2023	Dec - 2023	Sep - 2023
Ann-Marie Leman	MM-19-1562	N/A	N/A	N/A	N/A	N/A	N/A
Richard Harvey	MM-02-020	N/A	Dec - 2025	Nov - 2022	Mar - 2025	Mar - 2026	Dec - 2025

3.2 Standard Reference Methods (SRMs)

Determinand	SRM Standard	Type & Principle	Operational Range	Certified Range	Uncertainty	UKAS Accreditation
Oxides of Nitrogen	EN 14792:2017	Horiba PG-250 SRM Chemiluminesence	0 - 100 ppm	0 - 130 mg/m³	10%	Yes
Oxygen	EN 14789:2017	Horiba PG-250 SRM Paramagnetic	0 - 25%	0 - 25%	6%	Yes

Section 4 - Data and Calculations - QAL2

4.1 - Oxides of Nitrogen QAL2 Calculations - Siemens Ultramat 23

In order to determine a valid calibration function it is necessary to carry out at least fifteen tests using the SRM and comparing the results against the values obtained from the on site CEM. The SRM measurements are then corrected to the same conditions as the on site CEM to allow a direct comparison. The range of results from these parallel measurements then determine what procedure is used to calculate the calibration function. This is explained further later.

After the calibration function has been determined a variability test is performed to ensure that the derived values fall within the required uncertainty budget. The SRM values are compared against the calibrated CEM results (see BS EN 14181:2014 section 6).

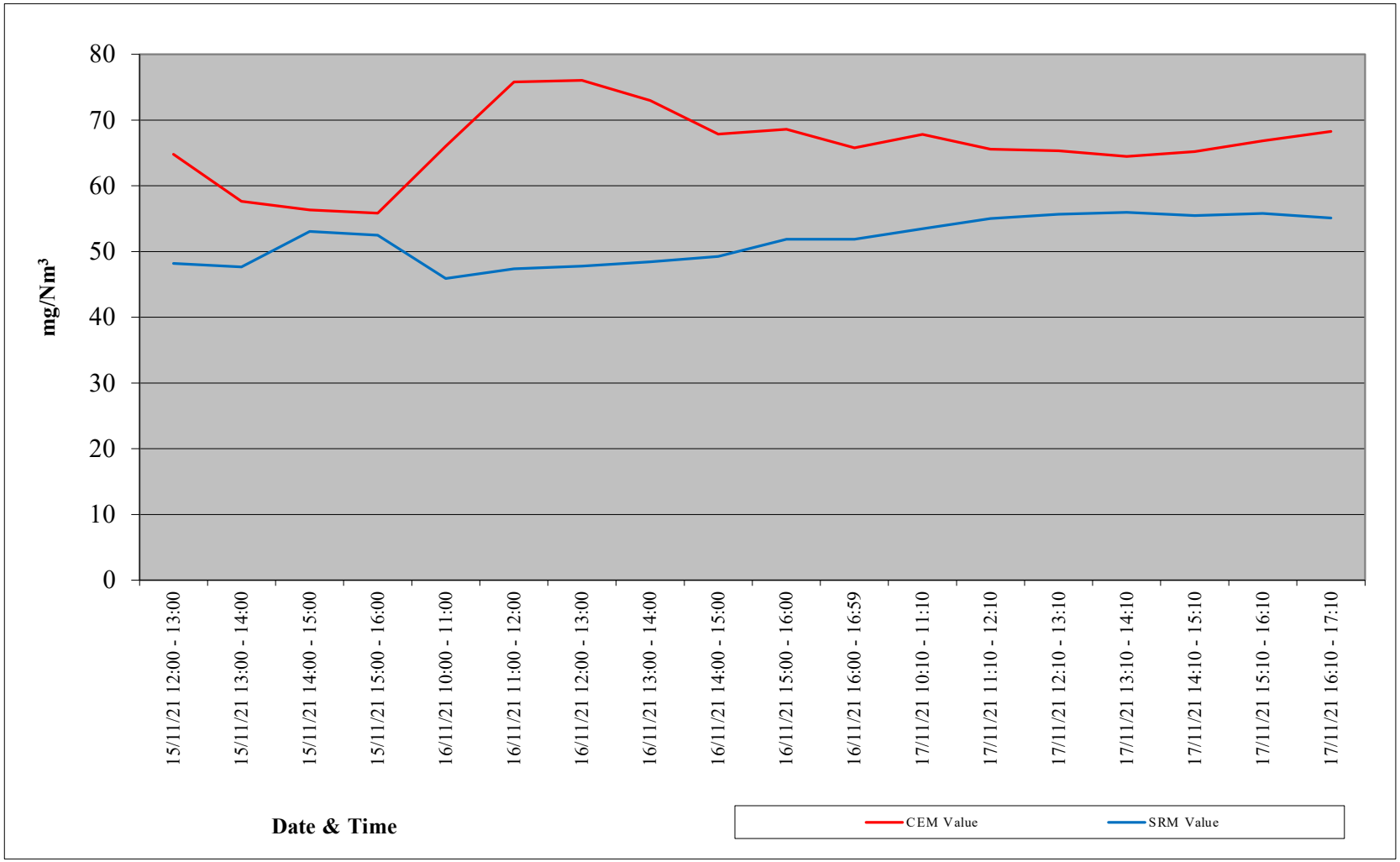
4.1.1 - Raw Monitoring Data CEM Monitoring Conditions:- mg/m3, 273K, 101.3 kPa, on a dry gas basis.

Test Number	Test Date	Test Time	Raw CEM Result	CEM Peripheral Measurements				Raw SRM Result	SRM Peripheral Measurements				SRM Result at CEM Conditions
				Temp	Pressure	Oxygen	Moisture		Temp	Pressure	Oxygen	Moisture	
	dd/mm/yyyy	(hh:mm-hh:mm)	mg/m^3	^oC	kPa	%Vol	%Vol	ppm	^oC	kPa	%Vol	%Vol	mg/m^3
1	15/11/2021	12:00 - 13:00	22.6	N/A	N/A	11.4	N/A	12.2	N/A	N/A	11.7	N/A	16.3
2	15/11/2021	13:00 - 14:00	20.1	N/A	N/A	11.4	N/A	12.0	N/A	N/A	11.7	N/A	16.1
3	15/11/2021	14:00 - 15:00	20.8	N/A	N/A	10.8	N/A	14.3	N/A	N/A	11.0	N/A	19.1
4	15/11/2021	15:00 - 16:00	21.2	N/A	N/A	10.5	N/A	14.6	N/A	N/A	10.8	N/A	19.5
5	16/11/2021	10:00 - 11:00	24.9	N/A	N/A	10.6	N/A	12.8	N/A	N/A	10.7	N/A	17.1
6	16/11/2021	11:00 - 12:00	28.7	N/A	N/A	10.6	N/A	13.2	N/A	N/A	10.7	N/A	17.7
7	16/11/2021	12:00 - 13:00	28.8	N/A	N/A	10.6	N/A	13.3	N/A	N/A	10.7	N/A	17.9
8	16/11/2021	13:00 - 14:00	27.6	N/A	N/A	10.6	N/A	13.5	N/A	N/A	10.7	N/A	18.1
9	16/11/2021	14:00 - 15:00	25.5	N/A	N/A	10.6	N/A	13.7	N/A	N/A	10.7	N/A	18.3
10	16/11/2021	15:00 - 16:00	25.9	N/A	N/A	10.6	N/A	14.4	N/A	N/A	10.7	N/A	19.3
11	16/11/2021	16:00 - 16:59	24.7	N/A	N/A	10.6	N/A	14.4	N/A	N/A	10.8	N/A	19.2
12	17/11/2021	10:10 - 11:10	24.8	N/A	N/A	10.9	N/A	14.1	N/A	N/A	11.2	N/A	18.9
13	17/11/2021	11:10 - 12:10	24.1	N/A	N/A	10.9	N/A	14.4	N/A	N/A	11.3	N/A	19.3
14	17/11/2021	12:10 - 13:10	24.0	N/A	N/A	10.8	N/A	14.6	N/A	N/A	11.3	N/A	19.6
15	17/11/2021	13:10 - 14:10	23.9	N/A	N/A	10.8	N/A	14.8	N/A	N/A	11.2	N/A	19.8
16	17/11/2021	14:10 - 15:10	24.1	N/A	N/A	10.8	N/A	14.7	N/A	N/A	11.2	N/A	19.6
17	17/11/2021	15:10 - 16:10	24.6	N/A	N/A	10.8	N/A	14.8	N/A	N/A	11.2	N/A	19.8
18	17/11/2021	16:10 - 17:10	24.9	N/A	N/A	10.9	N/A	14.5	N/A	N/A	11.3	N/A	19.4

4.1.2 - Oxides of Nitrogen Standardised Monitoring Data

Test Number	Test Date & Time	CEM Result at standard conditions	SRM Result at standard conditions
	dd/mm/yy hh:mm - hh:mm	mg/Nm^3	mg/Nm^3
1	15/11/21 12:00 - 13:00	64.8	48.2
2	15/11/21 13:00 - 14:00	57.6	47.7
3	15/11/21 14:00 - 15:00	56.3	53.0
4	15/11/21 15:00 - 16:00	55.8	52.5
5	16/11/21 10:00 - 11:00	66.0	45.9
6	16/11/21 11:00 - 12:00	75.8	47.4
7	16/11/21 12:00 - 13:00	76.0	47.7
8	16/11/21 13:00 - 14:00	72.9	48.4
9	16/11/21 14:00 - 15:00	67.8	49.3
10	16/11/21 15:00 - 16:00	68.6	51.9
11	16/11/21 16:00 - 16:59	65.7	51.9
12	17/11/21 10:10 - 11:10	67.8	53.5
13	17/11/21 11:10 - 12:10	65.6	55.0
14	17/11/21 12:10 - 13:10	65.3	55.7
15	17/11/21 13:10 - 14:10	64.5	56.0
16	17/11/21 14:10 - 15:10	65.2	55.5
17	17/11/21 15:10 - 16:10	66.8	55.8
18	17/11/21 16:10 - 17:10	68.2	55.1

4.1.3 - Plot 1 Time Series of Standardised Values for Oxides of Nitrogen



4.1.4 - Calculation and Elimination of Outliers

A test for outliers is carried out on the set of parallel measurements to make sure any invalid data is identified and removed, as this can have a negative effect on the final calibration function. The method used on this data set is set out in the Environment Agency TGN M20 (section 3.5.13 (ii)).
This procedure looks at the difference between raw CEM values and the parallel SRM measurement at CEM conditions, these differences should have an even spread. There will be an average of these differences as well as a standard deviation. If the difference between a parallel measurement and the average of all the differences is greater than two standard deviations then there is a strong chance it is an outlier and should be rejected from the data set. This test is only carried out once and need not be applied at all if the regression factor of the data set is above 0.9.

All outliers have been identified subsequently with an orange background, they are contained in the data sets for illustrative purposes but have not been used in the calculations.

4.1.5 - Determination of Method A, Method B or Method C?

Different installations give different spreads of data and can prove difficult when calculating a calibration function. As a result there are three main methods used, Method A, Method B and Method C (see BS EN 14181:2014 Page 19).

Method A is used if the spread of SRM results at reference conditions taken during the parallel measurements is equal to or greater than the permissible uncertainty of the CEM. This suggests there is a good spread of data.

Method B is used if the spread of SRM results at reference conditions taken during the parallel measurements is less than the permissible uncertainty of the CEM, and the lowest SRM result is greater than 15% of the ELV. This suggests there is a high cluster of data, so surrogate zero data is used to determine the offset of the CEM. However it is important to confirm that the analyser gives a reading at or near zero when the emissions are zero.

Method C is used if the spread of SRM results at reference conditions taken during the parallel measurements is less than the permissible uncertainty of the CEM, and the lowest SRM result is less than 15% of the ELV. This suggests there is a low cluster of data. As a result two surrogate data points are added to the parallel measurements, one at zero and one at or near the ELV, and converted to the measuring conditions of the CEM using average peripheral results. The calibration function is then calculated using the procedure set out in Method A.

Highest SRM measurement at reference conditions -	56.0	mg/m^3			
Lowest SRM measurement at reference conditions -	45.9	mg/m^3			
Spread of data -	10.1	mg/m^3			
Permissible Uncertainty of the CEM	21.4	mg/m^3	15% of the ELV -	16.1	mg/m^3

The spread of data is less than the permissible uncertainty of the CEM and the lowest SRM measurement at reference conditions is greater than or equal to 15% of the ELV. Therefore Method B has been chosen to calculate the calibration function.

4.1.6 - Oxides of Nitrogen Data Used to Calculate the Calibration Function

In order to calculate a valid QAL2 calibration function the parallel measurements obtained from testing are compared and analysed. To do this the SRM results are corrected to the same conditions at which the CEM takes its readings.

The measuring conditions at which the CEM takes its readings are mg/m3, 273K, 101.3 kPa, on a dry gas basis.

Test Number	Test Date	Test Time	CEM Reading	SRM Reading at CEM Conditions
	dd/mm/yyyy	hh:mm - hh:mm	mg/m^3	mg/m^3
1	15/11/2021	12:00 - 13:00	22.6	16.3
2	15/11/2021	13:00 - 14:00	20.1	16.1
3	15/11/2021	14:00 - 15:00	20.8	19.1
4	15/11/2021	15:00 - 16:00	21.2	19.5
5	16/11/2021	10:00 - 11:00	24.9	17.1
6	16/11/2021	11:00 - 12:00	28.7	17.7
7	16/11/2021	12:00 - 13:00	28.8	17.9
8	16/11/2021	13:00 - 14:00	27.6	18.1
9	16/11/2021	14:00 - 15:00	25.5	18.3
10	16/11/2021	15:00 - 16:00	25.9	19.3
11	16/11/2021	16:00 - 16:59	24.7	19.2
12	17/11/2021	10:10 - 11:10	24.8	18.9
13	17/11/2021	11:10 - 12:10	24.1	19.3
14	17/11/2021	12:10 - 13:10	24.0	19.6
15	17/11/2021	13:10 - 14:10	23.9	19.8
16	17/11/2021	14:10 - 15:10	24.1	19.6
17	17/11/2021	15:10 - 16:10	24.6	19.8
18	17/11/2021	16:10 - 17:10	24.9	19.4

4.1.7 - Calculation Determination of the Calibration Function using Method B for Oxides of Nitrogen

Table Summarising Values used in QAL2 Calibration Value Calculation

Test No.	Date	Time	SRM Value at CEM Conditions	CEM Signal				
			yi	xi	xi - xbar	yi - ybar	(xi - xbar)*(yi - ybar)	$(xi - xbar)^2$
No.	dd/mm/yyyy	hh:mm - hh:mm	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3
1	15/11/2021	12:00 - 13:00	16.3	22.6	-1.9	-2.3	4.4	3.6
2	15/11/2021	13:00 - 14:00	16.1	20.1	-4.4	-2.5	11.2	19.8
3	15/11/2021	14:00 - 15:00	19.1	20.8	-3.7	0.5	-1.9	13.5
4	15/11/2021	15:00 - 16:00	19.5	21.2	-3.3	0.9	-2.8	10.7
5	16/11/2021	10:00 - 11:00	17.1	24.9	0.4	-1.5	-0.6	0.2
6	16/11/2021	11:00 - 12:00	17.7	28.7	4.2	-0.9	-3.9	17.5
7	16/11/2021	12:00 - 13:00	17.9	28.8	4.2	-0.8	-3.2	18.0
8	16/11/2021	13:00 - 14:00	18.1	27.6	3.1	-0.5	-1.7	9.6
9	16/11/2021	14:00 - 15:00	18.3	25.5	1.0	-0.3	-0.3	1.0
10	16/11/2021	15:00 - 16:00	19.3	25.9	1.4	0.7	1.0	1.9
11	16/11/2021	16:00 - 16:59	19.2	24.7	0.2	0.6	0.1	0.0
12	17/11/2021	10:10 - 11:10	18.9	24.8	0.3	0.3	0.1	0.1
13	17/11/2021	11:10 - 12:10	19.3	24.1	-0.4	0.7	-0.3	0.2
14	17/11/2021	12:10 - 13:10	19.6	24.0	-0.5	0.9	-0.4	0.2
15	17/11/2021	13:10 - 14:10	19.8	23.9	-0.6	1.2	-0.8	0.4
16	17/11/2021	14:10 - 15:10	19.6	24.1	-0.5	1.0	-0.5	0.2
17	17/11/2021	15:10 - 16:10	19.8	24.6	0.1	1.2	0.1	0.0
18	17/11/2021	16:10 - 17:10	19.4	24.9	0.4	0.8	0.3	0.2
Zero	Surrogate	Data	0	3.3				
		Average =	**18.61**	**24.51**		**Sum =**	**0.84**	**97.10**

4.1.7 - Calculation Determination of the Calibration Function

The calibration function is described as:

$$y_i = a + bx_i$$

whereby,

x_i is the result from the CEM
y_i is the result from the SRM
a is the intercept
b is the slope
Z is the zero offset

Z = 3.333333

The slope (b) is calculated first with the following calculation:

$$\hat{b} = \frac{\bar{y}}{\bar{x} - Z}$$

whereby,

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i = 24.51$$

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i = 18.61$$

Therefore, ***b*** = 0.878991

Now that the slope has been calculated, the intercept (a) can then be determined:

$$\hat{a} = -\hat{b}Z$$

Therefore, ***a*** = -2.92997

The calibration function then becomes:

$$\hat{y}_i = \hat{a} + \hat{b}\,x_i$$

The calibration function then becomes:

$$\hat{y}_i = -2.93 + 0.88\,x_i$$

$\hat{y}_i$ = The calibrated CEM Output

x_i = The CEM Signal

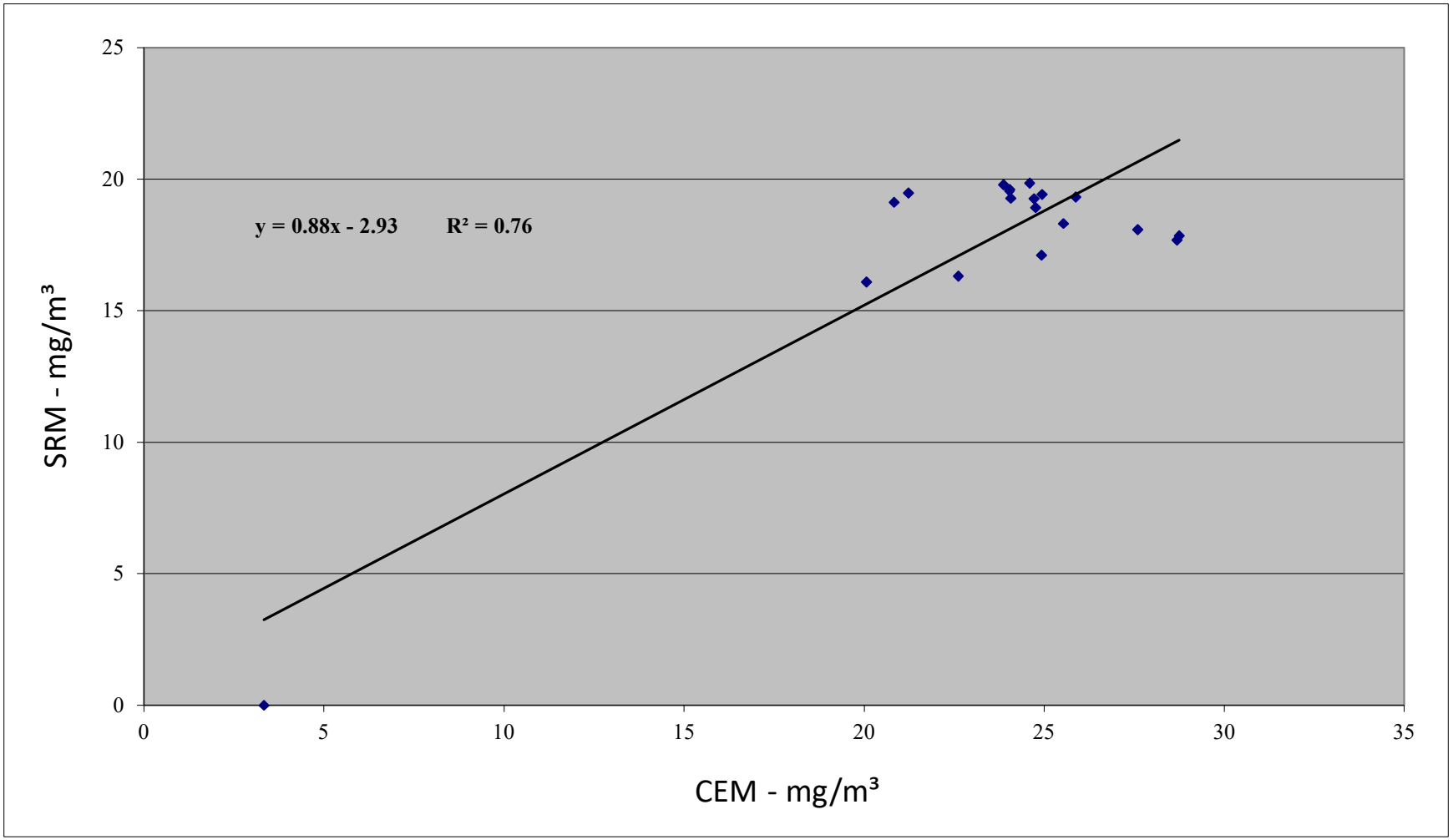
4.1.8 - Calculation of Calibrated CEM Values for Oxides of Nitrogen

Following the calculation of the calibration function, the CEM data can then be adjusted using this data. Finally the calibrated value is then corrected to reference conditions.

Reference Conditions - mg/m3, 273K, 101.3 kPa, 3% Oxygen on a dry gas basis.

Test No.	Date	Time	Raw CEM Value	Calibrated CEM Value at Stack Conditions	CEM Moisture Content	CEM Oxygen Content	CEM Calibrated Value at reference conditions
	dd/mm/yyyy	hh:mm-hh:mm	mg/m3	mg/m3	% Vol	% Vol	mg/m^3
1	15/11/2021	12:00 - 13:00	22.6	16.9	N/A	11.4	48.6
2	15/11/2021	13:00 - 14:00	20.1	14.7	N/A	11.4	42.3
3	15/11/2021	14:00 - 15:00	20.8	15.4	N/A	10.8	41.6
4	15/11/2021	15:00 - 16:00	21.2	15.7	N/A	10.5	41.4
5	16/11/2021	10:00 - 11:00	24.9	19.0	N/A	10.6	50.3
6	16/11/2021	11:00 - 12:00	28.7	22.3	N/A	10.6	58.9
7	16/11/2021	12:00 - 13:00	28.8	22.3	N/A	10.6	59.1
8	16/11/2021	13:00 - 14:00	27.6	21.3	N/A	10.6	56.4
9	16/11/2021	14:00 - 15:00	25.5	19.5	N/A	10.6	51.8
10	16/11/2021	15:00 - 16:00	25.9	19.8	N/A	10.6	52.5
11	16/11/2021	16:00 - 16:59	24.7	18.8	N/A	10.6	50.0
12	17/11/2021	10:10 - 11:10	24.8	18.8	N/A	10.9	51.6
13	17/11/2021	11:10 - 12:10	24.1	18.2	N/A	10.9	49.7
14	17/11/2021	12:10 - 13:10	24.0	18.2	N/A	10.8	49.4
15	17/11/2021	13:10 - 14:10	23.9	18.1	N/A	10.8	48.8
16	17/11/2021	14:10 - 15:10	24.1	18.2	N/A	10.8	49.4
17	17/11/2021	15:10 - 16:10	24.6	18.7	N/A	10.8	50.8
18	17/11/2021	16:10 - 17:10	24.9	19.0	N/A	10.9	52.0

4.1.9 - Plot 2 CEM vs SRM values measured at CEM conditions for Oxides of Nitrogen



4.1.10 - Data used for the Variability Test for Oxides of Nitrogen

The CEM data has had the QAL2 function applied, and been corrected to reference conditions, a test of variability can be carried out.

Test No.	Date	Time	Calibrated CEM value at reference conditions	SRM value at reference conditions	Difference	Difference minus average of the differences	Difference minus average of the differences, squared
					$D_i = y_{i,s}-y_{i,s}$	$D_i - D$	$(D_i - D)^2$
	dd/mm/yyyy	hh:mm - hh:mm	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3
1	15/11/2021	12:00 - 13:00	48.6	48.2	-0.3	-1.8	3.2
2	15/11/2021	13:00 - 14:00	42.3	47.7	5.4	4.0	15.8
3	15/11/2021	14:00 - 15:00	41.6	53.0	11.4	10.0	99.8
4	15/11/2021	15:00 - 16:00	41.4	52.5	11.1	9.7	93.7
5	16/11/2021	10:00 - 11:00	50.3	45.9	-4.4	-5.8	34.2
6	16/11/2021	11:00 - 12:00	58.9	47.4	-11.5	-13.0	168.0
7	16/11/2021	12:00 - 13:00	59.1	47.7	-11.3	-12.8	163.6
8	16/11/2021	13:00 - 14:00	56.4	48.4	-8.0	-9.4	88.5
9	16/11/2021	14:00 - 15:00	51.8	49.3	-2.5	-4.0	15.8
10	16/11/2021	15:00 - 16:00	52.5	51.9	-0.6	-2.1	4.4
11	16/11/2021	16:00 - 16:59	50.0	51.9	1.9	0.4	0.2
12	17/11/2021	10:10 - 11:10	51.6	53.5	1.9	0.5	0.2
13	17/11/2021	11:10 - 12:10	49.7	55.0	5.3	3.9	15.0
14	17/11/2021	12:10 - 13:10	49.4	55.7	6.2	4.8	22.9
15	17/11/2021	13:10 - 14:10	48.8	56.0	7.2	5.8	33.2
16	17/11/2021	14:10 - 15:10	49.4	55.5	6.1	4.7	21.8
17	17/11/2021	15:10 - 16:10	50.8	55.8	5.0	3.6	12.7
18	17/11/2021	16:10 - 17:10	52.0	55.1	3.1	1.7	2.8
				Average =	**1.4**	**Sum =**	**795.6**

4.1.11 - Oxides of Nitrogen Variability Test

The CEM is deemed to have passed the variability test if the standard deviation of the CEM vs SRM values at reference conditions is less than the absolute standard deviation permissible of the determinand under test. This is represented with the following.

$$s_D \leq \sigma_O k_v$$

The standard deviation of the calibrated CEM at reference conditions is determined with the following equation:

$$s_D = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(D-\overline{D})^2}$$

The absolute standard deviation is calculated by using the emission limit value for the determinand and the maximum uncertainty allowed by the authority for the species under test, then applying a coverage factor of 1.96.

$$\sigma_O = \%E / 1.96$$

S_D = 6.84 mg/m^3

Emission Limit Value = 107 mg/m^3

Uncertainty Allowed = 20 %

σ = 20% x 107/1.96
σ = 10.92

For 18 measurements the Kv value is 0.9803

Therefore, 6.84 mg/m^3 $\leq$ 10.70 mg/m^3

The standard deviation of the calibrated CEM is 6.84 which is lower than the absolute standard deviation of 10.7. Therefore the CEM has passed the variability test.

Valid Calibration Range

The calibration function of the CEM is valid between zero and the highest calibrated CEM value during the parallel measurements at reference conditions plus 10%, or 20% of the ELV. Whichever is the greatest.

In this case the highest calibrated CEM value during the parallel measurements at reference conditions plus 10% was the greatest and has been set as the valid calibration range.

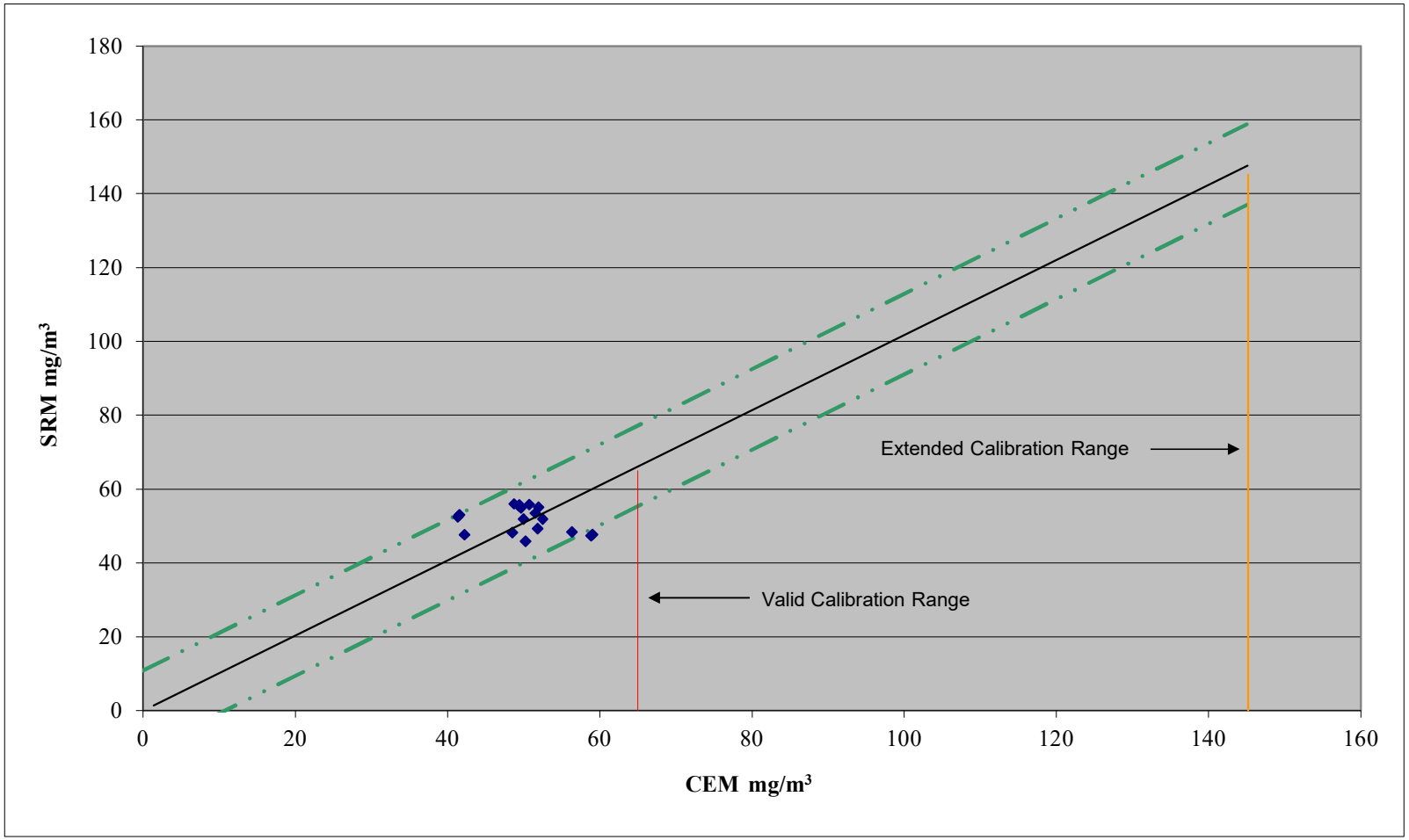
Valid Range = 0 to 65.0 mg/m^3

Extension of the Calibration Range

The calibration range of the CEM can be extended if the initial valid range does not meet the ELV.

Using surrogate data the valid range was extended to 145.2 mg/m^3.

4.1.12 - Plot 3 Calibrated CEM values and SRM values at reference conditions for Oxides of Nitrogen



Section 4 - Data and Calculations - QAL2

4.2 - Oxygen QAL2 Calculations - Siemens Oxymat 6F

In order to determine a valid calibration function it is necessary to carry out at least fifteen tests using the SRM and comparing the results against the values obtained from the on site CEM. The SRM measurements are then corrected to the same conditions as the on site CEM to allow a direct comparison. The range of results from these parallel measurements then determine what procedure is used to calculate the calibration function. This is explained further later.

After the calibration function has been determined a variability test is performed to ensure that the derived values fall within the required uncertainty budget. The SRM values are compared against the calibrated CEM results (see BS EN 14181:2014 section 6).

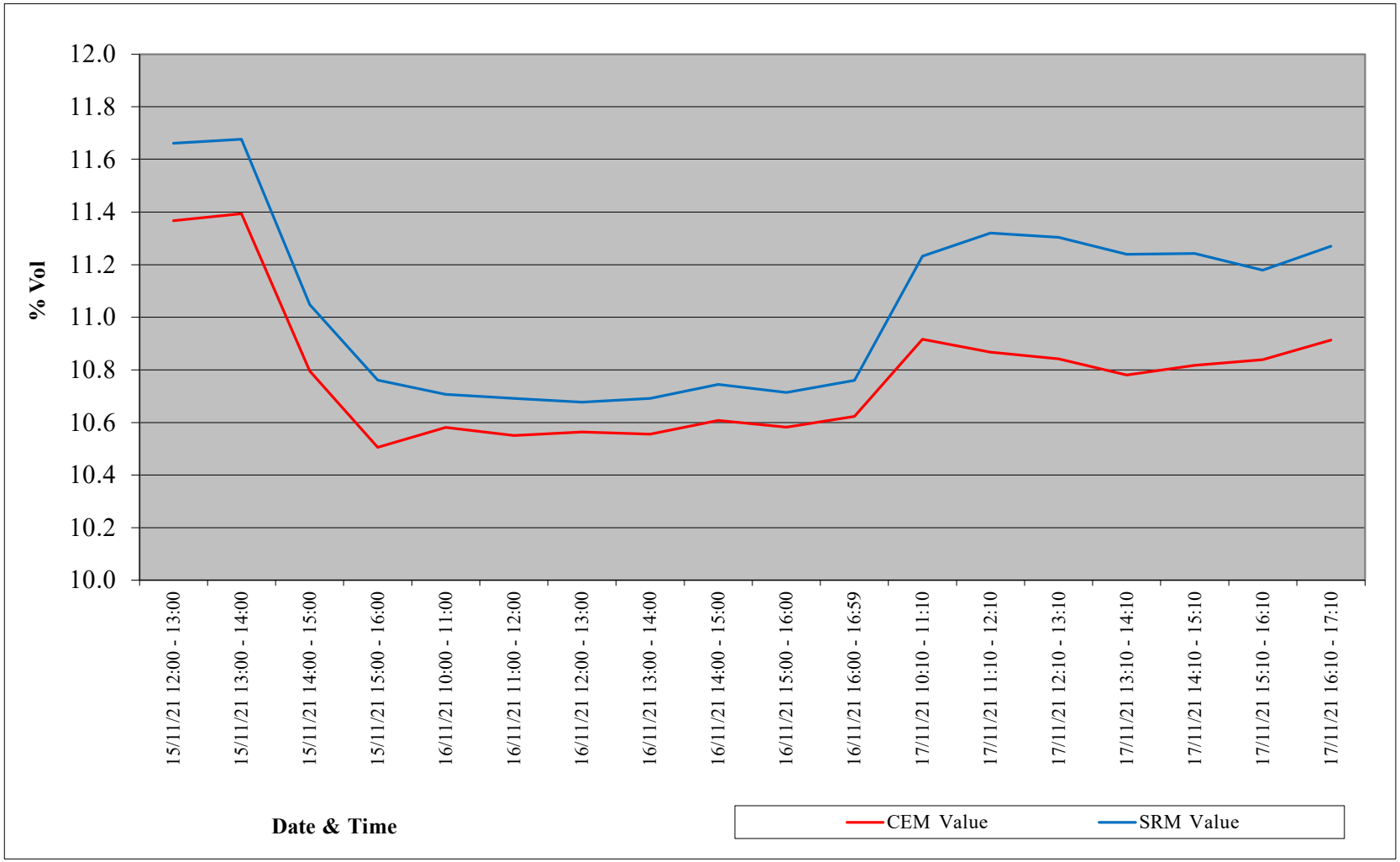
4.2.1 - Raw Monitoring Data CEM Monitoring Conditions:- % Vol on a Dry Gas Basis

Test Number	Test Date	Test Time	Raw CEM Result	CEM Moisture Measurements	Raw SRM Result	SRM Moisture Measurements	SRM Result at CEM Conditions
	dd/mm/yyyy	(hh:mm-hh:mm)	% Vol	%Vol	% Vol	%Vol	% Vol
1	15/11/2021	12:00 - 13:00	11.4	N/A	11.7	N/A	11.7
2	15/11/2021	13:00 - 14:00	11.4	N/A	11.7	N/A	11.7
3	15/11/2021	14:00 - 15:00	10.8	N/A	11.0	N/A	11.0
4	15/11/2021	15:00 - 16:00	10.5	N/A	10.8	N/A	10.8
5	16/11/2021	10:00 - 11:00	10.6	N/A	10.7	N/A	10.7
6	16/11/2021	11:00 - 12:00	10.6	N/A	10.7	N/A	10.7
7	16/11/2021	12:00 - 13:00	10.6	N/A	10.7	N/A	10.7
8	16/11/2021	13:00 - 14:00	10.6	N/A	10.7	N/A	10.7
9	16/11/2021	14:00 - 15:00	10.6	N/A	10.7	N/A	10.7
10	16/11/2021	15:00 - 16:00	10.6	N/A	10.7	N/A	10.7
11	16/11/2021	16:00 - 16:59	10.6	N/A	10.8	N/A	10.8
12	17/11/2021	10:10 - 11:10	10.9	N/A	11.2	N/A	11.2
13	17/11/2021	11:10 - 12:10	10.9	N/A	11.3	N/A	11.3
14	17/11/2021	12:10 - 13:10	10.8	N/A	11.3	N/A	11.3
15	17/11/2021	13:10 - 14:10	10.8	N/A	11.2	N/A	11.2
16	17/11/2021	14:10 - 15:10	10.8	N/A	11.2	N/A	11.2
17	17/11/2021	15:10 - 16:10	10.8	N/A	11.2	N/A	11.2
18	17/11/2021	16:10 - 17:10	10.9	N/A	11.3	N/A	11.3

4.2.2 - Oxygen Standardised Monitoring Data

Test Number	Test Date & Time	CEM Result at standard conditions	SRM Result at standard conditions
	dd/mm/yy hh:mm - hh:mm	% Vol	% Vol
1	15/11/21 12:00 - 13:00	11.4	11.7
2	15/11/21 13:00 - 14:00	11.4	11.7
3	15/11/21 14:00 - 15:00	10.8	11.0
4	15/11/21 15:00 - 16:00	10.5	10.8
5	16/11/21 10:00 - 11:00	10.6	10.7
6	16/11/21 11:00 - 12:00	10.6	10.7
7	16/11/21 12:00 - 13:00	10.6	10.7
8	16/11/21 13:00 - 14:00	10.6	10.7
9	16/11/21 14:00 - 15:00	10.6	10.7
10	16/11/21 15:00 - 16:00	10.6	10.7
11	16/11/21 16:00 - 16:59	10.6	10.8
12	17/11/21 10:10 - 11:10	10.9	11.2
13	17/11/21 11:10 - 12:10	10.9	11.3
14	17/11/21 12:10 - 13:10	10.8	11.3
15	17/11/21 13:10 - 14:10	10.8	11.2
16	17/11/21 14:10 - 15:10	10.8	11.2
17	17/11/21 15:10 - 16:10	10.8	11.2
18	17/11/21 16:10 - 17:10	10.9	11.3

4.2.3 - Plot 1 Time Series of Standardised Values for Oxygen



4.2.4 - Calculation and Elimination of Outliers

A test for outliers is carried out on the set of parallel measurements to make sure any invalid data is identified and removed, as this can have a negative effect on the final calibration function. The method used on this data set is set out in the Environment Agency TGN M20 (section 3.5.13 (ii)).
This procedure looks at the difference between raw CEM values and the parallel SRM measurement at CEM conditions, these differences should have an even spread. There will be an average of these differences as well as a standard deviation. If the difference between a parallel measurement and the average of all the differences is greater than two standard deviations then there is a strong chance it is an outlier and should be rejected from the data set. This test is only carried out once and need not be applied at all if the regression factor of the data set is above 0.9.

All outliers have been identified subsequently with an orange background, they are contained in the data sets for illustrative purposes but have not been used in the calculations.

4.2.5 - Determination of Method A, Method B or Method C?

Different installations give different spreads of data and can prove difficult when calculating a calibration function. As a result there are three main methods used, Method A, Method B and Method C (see BS EN 14181:2014 Page 19).

Method A is used if the spread of SRM results at reference conditions taken during the parallel measurements is equal to or greater than the permissible uncertainty of the CEM. This suggests there is a good spread of data.

Method B is used if the spread of SRM results at reference conditions taken during the parallel measurements is less than the permissible uncertainty of the CEM, and the lowest SRM result is greater than 15% of the ELV. This suggests there is a high cluster of data, so surrogate zero data is used to determine the offset of the CEM. However it is important to confirm that the analyser gives a reading at or near zero when the emissions are zero.

Method C is used if the spread of SRM results at reference conditions taken during the parallel measurements is less than the permissible uncertainty of the CEM, and the lowest SRM result is less than 15% of the ELV. This suggests there is a low cluster of data. As a result two surrogate data points are added to the parallel measurements, one at zero and one at or near the ELV, and converted to the measuring conditions of the CEM using average peripheral results. The calibration function is then calculated using the procedure set out in Method A.

Highest SRM measurement at reference conditions -	11.7	% Vol			
Lowest SRM measurement at reference conditions -	10.7	% Vol			
Spread of data -	1.0	% Vol			
Permissible Uncertainty of the CEM	2.1	% Vol	15% of the ELV -	3.15	% Vol

The spread of data is less than the permissible uncertainty of the CEM and the lowest SRM measurement at reference conditions is greater than or equal to 15% of the ELV. Therefore Method B has been chosen to calculate the calibration function.

4.2.6 - Oxygen Data Used to Calculate the Calibration Function

In order to calculate a valid QAL2 calibration function the parallel measurements obtained from testing are compared and analysed. To do this the SRM results are corrected to the same conditions at which the CEM takes its readings.

The measuring conditions at which the CEM takes its readings are % Vol on a Dry Gas Basis

Test Number	Test Date	Test Time	CEM Reading	SRM Reading at CEM Conditions
	dd/mm/yyyy	hh:mm - hh:mm	% Vol	% Vol
1	15/11/2021	12:00 - 13:00	11.4	11.7
2	15/11/2021	13:00 - 14:00	11.4	11.7
3	15/11/2021	14:00 - 15:00	10.8	11.0
4	15/11/2021	15:00 - 16:00	10.5	10.8
5	16/11/2021	10:00 - 11:00	10.6	10.7
6	16/11/2021	11:00 - 12:00	10.6	10.7
7	16/11/2021	12:00 - 13:00	10.6	10.7
8	16/11/2021	13:00 - 14:00	10.6	10.7
9	16/11/2021	14:00 - 15:00	10.6	10.7
10	16/11/2021	15:00 - 16:00	10.6	10.7
11	16/11/2021	16:00 - 16:59	10.6	10.8
12	17/11/2021	10:10 - 11:10	10.9	11.2
13	17/11/2021	11:10 - 12:10	10.9	11.3
14	17/11/2021	12:10 - 13:10	10.8	11.3
15	17/11/2021	13:10 - 14:10	10.8	11.2
16	17/11/2021	14:10 - 15:10	10.8	11.2
17	17/11/2021	15:10 - 16:10	10.8	11.2
18	17/11/2021	16:10 - 17:10	10.9	11.3

4.2.7 - Calculation Determination of the Calibration Function using Method B for Oxygen

Table Summarising Values used in QAL2 Calibration Value Calculation

Test No.	Date	Time	SRM Value at CEM Conditions	CEM Signal				
			yi	xi	xi - xbar	yi - ybar	(xi - xbar)*(yi - ybar)	$(xi - xbar)^2$
No.	dd/mm/yyyy	hh:mm - hh:mm	% Vol	% Vol	% Vol	% Vol	% Vol	% Vol
1	15/11/2021	12:00 - 13:00	11.7	11.4	0.6	0.6	0.4	0.3
2	15/11/2021	13:00 - 14:00	11.7	11.4	0.6	0.6	0.4	0.4
3	15/11/2021	14:00 - 15:00	11.0	10.8	0.0	0.0	0.0	0.0
4	15/11/2021	15:00 - 16:00	10.8	10.5	-0.3	-0.3	0.1	0.1
5	16/11/2021	10:00 - 11:00	10.7	10.6	-0.2	-0.3	0.1	0.0
6	16/11/2021	11:00 - 12:00	10.7	10.6	-0.2	-0.4	0.1	0.1
7	16/11/2021	12:00 - 13:00	10.7	10.6	-0.2	-0.4	0.1	0.0
8	16/11/2021	13:00 - 14:00	10.7	10.6	-0.2	-0.4	0.1	0.1
9	16/11/2021	14:00 - 15:00	10.7	10.6	-0.2	-0.3	0.1	0.0
10	16/11/2021	15:00 - 16:00	10.7	10.6	-0.2	-0.3	0.1	0.0
11	16/11/2021	16:00 - 16:59	10.8	10.6	-0.2	-0.3	0.0	0.0
12	17/11/2021	10:10 - 11:10	11.2	10.9	0.1	0.2	0.0	0.0
13	17/11/2021	11:10 - 12:10	11.3	10.9	0.1	0.3	0.0	0.0
14	17/11/2021	12:10 - 13:10	11.3	10.8	0.1	0.3	0.0	0.0
15	17/11/2021	13:10 - 14:10	11.2	10.8	0.0	0.2	0.0	0.0
16	17/11/2021	14:10 - 15:10	11.2	10.8	0.0	0.2	0.0	0.0
17	17/11/2021	15:10 - 16:10	11.2	10.8	0.1	0.1	0.0	0.0
18	17/11/2021	16:10 - 17:10	11.3	10.9	0.1	0.2	0.0	0.0
Zero	Surrogate	Data	0.0	0.0				
		Average =	**11.05**	**10.78**		**Sum =**	**1.41**	**1.13**

4.2.7 - Calculation Determination of the Calibration Function

The calibration function is described as:

$$y_i = a + bx_i$$

whereby,

x_i is the result from the CEM
y_i is the result from the SRM
a is the intercept
b is the slope
Z is the zero offset

Z = -0.01383

The slope (b) is calculated first with the following calculation:

$$\hat{b} = \frac{\bar{y}}{\bar{x} - Z}$$

whereby,

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \quad = \quad 10.78$$

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i \quad = \quad 11.05$$

Therefore, ***b*** = 1.023495

Now that the slope has been calculated, the intercept (a) can then be determined:

$$\hat{a} = -\hat{b}Z$$

Therefore, ***a*** = 0.014158

The calibration function then becomes:

$$\hat{y}_i = \hat{a} + \hat{b}\,x_i$$

The calibration function then becomes:

$$\hat{y}_i = 0.01 + 1.02\,x_i$$

$\hat{y}_i$ = The calibrated CEM Output

x_i = The CEM Signal

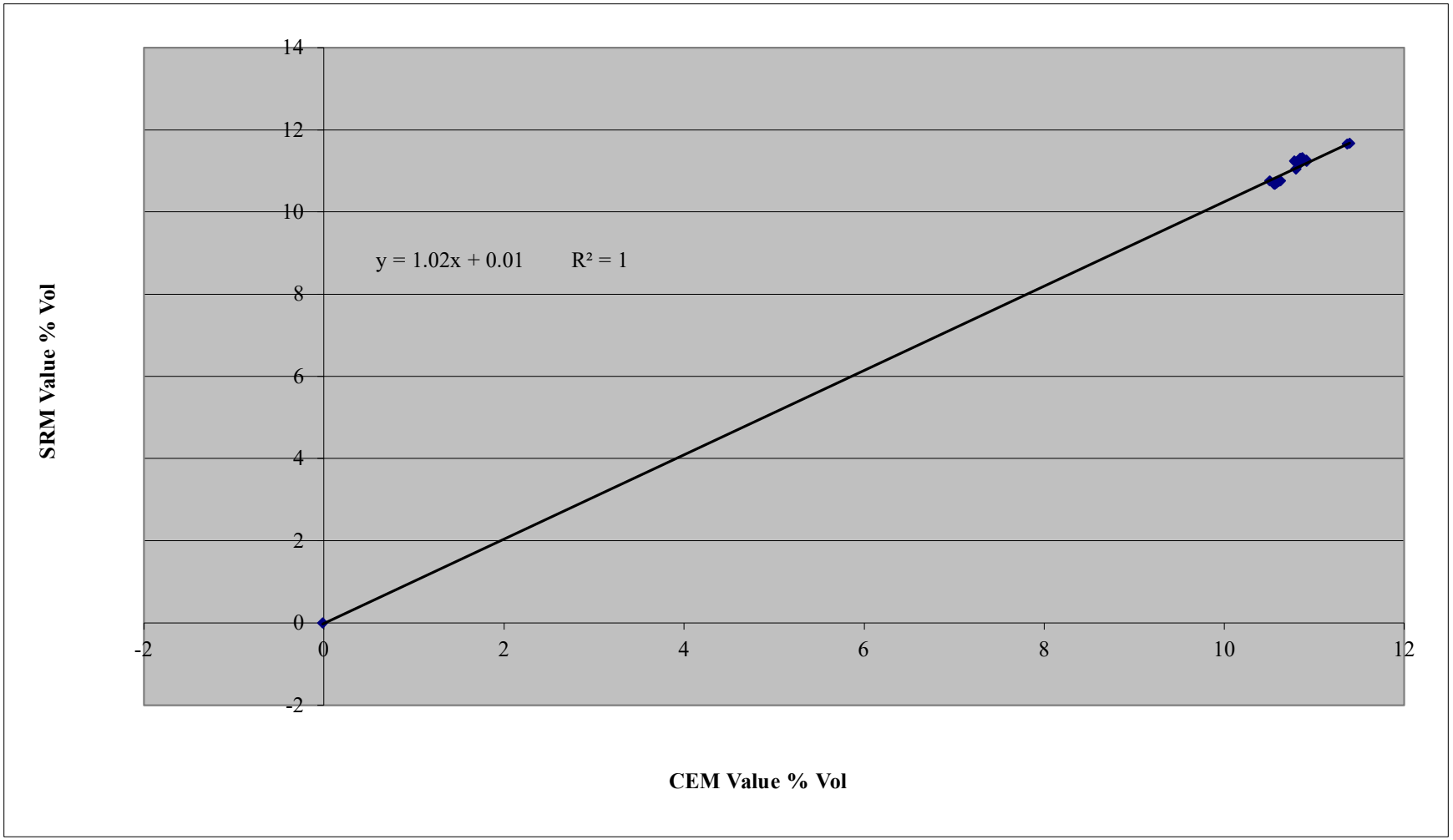
4.2.8 - Calculation of Calibrated CEM Values for Oxygen

Following the calculation of the calibration function, the CEM data can then be adjusted using this data. Finally the calibrated value is then corrected to reference conditions.

Reference Conditions - % Vol on a Dry Gas Basis

Test No.	Date	Time	Raw CEM Value	Calibrated CEM Value at Stack Conditions	CEM Moisture Content	CEM Calibrated Value at reference conditions
	dd/mm/yyyy	hh:mm-hh:mm	% Vol	% Vol	% Vol	% Vol
1	15/11/2021	12:00 - 13:00	11.4	11.6	N/A	11.6
2	15/11/2021	13:00 - 14:00	11.4	11.7	N/A	11.7
3	15/11/2021	14:00 - 15:00	10.8	11.1	N/A	11.1
4	15/11/2021	15:00 - 16:00	10.5	10.8	N/A	10.8
5	16/11/2021	10:00 - 11:00	10.6	10.8	N/A	10.8
6	16/11/2021	11:00 - 12:00	10.6	10.8	N/A	10.8
7	16/11/2021	12:00 - 13:00	10.6	10.8	N/A	10.8
8	16/11/2021	13:00 - 14:00	10.6	10.8	N/A	10.8
9	16/11/2021	14:00 - 15:00	10.6	10.9	N/A	10.9
10	16/11/2021	15:00 - 16:00	10.6	10.8	N/A	10.8
11	16/11/2021	16:00 - 16:59	10.6	10.9	N/A	10.9
12	17/11/2021	10:10 - 11:10	10.9	11.2	N/A	11.2
13	17/11/2021	11:10 - 12:10	10.9	11.1	N/A	11.1
14	17/11/2021	12:10 - 13:10	10.8	11.1	N/A	11.1
15	17/11/2021	13:10 - 14:10	10.8	11.0	N/A	11.0
16	17/11/2021	14:10 - 15:10	10.8	11.1	N/A	11.1
17	17/11/2021	15:10 - 16:10	10.8	11.1	N/A	11.1
18	17/11/2021	16:10 - 17:10	10.9	11.2	N/A	11.2

4.2.9 - Plot 2 CEM vs SRM values measured at CEM conditions for Oxygen



4.2.10 - Data used for the Variability Test for Oxygen

The CEM data has had the QAL2 function applied, and been corrected to reference conditions, a test of variability can be carried out.

Test No.	Date	Time	Calibrated CEM value at reference conditions	SRM value at reference conditions	Difference	Difference minus average of the differences	Difference minus average of the differences, squared
					$D_i = y_{i,s}-y_{i,s}$	$D_i - D$	$(D_i - D)^2$
	dd/mm/yyyy	hh:mm - hh:mm	% Vol	% Vol	% Vol	% Vol	% Vol
1	15/11/2021	12:00 - 13:00	11.6	11.7	0.0	0.0	0.0
2	15/11/2021	13:00 - 14:00	11.7	11.7	0.0	0.0	0.0
3	15/11/2021	14:00 - 15:00	11.1	11.0	0.0	0.0	0.0
4	15/11/2021	15:00 - 16:00	10.8	10.8	0.0	0.0	0.0
5	16/11/2021	10:00 - 11:00	10.8	10.7	-0.1	-0.1	0.0
6	16/11/2021	11:00 - 12:00	10.8	10.7	-0.1	-0.1	0.0
7	16/11/2021	12:00 - 13:00	10.8	10.7	-0.1	-0.1	0.0
8	16/11/2021	13:00 - 14:00	10.8	10.7	-0.1	-0.1	0.0
9	16/11/2021	14:00 - 15:00	10.9	10.7	-0.1	-0.1	0.0
10	16/11/2021	15:00 - 16:00	10.8	10.7	-0.1	-0.1	0.0
11	16/11/2021	16:00 - 16:59	10.9	10.8	-0.1	-0.1	0.0
12	17/11/2021	10:10 - 11:10	11.2	11.2	0.0	0.0	0.0
13	17/11/2021	11:10 - 12:10	11.1	11.3	0.2	0.2	0.0
14	17/11/2021	12:10 - 13:10	11.1	11.3	0.2	0.2	0.0
15	17/11/2021	13:10 - 14:10	11.0	11.2	0.2	0.2	0.0
16	17/11/2021	14:10 - 15:10	11.1	11.2	0.2	0.2	0.0
17	17/11/2021	15:10 - 16:10	11.1	11.2	0.1	0.1	0.0
18	17/11/2021	16:10 - 17:10	11.2	11.3	0.1	0.1	0.0
				Average =	**0.0**	**Sum =**	**0.3**

4.2.11 - Oxygen Variability Test

The CEM is deemed to have passed the variability test if the standard deviation of the CEM vs SRM values at reference conditions is less than the absolute standard deviation permissible of the determinand under test. This is represented with the following.

$$s_D \leq \sigma_O k_v$$

The standard deviation of the calibrated CEM at reference conditions is determined with the following equation:

$$s_D = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(D-\overline{D})^2}$$

S_D = 0.13 % Vol

The absolute standard deviation is calculated by using the emission limit value for the determinand and the maximum uncertainty allowed by the authority for the species under test, then applying a coverage factor of 1.96.

$$\sigma_O = \%E / 1.96$$

Emission Limit Value = 21 % Vol

Uncertainty Allowed = 10 %

σ = 10% x 21/1.96
σ = 1.07

For 18 measurements the Kv value is 0.9803

Therefore, 0.13 % Vol $\leq$ 1.05 % Vol

The standard deviation of the calibrated CEM is 0.13 which is lower than the absolute standard deviation of 1.05. Therefore the CEM has passed the variability test.

Valid Calibration Range

The calibration function of the CEM is valid between zero and the highest calibrated CEM value during the parallel measurements at reference conditions plus 10%, or 20% of the ELV. Whichever is the greatest.

In this case the highest calibrated CEM value during the parallel measurements at reference conditions plus 10% was the greatest and has been set as the valid calibration range.

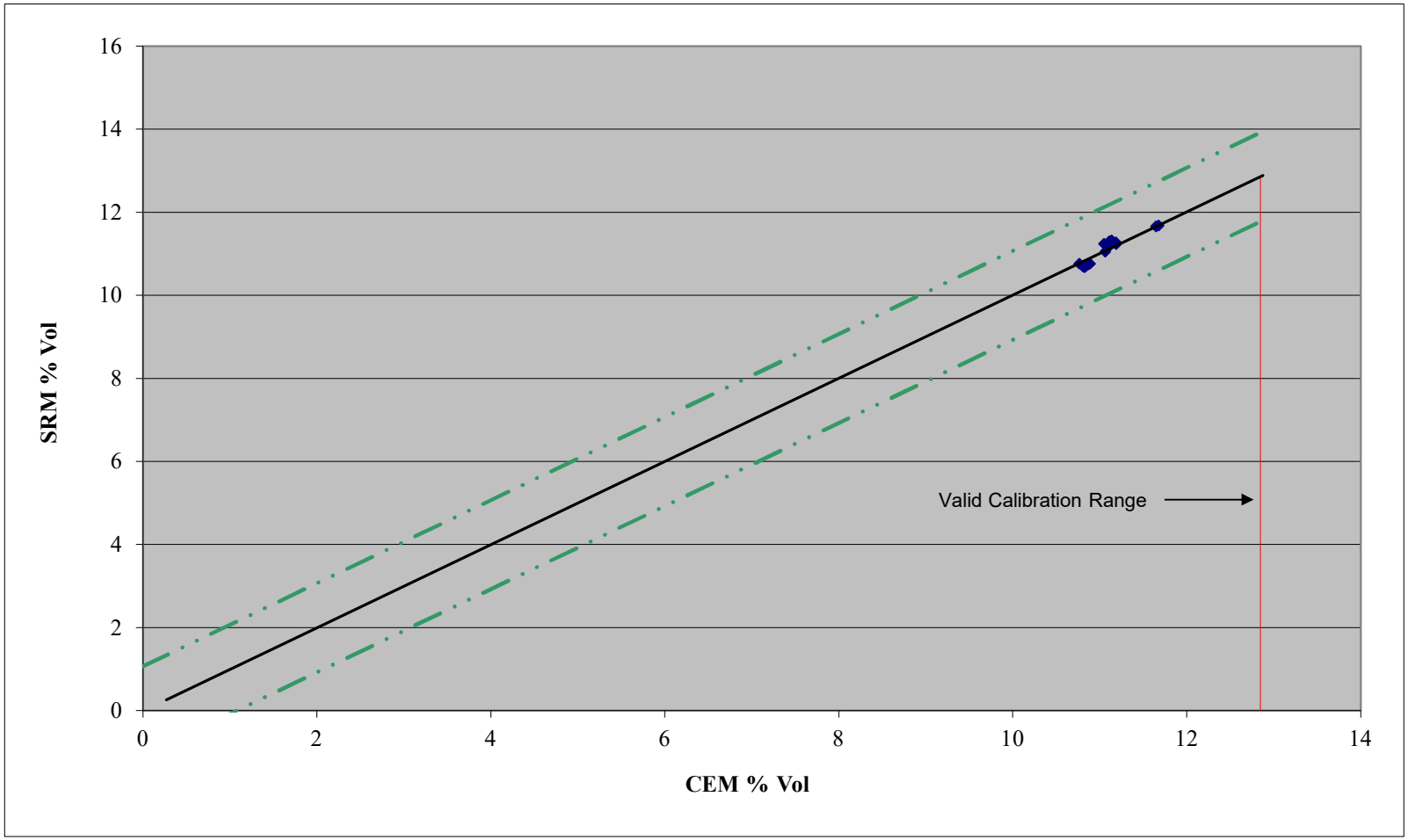
Valid Range = 0 to 12.8 % Vol

Extension of the Calibration Range

The calibration range of the CEM can be extended if the initial valid range does not meet the ELV.

An extension of the range was not necessary.

4.2.12 - Plot 3 Calibrated CEM values and SRM values at reference conditions for Oxygen



Section 5 - Results of the Functional Tests

NATIONAL PHYSICAL LABORATORY

FUNCTIONAL TEST AUDIT CHECK SHEET

1. CEM Details

NB: Page 1 To be filled in one for each CEM analyser

Manufacturer	**Siemens**			
Model	**Ultramat 23 – NOx and JNOx – T/C**			
Serial Number/Identifier	**(2A) 44AT69002/N1M8063 and 1705761**			
Species 1	NOx (as NO)	Current Range 0 to 400	**mg m^{-3}**	STP, Dry
Species 2 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 3 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 4 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 5 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 6 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 7 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 8 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Operation (Circle)	Extractive			
Does it Have MCERTS?	Yes ■	No □	**MCERTS Ref No. MC040033/04**	
Does it have a QAL2 Calibration function? (y = Bx + A)	Yes ■	No □	**Date of Last QAL2 Calibration September 2020**	
Has the QAL2 cal. Function been applied to the AMS data?	YES			

QAL2 Results Species 1	**Linear B = 0.08**	**Absolute A = 1.20**
QAL2 Results Species 2 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 3 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 4 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 5 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 6 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 7 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 8 (if app.)	**Linear B =**	**Absolute A =**

NATIONAL PHYSICAL LABORATORY

Functional Test Requirements Depending on CEM type

Activity	QAL2 & AST		
	Extractive AMS	In-situ AMS	Volumetric flow rate AMS
1 - CEM Details	x	x	x
2 - Measurement Site and Installation	x	x	x
3 - Alignment and Cleanliness		x	x
4 - Sampling System	x		
5 - Leak Test	x		
6 - Zero and Span Check (or internal reference point check)	x	x	x
7 - Linearity	x	x	x
8 - Interferences	x	x	
9 - Zero and Span Drift Audit (or internal reference point drift audit)	x	x	x
10 - Response Time	x	x	x
11 - Documentation and Records	x	x	x
12 - QAL2/AST Service Report	x	x	x
13 - General Service Report	x	x	x
14 - Report of Faults	x	x	x
15 - Geometrical configuration			x
16 - Any variation from normal operation			x
17 – Duct cross sectional area measurement			x
Sections to be filled in below	1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 6, 7, 9, 10, 11, 12, 13, 14,15,16,17

2. Measurement Site and Installation	*Compliance*	*Notes*
Is there a safe and clean working environment with sufficient space and weather protections	*YES*	*Air conditioned CEMS facility which houses analysers, sampling system and controls, no weather protection at platform*
Is there easy and safe access to AMS	*YES*	*Permanent platform and ladders to probe/sampling head and safe area to CEM analyser house*
Adequate supplies of tools, spares and reference materials	*YES*	*Certain tools kept in analyser house, gases stored by CEMS facility, but all spares and certain tools stored in workshop. Pictures of all spares for CEM systems are stored on I:\ and all parts are readily available.*
Facilities to introduce the reference materials for gaseous-monitoring systems, both at the inlet of the sampling line (where present), and at the inlet of the AMS	*YES*	*Sample and reference materials can be introduced directly at the sampling probe or can be sent up the spare sample line into the sample probe head and back down the sample line or straight into the AMS by altering one connection.*
Compliance with TGN M1 and BS EN 15259:2007 and MID EN 15259:2009	*YES*	*The platform is compliant with TGN M1 and a homogeneity test was carried out in 2012.*

Requirement	√	*Notes*
3. Alignment and Cleanliness	*A visual inspection, with reference to the AMS manuals, shall be carried out when applicable:*	
Internal check of the AMS		
Cleanliness of the optical components		
Flushing of air supply		

NATIONAL PHYSICAL LABORATORY

Any obstructions in the optical path		
After re-assembly the following requirements below shall be checked		
Contamination control (internal check of optical surfaces)		
Alignment of the measuring system		
Requirement	√	***Notes***
4. Sampling System	*A visual inspection of the sampling system shall be performed, noting the condition of the following components, when fitted:*	
Sample probe	√	*Checked - OK*
Gas conditioning systems	√	*Checked - OK*
Pumps	√	*Checked - OK*
All connections	√	*Checked - OK*
Sample lines	√	*Checked – OK*
Power supplies	√	*Checked - OK*
Filters	√	*Checked - OK*
NOx converters (if applicable) – record date of last efficiency test and result	**X**	*Converter efficiency below 95%*
The sampling system is in good condition and free of any visible faults	√	*Checked - OK*
5. Leak Test	*Leak test of complete system according to the AMS's manuals*	
Leak test of complete system	√	*Checked – OK. The agreement between span gas supplied directly to the analyser and to the analyser via the complete sampling system was within 2%.*
6. Zero and Span Check		
Reference zero and span materials introduced to verify the readings of the AMS	√	*Passed check.*
For a non-extractive AMS, zero and span checks performed using a reference-path free of flue gas before and after re-adjustment and after re-assembly of the AMS at the measurement location	*N/A*	
7. Linearity		
Are the applied concentrations logged onto the DCS to prove the complete system during the linearity/calibration tests	√	*Yes, on DCS CEM Data system. Also, taken from Envirosoft CEM software and typed onto data log sheets.*
Are DCS logged values included in the instrument service report	N/A	

NATIONAL PHYSICAL LABORATORY

Is the linearity of the AMS response checked using five different reference materials which have a variable quantity and quality (2% uncertainty), including a zero concentration	√	*Yes*
Are the gas reference materials introduced by either a gas dilution system or multiple single concentration cylinders	√	*A Chell gas dilution system was used - mass flow controllers AS0664 and AS0665*
Requirement	**√**	***Notes***
The AMS is tested using the following concentrations applied in a randomised sequence and shall be applied to the inlet of the AMS:		
Reference material with zero concentration	√	*3 readings were taken after the relevant T90 time for each species*
Reference material concentration approximately 20% of at least the short term ELV	√	*3 readings were taken after the relevant T90 time for each species*
Reference material concentration approximately 40% of at least the short term ELV	√	*3 readings were taken after the relevant T90 time for each species*
Reference material concentration approximately 60% of at least the short term ELV	√	*3 readings were taken after the relevant T90 time for each species*
Reference material concentration approximately 80% of at least the short term ELV	√	*3 readings were taken after the relevant T90 time for each species*
Reference material with zero concentration	√	*3 readings were taken after the relevant T90 time for each species*
Has the linearity tests been performed with the use of reference materials such as grating or gas filters	***N/A***	*-*
Calculate and check the linearity data using the procedure as given in EN 14181 Annex B	√	*See additional sheets attached to functional test audit.*
Does the AMS pass this test	√	*Yes. The highest residual was 2.54%.*
8. Interferences	*Carried out if stack gas to be measured contains interferences as identified in QAL1*	
Has an interference check been carried out	√	*Checked all required species read zero during span checks for other species.*
9. Zero and Span Drift Audit	*A review of the QAL3 results*	
Has a check of zero and span drift in QAL3 results been carried out	√	*Computer records are stored on shared area I:\. Control charts produced and deviations noted. All species passed the requirements of the QAL1 specification for the maintenance interval for any re-calibration of the analyser. QAL3 procedure in place. A ~150 ppm gas cylinder is used for the QAL3 checks, and it is within the expiry date.*
10. Response Time	*A check of the T_{90} of the entire Sampling system*	
Response time of the AMS checked	√	*53 seconds*

NATIONAL PHYSICAL LABORATORY

11. Documentation and Records	*Should be controlled, readily accessible and up to date*	
Manuals, log books & service records	√	*Manuals, log books and service records stored on I:\ on shared area. Also stored in instrument/mechanical and electrical tech office. A fault is logged on SAP system, a PO is raised and work order generated and site has a 24 hour call out with Orbital (service company).*
QAL3 records	√	*Stored locally and on hard drive centrally for a period of 2 years which is in accordance with requirements of BS EN 14181:2014. The CEMS system is from Envirosoft with use of Liveexplore/Exoquantum hardware.*
QA management system	√	*In place and a compliant management system - SAP*
Training records	√	*Internal and external training records stored in central electronic folder (I:\) in central office.*
Auditing plans and records	√	*No specific audit plan for servicing staff, however site contact shadows Orbital service engineer whilst on-site (see actions). Plan is in place to audit NPL staff for either emission compliance or AST/QAL2 by Intertek and SHLNG.*
Requirement	√	***Notes***
12. QAL2/AST Service Report	*As a minimum the service report should have: -*	
Date of service report and reference	√	*Carried out as part of general service*
Carried out by name/signature/company	√	*Carried out as part of general service*
Document reference for work instruction for the type of work being undertaken	√	*Service engineer used a documented procedure*
Instrument manufacturer	√	
Instrument type/model and serial no	√	
Operating principal	√	*Not included in general service report*
Operating range	√	*Not included in general service report*
Certification details	√	*Not included in general service report*
Compliance with MCERTs and certificate number	√	
Location	√	*Not included in general service report*
Equipment used – type, serial no's, calibration dates	√	
Gases used – certificate numbers, expiry dates, binary / mix	√	
NOx converter efficiency test, if applicable	√	
Calibration and linearity data as required by EN14181	√	
Logged data for period of calibration and linearity	√	

NATIONAL PHYSICAL LABORATORY

13. General Service Report	*Details of Service Report*	
Date of Service Report	√	
Carried out by Name/Company	√	*Orbital*
Report Reference ID	√	
14. Report of Faults		
Any clear faults		
15. Geometrical configuration	*An assessment on whether the configuration of the CEMS is suitable for the specific flow profile*	
Has a pre-investigation been carried out		
Do the pre-investigation results (crest factor, skewness and reproducibility) correlate with the type of CEMS installed		
16. Variation from normal operation	*An assessment of any changes in any reference quantity with influence on the CEMS output resulting from any variation from normal site operation. See CEMS manual for influencing quantities.*	
Has any reference quantity such as temperature, pressure, gas composition changed in such way that will affect the CEMS monitoring result		
17. Duct cross sectional area measurement	*An assessment on whether the duct cross sectional area value used by the CEMS corresponds to the true value within the uncertainty tolerance*	
Has the duct cross sectional area measured by NPL in the past - if not measure		
Does the NPL value correlate with the CEMS value (<2%)		

NPL USE ONLY	**Name and Date**	**Company**	**MCERTS ID No. (if applicable)**
Name of person performing functional test	**Matthew Ellison and 15/11/2021**	**NPL**	**MM-05-682**
Name of person witnessing the tests	**Matthew Ellison and 15/11/2021**	**NPL**	**MM-05-682**

ACTIONS/COMMENTS

1. NOx converter efficiency was below 95%.

NATIONAL PHYSICAL LABORATORY

FUNCTIONAL TEST AUDIT CHECK SHEET

1. CEM Details

NB: Page 1 To be filled in one for each CEM analyser

Manufacturer	**Siemens**			
Model	**Oxymat 6F**			
Serial Number/Identifier	**(2A) 44AT69002/N1-U3-0441**			
Species 1	O_2	Current Range 0 to 25	**%Vol**	STP, Dry
Species 2 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 3 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 4 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 5 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 6 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 7 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Species 8 (if app.)		Current Range ___ to_____	**mA / mV / ppm / mg m^{-3} / m/s / m3/s** (circle correct one)	Conditions
Operation (Circle)	Extractive			
Does it Have MCERTS?	Yes ■	No □	**MCERTS Ref No. MC040032/06**	
Does it have a QAL2 Calibration function? (y = Bx + A)	Yes ■	No □	**Date of Last QAL2 Calibration September 2020**	
Has the QAL2 cal. Function been applied to the AMS data?	YES			

QAL2 Results Species 1	**Linear B = 0.25**	**Absolute A = 0.98**
QAL2 Results Species 2 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 3 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 4 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 5 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 6 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 7 (if app.)	**Linear B =**	**Absolute A =**
QAL2 Results Species 8 (if app.)	**Linear B =**	**Absolute A =**

NATIONAL PHYSICAL LABORATORY

Functional Test Requirements Depending on CEM type

Activity	QAL2 & AST		
	Extractive AMS	In-situ AMS	Volumetric flow rate AMS
1 - CEM Details	x	x	x
2 - Measurement Site and Installation	x	x	x
3 - Alignment and Cleanliness		x	x
4 - Sampling System	x		
5 - Leak Test	x		
6 - Zero and Span Check (or internal reference point check)	x	x	x
7 - Linearity	x	x	x
8 - Interferences	x	x	
9 - Zero and Span Drift Audit (or internal reference point drift audit)	x	x	x
10 - Response Time	x	x	x
11 - Documentation and Records	x	x	x
12 - QAL2/AST Service Report	x	x	x
13 - General Service Report	x	x	x
14 - Report of Faults	x	x	x
15 - Geometrical configuration			x
16 - Any variation from normal operation			x
17 – Duct cross sectional area measurement			x
Sections to be filled in below	1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 6, 7, 9, 10, 11, 12, 13, 14,15,16,17

2. Measurement Site and Installation	*Compliance*	*Notes*
Is there a safe and clean working environment with sufficient space and weather protections	*YES*	*Air conditioned CEMS facility which houses analysers, sampling system and controls, no weather protection at platform*
Is there easy and safe access to AMS	*YES*	*Permanent platform and ladders to probe/sampling head and safe area to CEM analyser house*
Adequate supplies of tools, spares and reference materials	*YES*	*Certain tools kept in analyser house, gases stored by CEMS facility, but all spares and certain tools stored in workshop. Pictures of all spares for CEM systems are stored on I:\ and all parts are readily available.*
Facilities to introduce the reference materials for gaseous-monitoring systems, both at the inlet of the sampling line (where present), and at the inlet of the AMS	*YES*	*Sample and reference materials can be introduced directly at the sampling probe or can be sent up the spare sample line into the sample probe head and back down the sample line or straight into the AMS by altering one connection.*
Compliance with TGN M1 and BS EN 15259:2007 and MID EN 15259:2009	*YES*	*The platform is compliant with TGN M1 and a homogeneity test was carried out in 2012.*

Requirement	√	*Notes*
3. Alignment and Cleanliness	*A visual inspection, with reference to the AMS manuals, shall be carried out when applicable:*	
Internal check of the AMS		
Cleanliness of the optical components		
Flushing of air supply		

NATIONAL PHYSICAL LABORATORY

Any obstructions in the optical path		
After re-assembly the following requirements below shall be checked		
Contamination control (internal check of optical surfaces)		
Alignment of the measuring system		
Requirement	√	***Notes***
4. Sampling System	*A visual inspection of the sampling system shall be performed, noting the condition of the following components, when fitted:*	
Sample probe	√	*Checked - OK*
Gas conditioning systems	√	*Checked - OK*
Pumps	√	*Checked - OK*
All connections	√	*Checked - OK*
Sample lines	√	*Checked – OK*
Power supplies	√	*Checked - OK*
Filters	√	*Checked - OK*
NOx converters (if applicable) – record date of last efficiency test and result	N/A	
The sampling system is in good condition and free of any visible faults	√	*Checked - OK*
5. Leak Test	*Leak test of complete system according to the AMS's manuals*	
Leak test of complete system	√	*Checked – OK. The agreement between span gas supplied directly to the analyser and to the analyser via the complete sampling system was within 2%.*
6. Zero and Span Check		
Reference zero and span materials introduced to verify the readings of the AMS	√	*O_2 – passed check.*
For a non-extractive AMS, zero and span checks performed using a reference-path free of flue gas before and after re-adjustment and after re-assembly of the AMS at the measurement location	*N/A*	
7. Linearity		
Are the applied concentrations logged onto the DCS to prove the complete system during the linearity/calibration tests	√	*Yes, on DCS CEM Data system. Also, taken from Envirosoft CEM software and typed onto data log sheets.*
Are DCS logged values included in the instrument service report	N/A	

NATIONAL PHYSICAL LABORATORY

Is the linearity of the AMS response checked using five different reference materials which have a variable quantity and quality (2% uncertainty), including a zero concentration	√	*Yes*
Are the gas reference materials introduced by either a gas dilution system or multiple single concentration cylinders	√	*A Chell gas dilution system was used - mass flow controllers AS0664 and AS0665*
Requirement	**√**	***Notes***
The AMS is tested using the following concentrations applied in a randomised sequence and shall be applied to the inlet of the AMS:		
Reference material with zero concentration	√	*3 readings were taken after the relevant T90 time for each species*
Reference material concentration approximately 20% of at least the short term ELV	√	*3 readings were taken after the relevant T90 time for each species*
Reference material concentration approximately 40% of at least the short term ELV	√	*3 readings were taken after the relevant T90 time for each species*
Reference material concentration approximately 60% of at least the short term ELV	√	*3 readings were taken after the relevant T90 time for each species*
Reference material concentration approximately 80% of at least the short term ELV	√	*3 readings were taken after the relevant T90 time for each species*
Reference material with zero concentration	√	*3 readings were taken after the relevant T90 time for each species*
Has the linearity tests been performed with the use of reference materials such as grating or gas filters	***N/A***	*-*
Calculate and check the linearity data using the procedure as given in EN 14181 Annex B	√	*See additional sheets attached to functional test audit.*
Does the AMS pass this test	√	*Yes. The highest residual was 0.42%.*
8. Interferences	*Carried out if stack gas to be measured contains interferences as identified in QAL1*	
Has an interference check been carried out	√	*Checked all required species read zero during span checks for other species.*
9. Zero and Span Drift Audit	*A review of the QAL3 results*	
Has a check of zero and span drift in QAL3 results been carried out	√	*Computer records are stored on shared area I:\. Control charts produced and deviations noted. All species passed the requirements of the QAL1 specification for the maintenance interval for any re-calibration of the analyser. QAL3 procedure in place.*
10. Response Time	*A check of the T_{90} of the entire Sampling system*	
Response time of the AMS checked	√	▪ *O_2 – 52 seconds*

NATIONAL PHYSICAL LABORATORY

11. Documentation and Records	*Should be controlled, readily accessible and up to date*	
Manuals, log books & service records	√	*Manuals, log books and service records stored on I:\ on shared area. Also stored in instrument/mechanical and electrical tech office. A fault is logged on SAP system, a PO is raised and work order generated and site has a 24 hour call out with Orbital (service company).*
QAL3 records	√	*Stored locally and on hard drive centrally for a period of 2 years which is in accordance with requirements of BS EN 14181:2014. The CEMS system is from Envirosoft with use of Liveexplore/Exoquantum hardware.*
QA management system	√	*In place and a compliant management system - SAP*
Training records	√	*Internal and external training records stored in central electronic folder (I:\) in central office.*
Auditing plans and records	√	*No specific audit plan for servicing staff, however site contact shadows Orbital service engineer whilst on-site (see actions). Plan is in place to audit NPL staff for either emission compliance or AST/QAL2 by Intertek and SHLNG.*
Requirement	√	***Notes***
12. QAL2/AST Service Report	*As a minimum the service report should have: -*	
Date of service report and reference	√	*Carried out as part of general service*
Carried out by name/signature/company	√	*Carried out as part of general service*
Document reference for work instruction for the type of work being undertaken	√	*Service engineer used a documented procedure*
Instrument manufacturer	√	
Instrument type/model and serial no	√	
Operating principal	√	*Not included in general service report*
Operating range	√	*Not included in general service report*
Certification details	√	*Not included in general service report*
Compliance with MCERTs and certificate number	√	
Location	√	*Not included in general service report*
Equipment used – type, serial no's, calibration dates	√	
Gases used – certificate numbers, expiry dates, binary / mix	√	
NOx converter efficiency test, if applicable	*N/A*	
Calibration and linearity data as required by EN14181	√	
Logged data for period of calibration and linearity	√	

NATIONAL PHYSICAL LABORATORY

13. General Service Report	*Details of Service Report*	
Date of Service Report	√	
Carried out by Name/Company	√	*Orbital*
Report Reference ID	√	
14. Report of Faults		
Any clear faults		
15. Geometrical configuration	*An assessment on whether the configuration of the CEMS is suitable for the specific flow profile*	
Has a pre-investigation been carried out		
Do the pre-investigation results (crest factor, skewness and reproducibility) correlate with the type of CEMS installed		
16. Variation from normal operation	*An assessment of any changes in any reference quantity with influence on the CEMS output resulting from any variation from normal site operation. See CEMS manual for influencing quantities.*	
Has any reference quantity such as temperature, pressure, gas composition changed in such way that will affect the CEMS monitoring result		
17. Duct cross sectional area measurement	*An assessment on whether the duct cross sectional area value used by the CEMS corresponds to the true value within the uncertainty tolerance*	
Has the duct cross sectional area measured by NPL in the past - if not measure		
Does the NPL value correlate with the CEMS value (<2%)		

NPL USE ONLY	**Name and Date**	**Company**	**MCERTS ID No. (if applicable)**
Name of person performing functional test	**Matthew Ellison and 15/11/2021**	**NPL**	**MM-05-682**
Name of person witnessing the tests	**Matthew Ellison and 15/11/2021**	**NPL**	**MM-05-682**

ACTIONS/COMMENTS

1. Linearity and response time tests were carried out greater than one month prior to the parallel measurements (05/10/2021).

Section 6 - Supporting Information

6.1 - QAL2 Summary Sheets

Oxides of Nitrogen QAL2 Results Overview

SRM Measured Conditions - PPM, sampled on a 'Cool/Dry' basis corrected to STP
CEM Measured Conditions - mg/m3, 273K, 101.3 kPa, on a dry gas basis.
Reference Conditions - mg/m3, 273K, 101.3 kPa, 3% Oxygen on a dry gas basis.

Field	Units	Test 1	Test 2	Test 3	Test 4	Test 5
Date	dd/mm/yyyy	15/11/21	15/11/21	15/11/21	15/11/21	16/11/21
Start Time	hh:mm	12:00	13:00	14:00	15:00	10:00
End Time	hh:mm	13:00	14:00	15:00	16:00	11:00
Total Time	hh:mm	1:00	1:00	1:00	1:00	1:00
SRM Results Overview						
SRM Raw Nitrogen Oxide Result	PPM	12.2	12.0	14.3	14.6	12.8
SRM Nitrogen Oxide at CEM Conditions	mg/m^3	16.3	16.1	19.1	19.5	17.1
SRM Oxides of Nitrogen (as NO_2) Result at Standard Conditions	mg/m^3	48.2	47.7	53.0	52.5	45.9
SRM Nitrogen Oxide Result at Reference Conditions	mg/m^3	31.4	31.1	34.6	34.2	29.9
SRM Oxygen Value	% Vol/Vol	11.7	11.7	11.0	10.8	10.7
SRM Moisture Value	% Vol/Vol	N/A	N/A	N/A	N/A	N/A
SRM Pressure	kPa	N/A	N/A	N/A	N/A	N/A
SRM Stack Temperature	^oC	N/A	N/A	N/A	N/A	N/A
SRM Oxides of Nitrogen Expanded Uncertainty	mg/m^3	9.7	9.6	9.9	9.6	8.5
CEM Results Overview						
CEM Raw Nitrogen Oxide Result	mg/m^3	22.6	20.1	20.8	21.2	24.9
CEM Nitrogen Oxide Result at Reference Conditions	mg/m^3	42.3	37.6	36.7	36.4	43.1
CEM Oxygen Value	% Vol/Vol	11.4	11.4	10.8	10.5	10.6
CEM Moisture Value	% Vol/Vol	N/A	N/A	N/A	N/A	N/A
CEM Pressure	kPa	N/A	N/A	N/A	N/A	N/A
CEM Temperature	^oC	N/A	N/A	N/A	N/A	N/A

Oxides of Nitrogen QAL2 Results Overview

SRM Measured Conditions - PPM, sampled on a 'Cool/Dry' basis corrected to STP
CEM Measured Conditions - mg/m3, 273K, 101.3 kPa, on a dry gas basis.
Reference Conditions - mg/m3, 273K, 101.3 kPa, 3% Oxygen on a dry gas basis.

Field	Units	Test 6	Test 7	Test 8	Test 9	Test 10
Date	dd/mm/yyyy	16/11/21	16/11/21	16/11/21	16/11/21	16/11/21
Start Time	hh:mm	11:00	12:00	13:00	14:00	15:00
End Time	hh:mm	12:00	13:00	14:00	15:00	16:00
Total Time	hh:mm	1:00	1:00	1:00	1:00	1:00
SRM Results Overview						
SRM Raw Nitrogen Oxide Result	PPM	13.2	13.3	13.5	13.7	14.4
SRM Nitrogen Oxide at CEM Conditions	mg/m^3	17.7	17.9	18.1	18.3	19.3
SRM Oxides of Nitrogen (as NO_2) Result at Standard Conditions	mg/m^3	47.4	47.7	48.4	49.3	51.9
SRM Nitrogen Oxide Result at Reference Conditions	mg/m^3	30.9	31.1	31.6	32.1	33.8
SRM Oxygen Value	% Vol/Vol	10.7	10.7	10.7	10.7	10.7
SRM Moisture Value	% Vol/Vol	N/A	N/A	N/A	N/A	N/A
SRM Pressure	kPa	N/A	N/A	N/A	N/A	N/A
SRM Stack Temperature	^oC	N/A	N/A	N/A	N/A	N/A
SRM Oxides of Nitrogen Expanded Uncertainty	mg/m^3	8.7	8.8	8.9	9.1	9.4
CEM Results Overview						
CEM Raw Nitrogen Oxide Result	mg/m^3	28.7	28.8	27.6	25.5	25.9
CEM Nitrogen Oxide Result at Reference Conditions	mg/m^3	49.4	49.6	47.6	44.2	44.7
CEM Oxygen Value	% Vol/Vol	10.6	10.6	10.6	10.6	10.6
CEM Moisture Value	% Vol/Vol	N/A	N/A	N/A	N/A	N/A
CEM Pressure	kPa	N/A	N/A	N/A	N/A	N/A
CEM Temperature	^oC	N/A	N/A	N/A	N/A	N/A

Oxides of Nitrogen QAL2 Results Overview

SRM Measured Conditions - PPM, sampled on a 'Cool/Dry' basis corrected to STP
CEM Measured Conditions - mg/m3, 273K, 101.3 kPa, on a dry gas basis.
Reference Conditions - mg/m3, 273K, 101.3 kPa, 3% Oxygen on a dry gas basis.

Field	Units	Test 11	Test 12	Test 13	Test 14	Test 15
Date	dd/mm/yyyy	16/11/21	17/11/21	17/11/21	17/11/21	17/11/21
Start Time	hh:mm	16:00	10:10	11:10	12:10	13:10
End Time	hh:mm	16:59	11:10	12:10	13:10	14:10
Total Time	hh:mm	0:59	1:00	1:00	1:00	1:00
SRM Results Overview						
SRM Raw Nitrogen Oxide Result	PPM	14.4	14.1	14.4	14.6	14.8
SRM Nitrogen Oxide at CEM Conditions	mg/m^3	19.2	18.9	19.3	19.6	19.8
SRM Oxides of Nitrogen (as NO_2) Result at Standard Conditions	mg/m^3	51.9	53.5	55.0	55.7	56.0
SRM Nitrogen Oxide Result at Reference Conditions	mg/m^3	33.8	34.9	35.9	36.3	36.5
SRM Oxygen Value	% Vol/Vol	10.8	11.2	11.3	11.3	11.2
SRM Moisture Value	% Vol/Vol	N/A	N/A	N/A	N/A	N/A
SRM Pressure	kPa	N/A	N/A	N/A	N/A	N/A
SRM Stack Temperature	^oC	N/A	N/A	N/A	N/A	N/A
SRM Oxides of Nitrogen Expanded Uncertainty	mg/m^3	9.5	10.1	10.5	10.6	10.5
CEM Results Overview						
CEM Raw Nitrogen Oxide Result	mg/m^3	24.7	24.8	24.1	24.0	23.9
CEM Nitrogen Oxide Result at Reference Conditions	mg/m^3	42.9	44.2	42.8	42.6	42.0
CEM Oxygen Value	% Vol/Vol	10.6	10.9	10.9	10.8	10.8
CEM Moisture Value	% Vol/Vol	N/A	N/A	N/A	N/A	N/A
CEM Pressure	kPa	N/A	N/A	N/A	N/A	N/A
CEM Temperature	^oC	N/A	N/A	N/A	N/A	N/A

Oxides of Nitrogen QAL2 Results Overview

SRM Measured Conditions - PPM, sampled on a 'Cool/Dry' basis corrected to STP
CEM Measured Conditions - mg/m3, 273K, 101.3 kPa, on a dry gas basis.
Reference Conditions - mg/m3, 273K, 101.3 kPa, 3% Oxygen on a dry gas basis.

Field	Units	Test 16	Test 17	Test 18
Date	dd/mm/yyyy	17/11/21	17/11/21	17/11/21
Start Time	hh:mm	14:10	15:10	16:10
End Time	hh:mm	15:10	16:10	17:10
Total Time	hh:mm	1:00	1:00	1:00
SRM Results Overview				
SRM Raw Nitrogen Oxide Result	PPM	14.7	14.8	14.5
SRM Nitrogen Oxide at CEM Conditions	mg/m^3	19.6	19.8	19.4
SRM Oxides of Nitrogen (as NO_2) Result at Standard Conditions	mg/m^3	55.5	55.8	55.1
SRM Nitrogen Oxide Result at Reference Conditions	mg/m^3	36.2	36.4	35.9
SRM Oxygen Value	% Vol/Vol	11.2	11.2	11.3
SRM Moisture Value	% Vol/Vol	N/A	N/A	N/A
SRM Pressure	kPa	N/A	N/A	N/A
SRM Stack Temperature	^oC	N/A	N/A	N/A
SRM Oxides of Nitrogen Expanded Uncertainty	mg/m^3	10.5	10.5	10.4
CEM Results Overview				
CEM Raw Nitrogen Oxide Result	mg/m^3	24.1	24.6	24.9
CEM Nitrogen Oxide Result at Reference Conditions	mg/m^3	42.5	43.6	44.5
CEM Oxygen Value	% Vol/Vol	10.8	10.8	10.9
CEM Moisture Value	% Vol/Vol	N/A	N/A	N/A
CEM Pressure	kPa	N/A	N/A	N/A
CEM Temperature	^oC	N/A	N/A	N/A

Oxygen QAL2 Results Overview

SRM Measured Conditions - % Vol on a Dry Gas Basis
CEM Measured Conditions - % Vol on a Dry Gas Basis
Reference Conditions - % Vol on a Dry Gas Basis

Field	Units	Test 1	Test 2	Test 3	Test 4	Test 5
Date	dd/mm/yyyy	15/11/21	15/11/21	15/11/21	15/11/21	16/11/21
Start Time	hh:mm	12:00	13:00	14:00	15:00	10:00
End Time	hh:mm	13:00	14:00	15:00	16:00	11:00
Total Time	hh:mm	1:00	1:00	1:00	1:00	1:00
SRM Results Overview						
SRM Raw Oxygen Result	% Vol	11.7	11.7	11.0	10.8	10.7
SRM Oxygen at CEM Conditions	% Vol	11.7	11.7	11.0	10.8	10.7
SRM Oxygen Result at Reference Conditions	% Vol	11.7	11.7	11.0	10.8	10.7
SRM Moisture Value	% Vol	N/A	N/A	N/A	N/A	N/A
SRM Expanded Uncertainty	% Vol	0.7	0.7	0.7	0.7	0.7
CEM Results Overview						
CEM Raw Oxygen Result	% Vol	11.4	11.4	10.8	10.5	10.6
CEM Oxygen Result at Reference Conditions	% Vol	11.4	11.4	10.8	10.5	10.6
CEM Moisture Value	% Vol	N/A	N/A	N/A	N/A	N/A

Oxygen QAL2 Results Overview

SRM Measured Conditions - % Vol on a Dry Gas Basis
CEM Measured Conditions - % Vol on a Dry Gas Basis
Reference Conditions - % Vol on a Dry Gas Basis

Field	Units	Test 6	Test 7	Test 8	Test 9	Test 10
Date	dd/mm/yyyy	16/11/21	16/11/21	16/11/21	16/11/21	16/11/21
Start Time	hh:mm	11:00	12:00	13:00	14:00	15:00
End Time	hh:mm	12:00	13:00	14:00	15:00	16:00
Total Time	hh:mm	1:00	1:00	1:00	1:00	1:00
SRM Results Overview						
SRM Raw Oxygen Result	% Vol	10.7	10.7	10.7	10.7	10.7
SRM Oxygen at CEM Conditions	% Vol	10.7	10.7	10.7	10.7	10.7
SRM Oxygen Result at Reference Conditions	% Vol	10.7	10.7	10.7	10.7	10.7
SRM Moisture Value	% Vol	N/A	N/A	N/A	N/A	N/A
SRM Expanded Uncertainty	% Vol	0.7	0.7	0.7	0.7	0.7
CEM Results Overview						
CEM Raw Oxygen Result	% Vol	10.6	10.6	10.6	10.6	10.6
CEM Oxygen Result at Reference Conditions	% Vol	10.6	10.6	10.6	10.6	10.6
CEM Moisture Value	% Vol	N/A	N/A	N/A	N/A	N/A

Oxygen QAL2 Results Overview

SRM Measured Conditions - % Vol on a Dry Gas Basis
CEM Measured Conditions - % Vol on a Dry Gas Basis
Reference Conditions - % Vol on a Dry Gas Basis

Field	Units	Test 11	Test 12	Test 13	Test 14	Test 15
Date	dd/mm/yyyy	16/11/21	17/11/21	17/11/21	17/11/21	17/11/21
Start Time	hh:mm	16:00	10:10	11:10	12:10	13:10
End Time	hh:mm	16:59	11:10	12:10	13:10	14:10
Total Time	hh:mm	0:59	1:00	1:00	1:00	1:00
SRM Results Overview						
SRM Raw Oxygen Result	% Vol	10.8	11.2	11.3	11.3	11.2
SRM Oxygen at CEM Conditions	% Vol	10.8	11.2	11.3	11.3	11.2
SRM Oxygen Result at Reference Conditions	% Vol	10.8	11.2	11.3	11.3	11.2
SRM Moisture Value	% Vol	N/A	N/A	N/A	N/A	N/A
SRM Expanded Uncertainty	% Vol	0.7	0.7	0.7	0.7	0.7
CEM Results Overview						
CEM Raw Oxygen Result	% Vol	10.6	10.9	10.9	10.8	10.8
CEM Oxygen Result at Reference Conditions	% Vol	10.6	10.9	10.9	10.8	10.8
CEM Moisture Value	% Vol	N/A	N/A	N/A	N/A	N/A

Oxygen QAL2 Results Overview

SRM Measured Conditions - % Vol on a Dry Gas Basis
CEM Measured Conditions - % Vol on a Dry Gas Basis
Reference Conditions - % Vol on a Dry Gas Basis

Field	Units	Test 16	Test 17	Test 18
Date	dd/mm/yyyy	17/11/21	17/11/21	17/11/21
Start Time	hh:mm	14:10	15:10	16:10
End Time	hh:mm	15:10	16:10	17:10
Total Time	hh:mm	1:00	1:00	1:00
SRM Results Overview				
SRM Raw Oxygen Result	% Vol	11.2	11.2	11.3
SRM Oxygen at CEM Conditions	% Vol	11.2	11.2	11.3
SRM Oxygen Result at Reference Conditions	% Vol	11.2	11.2	11.3
SRM Moisture Value	% Vol	N/A	N/A	N/A
SRM Expanded Uncertainty	% Vol	0.7	0.7	0.7
CEM Results Overview				
CEM Raw Oxygen Result	% Vol	10.8	10.8	10.9
CEM Oxygen Result at Reference Conditions	% Vol	10.8	10.8	10.9
CEM Moisture Value	% Vol	N/A	N/A	N/A

6.2 - Linearity Data

Linearity Calculations for Field Monitoring

Test Information		
Client:	Intertek Ltd (on behalf of SHLNG)	
Site:	South Hook Terminal	
Stack:	SCV 2A	
Date:	15/11/2021	dd/mm/yyyy
CEM ID:	Siemens Ultramat 23	
Species:	Nitrogen Oxide	
Conversion Factor:	1.34	
Measured Units:	mg/m3	Reported units
Range under test:	140	mg/m3
ELV:	70	mg/m3
Method:	Dilution	Cylinders or blender

Cylinder Information for Lack of Fit Test					
% of 2 x range under test		20	40	60	80
mg/m3		28	56	84	112
Target Conc (ppm):	Diluted Cylinder	20.9	41.8	62.8	83.7
Cylinder ID:	188111SG				
Components:	NO/N2				
Cert value (ppm):	137				
Uncertainty (%):	1				
Flow Rate (l/min):	5.75				
Set Point A (l/min):					
Set Point B (l/min):					
Actual Concentrations (ppm):		20.90	41.80	62.60	83.70

Sampling System Check and Response Time Test							
	Sampling System Check	Tests Directly to the CEM					
		1st Test (Zero)	2nd Test	3rd Test	4th Test	5th Test	6th Test (Zero)
% of 2 x range under test	80	0	60	20	80	40	0
Test Gas Concentration	112.0	0.0	83.8	28.0	112.0	55.9	0.0
T90 Target Value	100.8						
Start Time:	10:19:35	10:28:00	11:11:00	11:17:00	11:23:00	11:29:00	11:35:00
T90 Time:	10:20:28						
Total Time (seconds)	53						
1st Reading Time (Start Time + 3 x T90)	10:22:35	10:31:00	11:14:00	11:20:00	11:26:00	11:32:00	11:38:00
Reading:	117	2	95	33	118	59	3
2nd Reading Time (1st Reading + 1 x T90)	10:23:35	10:32:00	11:15:00	11:21:00	11:27:00	11:33:00	11:39:00
Reading:	116	5	94	34	119	62	0
3rd Reading Time (2nd Reading + 1 x T90)	10:24:35	10:33:00	11:16:00	11:22:00	11:28:00	11:34:00	11:40:00
Reading:	117	4	95	33	119	60	6

Linear Regression

Linearity Point	Reference Value (x)	CEM Value (y)	Xi - X_z	$(Xi - X_z)^2$	Yi (Xi - X_z)	Yi
0.0	0.0	2.0	-46.6	2173.7	-93.2	3.6
0.0	0.0	5.0	-46.6	2173.7	-233.1	3.6
0.0	0.0	4.0	-46.6	2173.7	-186.5	3.6
20.0	28.0	33.0	-18.6	347.8	-615.4	32.8
20.0	28.0	34.0	-18.6	347.8	-634.1	32.8
20.0	28.0	33.0	-18.6	347.8	-615.4	32.8
40.0	55.9	59.0	9.3	86.9	550.1	62.0
40.0	55.9	62.0	9.3	86.9	578.1	62.0
40.0	55.9	60.0	9.3	86.9	559.5	62.0
60.0	83.8	95.0	37.2	1381.2	3530.6	91.1
60.0	83.8	94.0	37.2	1381.2	3493.4	91.1
60.0	83.8	95.0	37.2	1381.2	3530.6	91.1
80.0	112.0	118.0	65.4	4277.9	7717.9	120.6
80.0	112.0	119.0	65.4	4277.9	7783.3	120.6
80.0	112.0	119.0	65.4	4277.9	7783.3	120.6
0.0	0.0	3.0	-46.6	2173.7	-139.9	3.6
0.0	0.0	0.0	-46.6	2173.7	0.0	3.6
0.0	0.0	6.0	-46.6	2173.7	-279.7	3.6
Sum	839.2	941.0	0.0	31323.4	32729.4	941.0
Average	46.6	52.3	A	3.562	B	1.045

Residuals

Linearity Point	C	Yc	dc	dc,rel (%)
0%	0.0	3.3	-0.2	0.16
20%	27.97	33.33	0.5	0.39
40%	55.95	60.33	-1.7	1.21
60%	83.79	94.67	3.6	2.54
80%	112.03	118.67	-2.0	1.39

The residual for each test concentration relative to the range under test shall not exceed 5%.

Sample System Leak Check		
Average of readings through Sampling System and CEM	116.7	mg/m3
Average of readings directly into the CEM	118.7	mg/m3
Difference	98.3	%

The agreement between readings of a test gas applied directly to the analyser and through the sampling system shall be greater than 98%.

Linearity Calculations for Field Monitoring

Test Information		
Client:	Intertek Ltd (on behalf of SHLNG)	
Site:	South Hook Terminal	
Stack:	SCV 2A	
Date:	05/10/2021	dd/mm/yyyy
CEM ID:	Siemens Oxymat 61	
Species:	Oxygen	
Conversion Factor:	1.00	
Measured Units:	%	Reported units
Range under test:	21	%
ELV:	21	%
Method:	Dilution	Cylinders or blender

Cylinder Information for Lack of Fit Test					
% of 2 x range under test		20	40	60	80
%		4.2	8.4	12.6	16.8
Target Conc (%):	Diluted Cylinder	4.2	8.4	12.6	16.8
Cylinder ID:	245031SG				
Components:	O2/N2				
Cert value (ppm):	21				
Uncertainty (%):	1				
Flow Rate (l/min):	5.75				
Set Point A (l/min):					
Set Point B (l/min):					
Actual Concentrations (%):		4.20	8.40	12.60	16.80

Sampling System Check and Response Time Test							
	Sampling System Check	Tests Directly to the CEM					
		1st Test (Zero)	2nd Test	3rd Test	4th Test	5th Test	6th Test (Zero)
% of 2 x range under test	80	0	80	40	60	20	0
Test Gas Concentration	16.8	0.0	16.8	8.4	12.6	4.2	0.0
T90 Target Value	15.1						
Start Time:	15:08:30	15:16:00	15:22:00	15:28:00	15:34:00	15:40:00	15:46:00
T90 Time:	15:09:22						
Total Time (seconds)	52						
1st Reading Time (Start Time + 3 x T90)	15:11:30	15:19:00	15:25:00	15:31:00	15:37:00	15:43:00	15:49:00
Reading:	**16.61**	0	16.62	8.241	12.43	4.02	-0.022
2nd Reading Time (1st Reading + 1 x T90)	15:12:30	15:20:00	15:26:00	15:32:00	15:38:00	15:44:00	15:50:00
Reading:	16.61	0	16.63	8.253	12.44	4.021	-0.029
3rd Reading Time (2nd Reading + 1 x T90)	15:13:30	15:21:00	15:27:00	15:33:00	15:39:00	15:45:00	15:51:00
Reading:	16.6	0	16.64	8.262	12.44	4.027	-0.032

Linear Regression						
Linearity Point	Reference Value (x)	CEM Value (y)	Xi - X_2	$(Xi - X_2)^2$	Yi (Xi - X_2)	Yi
0.0	0.0	0.0	-7.0	49.0	0.0	-0.1
0.0	0.0	0.0	-7.0	49.0	0.0	-0.1
0.0	0.0	0.0	-7.0	49.0	0.0	-0.1
20.0	4.2	4.0	-2.8	7.8	-11.3	4.1
20.0	4.2	4.0	-2.8	7.8	-11.3	4.1
20.0	4.2	4.0	-2.8	7.8	-11.3	4.1
40.0	8.4	8.2	1.4	2.0	11.5	8.3
40.0	8.4	8.3	1.4	2.0	11.6	8.3
40.0	8.4	8.3	1.4	2.0	11.6	8.3
60.0	12.6	12.4	5.6	31.4	69.6	12.4
60.0	12.6	12.4	5.6	31.4	69.7	12.4
60.0	12.6	12.4	5.6	31.4	69.7	12.4
80.0	16.8	16.6	9.8	96.0	162.9	16.6
80.0	16.8	16.6	9.8	96.0	163.0	16.6
80.0	16.8	16.6	9.8	96.0	163.1	16.6
0.0	0.0	0.0	-7.0	49.0	0.2	-0.1
0.0	0.0	0.0	-7.0	49.0	0.2	-0.1
0.0	0.0	0.0	-7.0	49.0	0.2	-0.1
Sum	126.0	123.9	0.0	705.6	699.3	123.9
Average	7.0	6.9	A	-0.052	B	0.991

Residuals				
Linearity Point	C	Yc	dc	dc,rel (%)
0%	0.0	0.0	0.0	0.18
20%	4.20	4.02	-0.1	0.42
40%	8.40	8.25	0.0	0.10
60%	12.60	12.44	0.0	0.00
80%	16.80	16.63	0.0	0.15
The residual for each test concentration relative to the range under test shall not exceed 5%.				

Sample System Leak Check		
Average of readings through Sampling System and CEM	16.6	%
Average of readings directly into the CEM	16.6	%
Difference	99.9	%
The agreement between readings of a test gas applied directly to the analyser and through the sampling system shall be greater than 98%.		

6.3 - Calculations Used in Reporting Results

Nozzle Selection

the pressure difference of the Pitot tube pressure multiplied by the K-factor.
Where:

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

$$DH = K \times Dp$$

Where:-

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

D_n the nozzle diameter mm

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

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

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

C_p Pitot tube coefficient dependent on the Pitot tube type

T_m the meter temperature in ^oC

T_s the stack temperature in ^oC

P_s the stack pressure

P_m the meter pressure

M_d dry gas molecular weight

M_s apparent stack gas molecular weight

DH pressure drop across the orifice (mm water)

DP differential Pitot pressure (mm water)

From this the correct nozzle size can be determined.

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

Where the Constant = 0.6071 Metric

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

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

Where Km =Orifice meter coefficient

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

Where Const = 183.7 metric

Moisture Determination Calculations

These calculations are based at 273K and 101.325kPa

To calculate moisture the following equation is used:

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

Particulate Concentration C_s in stack Gases
At 273K and 101.325kPa and dry gas

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

Oxygen Concentration Correction C_{oxy} to Particulate concentration

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

Dry Molecular Weight of gases

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

Stack Molecular Weight of gases

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

Stack Gas Velocity

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

Mass Emission Rate M_R

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

IsoKinicity

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

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