

## STACK EMISSIONS MONITORING REPORT



Units C & D  
Bankside Trade Park  
Cirencester  
GL7 1YT  
Tel: 01285 700 593

### Your contact at SOCOTEC UK LTD

Mike Davies  
Business Manager - South  
Tel: 07976 297 465  
Email: mike.davies@socotec.com

### Operator & Address:

RWE Generation Ltd  
Aberthaw Power Station  
The Leys  
Nr Barry  
CF62 4ZW

### Permit Reference:


EPR Permit: RP3133LD/V012

### Release Point:

Unit 7

### Sampling Date(s):

22nd - 24th January 2019

SOCOTEC UK Job Number:	LSO 181001
Report Date:	13th March 2019
Version:	1
Report By:	Jonathan Ward
MCERTS Number:	MM02 080
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Report Approved By:	David May
MCERTS Number:	MM 07 862
Business Title:	MCERTS Level 2 - Operations Manager (LSO)
Technical Endorsements:	1, 2, 3 & 4
Signature:	



1015



## CONTENTS

### EXECUTIVE SUMMARY

#### Stack Emissions Monitoring Objectives

- Plant
- Operator
- Stack Emissions Monitoring Test House

#### Emissions Summary

#### Monitoring Times

#### Process Details

#### Monitoring Methods

#### Analytical Methods

- Sampling Methods with Subsequent Analysis
- On-Site Testing

#### Sampling Location

- Sampling Plane Validation Criteria
- Duct Characteristics
- Sampling Lines & Sample Points
- Sampling Platform
- Sampling Location / Platform Improvement Recommendations

#### Sampling and Analytical Method Deviations

### APPENDICES

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

APPENDIX 3 - Measurement Uncertainty Budget Calculations

## EXECUTIVE SUMMARY

### MONITORING OBJECTIVES

RWE Generation Ltd operates a coal fired steam turbine process at Aberthaw which is subject to EPR Permit RP3133LD/V012, under the Environmental Permitting Regulations 2010.

SOCOTEC UK LTD were commissioned by RWE Generation Ltd to carry out stack emissions monitoring to determine the release of prescribed pollutants from the following Plant under normal operating conditions.

The results of these tests shall be used to demonstrate compliance with a set of emission limit values for prescribed pollutants as specified in the Plant's EPR Permit, RP3133LD/V012.

#### **Plant**

Unit 7

#### **Operator**

RWE Generation Ltd  
Aberthaw Power Station  
The Leys  
Nr Barry  
CF62 4ZW

EPR Permit: RP3133LD/V012

#### **Stack Emissions Monitoring Test House**

SOCOTEC UK - Cirencester Laboratory  
Units C & D  
Bankside Trade Park  
Cirencester  
GL7 1YT  
UKAS and MCERTS Accreditation Number: 1015

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.  
MCERTS accredited results will only be claimed where both the sampling and analytical stages are UKAS accredited.  
This test report shall not be reproduced, except in full, without written approval of SOCOTEC UK LTD.

## EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	Units	Result	Calculated Uncertainty +/-	Limit	MCERTS accredited result
Mercury	mg/m <sup>3</sup>	0.0011	0.0011	0.005	✓
Mercury Emission Rate	g/hr	1.6433	1.6482	-	✓
Oxygen	% v/v	8.6	0.5	-	✓
Moisture	%	1.6	0.06	-	✓
Stack Gas Temperature	°C	57	-	-	✓
Stack Gas Velocity	m/s	21.6	0.53	-	
Gas Volumetric Flow Rate (Actual)	m <sup>3</sup> /hr	2345699	120604	-	
Gas Volumetric Flow Rate (STP, Wet)	m <sup>3</sup> /hr	1878357	96575	-	
Gas Volumetric Flow Rate (STP, Dry)	m <sup>3</sup> /hr	1848415	95036	-	
Gas Volumetric Flow Rate at Reference Conditions	m <sup>3</sup> /hr	1532653	78801	-	

ND = None Detected,

Results at or below the limit of detection are highlighted by bold italic text.

The above volumetric flow rate is calculated using data from the preliminary survey. Mass emissions for non isokinetic tests are calculated using these values. For all isokinetic testing the mass emission is calculated using test specific flow data and not the above values.

Reference conditions are 273K, 101.3kPa, dry gas 6% Oxygen.

## EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	Sampling Date(s)	Sampling Times	Sampling Duration
Mercury Run 1	22 January 2019	16:53 - 17:53	60 minutes
Mercury Run 2	23 January 2019	16:46 - 17:46	60 minutes
Mercury Run 3	24 January 2019	16:17 - 17:17	60 minutes
Preliminary Stack Traverse	21 January 2019	12:46	-

## EXECUTIVE SUMMARY

### PROCESS DETAILS

Parameter	Process Details
Description of process	Coal fired steam turbine
Continuous or batch	Continuous
Product Details	Energy
Part of batch to be monitored (if applicable)	N/A
Normal load, throughput or continuous rating	Day 1 = 410 MW, Day 2 = 397 MW, Day 3 = 425 MW
Fuel used during monitoring	Coal
Abatement	None
Plume Appearance	Slight Plume Visible

## EXECUTIVE SUMMARY

### Monitoring Methods

The selection of standard reference / alternative methods employed by SOCOTEC UK is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency Technical Guidance Note (Monitoring) M2.

MONITORING METHODS						
Species	Method Standard Reference Method / Alternative Method	SOCOTEC UK Technical Procedure	UKAS Lab Number	MCERTS Accredited Method	Limit of Detection (LOD)	Calculated MU +/- %
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	Yes	0.0005 mg/m <sup>3</sup>	100.3%
H <sub>2</sub> O	SRM - BS EN 14790	AE 063	1015	Yes	0.01%	3.51%
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	5 Pa	2.4%
Volumetric Flow Rate	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	-	5.1%

BS EN 14790 has been validated over a range of 4 - 40%. It is however the preferred method of the Environment Agency for concentrations below 4%

The measurement of Moisture is covered by UKAS under the conditions of ESG's flexible scope.

## EXECUTIVE SUMMARY

### Analytical Methods

The following tables list the analytical methods employed together with the custody and archiving details:

SAMPLING METHODS WITH SUBSEQUENT ANALYSIS							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	UKAS Accredited Lab Analysis	Analysis Lab	Sample Archive Location	Archive Period
Mercury	Inductively coupled Plasma - Mass Spectrometry	ASC/SOP/117	1252	Yes	SOCOTEC UK (Bretby)	SOCOTEC UK (Bretby)	8 Weeks

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	MCERTS Accredited Analysis	Laboratory	Data Archive Location	Archive Period
O <sub>2</sub>	Paramagnetism	AE 102	1015	Yes	SOCOTEC UK - (Cirencester)	SOCOTEC UK - (Cirencester)	5 years
H <sub>2</sub> O	Gravimetric	AE 105	1015	Yes	SOCOTEC UK - (Cirencester)	-	-



## EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	Value	Units	Requirement	Compliant	Method
Lowest Differential Pressure	333	Pa	$\geq 5$ Pa	Yes	BS EN 15259
Lowest Gas Velocity	21.1	m/s	-	-	-
Highest Gas Velocity	21.9	m/s	-	-	-
Ratio of Gas Velocities	1.0	: 1	$< 3 : 1$	Yes	BS EN 15259
Mean Velocity	21.6	m/s	-	-	-
Maximum angle of flow with regard to duct axis	$< 15$	$^{\circ}$	$< 15^{\circ}$	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259

DUCT CHARACTERISTICS		
	Value	Units
Shape	Circular	-
Depth	6.20	m
Width	-	m
Area	30.19	m <sup>2</sup>
Port Depth	300	mm

SAMPLING LINES & POINTS		
	Isokinetic	Non-Iso & Gases
Sample port size	4" BSP	4" BSP
Number of lines used	1	1
Number of points / line	1	1
Duct orientation	Vertical	Vertical

SAMPLING PLATFORM	
General Platform Information	
Permanent / Temporary Platform / Ground level / Floor Level / Roof	Permanent
Inside / Outside	Inside

M1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	No
Platform has 2 levels of handrails (approximately 0.5 m & 1.0 m high)	Yes
Platform has vertical base boards (approximately 0.25 m high)	N/A
Platform has removable chains / self closing gates at the top of ladders	Yes
Handrail / obstructions do not hamper insertion of sampling equipment	Yes
Depth of Platform = $>$ Stack depth / diameter + wall and port thickness + 1.5m	No

### Sampling Platform Improvement Recommendations (if applicable)

No Improvements Possible

## EXECUTIVE SUMMARY

### Sampling & Analytical Method Deviations

#### **Sample Points**

One Point per port available to test due to platform restrictions behind ports

#### **Sample Ports**

One Port used due to platform restrictions and safety issues

APPENDICES

**CONTENTS**

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

APPENDIX 3 - Measurement Uncertainty Budget Calculations

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	Method Standard Reference Method / Alternative Method	SOCOTEC UK Technical Procedure	UKAS Lab Number	MCERTS Accredited Method	Number of Samples
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	Yes	3
Moisture	AM - M22/FTIR	AE 063	1015	Yes	1
H <sub>2</sub> O	SRM - BS EN 14790	AE 063	1015	Yes	1
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	1

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

CALIBRATEABLE EQUIPMENT CHECKLIST					
Extractive Sampling		Instrumental Analyser/s		Miscellaneous	
Equipment	Equipment I.D.	Equipment	Equipment I.D.	Equipment	Equipment I.D.
Control Box DGM	P2556	Horiba PG-250 Analyser	-	Laboratory Balance	P66
Box Thermocouples	P2556	FT-IR Protea	LNO 5858	Tape Measure	P2896
Meter In Thermocouple	P2556	FT-IR Oven Box	-	Stopwatch	P2240
Meter Out Thermocouple	P2556	Bernath 3006 FID	-	Protractor	-
Control Box Timer	P2556	Signal 3030 FID	-	Barometer	P1408
Oven Box	P1873	Servomex	-	Digital Micromanometer	P2053
Probe	P2174	JCT Heated Head Filter	-	Digital Temperature Meter	P599
Probe Thermocouple	P2832	Thermo FID	-	Stack Thermocouple	P2707
Probe	-	Stackmaster	Appliance ID 8600	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	P2174	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	-	Chiller (JCT/MAK 10)	-	1m Heated Line (3)	-
Last Impinger Arm	P1033	Heated Line Controller (1)	P2543	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	P2438
Callipers	-	Site temperature Logger	P2203	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	-
Inclinometer (Swirl Device)	P2594		-	20m Heated Line (2)	-

NOTE: If the equipment I.D. is represented by a dash (-), then this piece of equipment has not been used for this test.

CALIBRATION / CHECK GASES					
Gas (traceable to ISO 17025)	Cylinder I.D Number	Supplier	ppm	%	Analytical Tolerance +/- %
Oxygen	CD 4	BOC	-	10.15	2.0
-	-	-	-	-	-

**STACK EMISSIONS MONITORING TEAM**

MONITORING TEAM								
Personnel	MCERTS Number	MCERTS		TE / H&S Qualifications and Expiry Date				
		Level	Expiry	TE1	TE2	TE3	TE4	H&S
Jonathan Ward	MM 02 080	MCERTS Level 2	Jun-20	Mar-23	Jun-23	Aug-21	Mar-21	Jun-20
Alistair Holmes	MM 13 1218	MCERTS Level 1	Mar-23	-	-	-	-	Mar-23

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

**MERCURY SUMMARY - PARTICULATE & VAPOUR PHASES COMBINED**

Test	Sampling Times	Concentration mg/m <sup>3</sup>	LOD mg/m <sup>3</sup>	Limit mg/m <sup>3</sup>	Emission Rate g/hr
Run 1	16:53 - 17:53 22 January 2019	0.0009	0.0005	0.005	1.412
Run 2	16:46 - 17:46 23 January 2019	0.0015	0.0005	0.005	2.126
Run 3	16:17 - 17:17 24 January 2019	0.0011	0.0006	0.005	1.392
Field Blank	-	0.0005	-	-	-

Mercury	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mean mg/m <sup>3</sup>	Lab Result ug	Concentration mg/m <sup>3</sup>	Stack LOD mean mg/m <sup>3</sup>	Lab Result ug	Concentration mg/m <sup>3</sup>
Run 1	0.00046	0.50	0.00046	0.0000	0.49	0.000
Volume Sampled m <sup>3</sup>		1.0888			1.0888	
Run 2	0.00	0.50	0.00	0.0000	0.92	0.001
Volume Sampled m <sup>3</sup>		0.96			0.9640	
Run 3	0.00	0.50	0.00	0.0000	0.41	0.000
Volume Sampled m <sup>3</sup>		0.86			0.8614	
Field Blank	-	0.50	0.00051	-	0.01	0.0000
Volume Sampled m <sup>3</sup>		0.9714			1.0888	

Reference conditions are 273K, 101.3kPa, dry gas 6% Oxygen.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1			Mercury	
<b>Absolute pressure of stack gas, P<sub>s</sub></b>			<b>Molecular weight of dry gas, M<sub>d</sub></b>	
Barometric pressure, P <sub>b</sub>	mm Hg	735.0	CO <sub>2</sub>	% 12.67
Stack static pressure, P <sub>static</sub>	mm H <sub>2</sub> O	-12.2	O <sub>2</sub>	% 8.00
P <sub>s</sub> = $\frac{P_b + (P_{static})}{13.6}$	mm Hg	734.1	Total	% 20.67
			N <sub>2</sub> (100 -Total)	% 79.33
			M <sub>d</sub> = 0.44(%CO <sub>2</sub> )+0.32(%O <sub>2</sub> )+0.28(%N <sub>2</sub> )	30.35
<b>Vol. of water vapour collected, V<sub>wstd</sub></b>			<b>Molecular weight of wet gas, M<sub>s</sub></b>	
Moisture trap weight increase, V <sub>lc</sub>	g	H <sub>2</sub> O by Non Iso	M <sub>s</sub> = M <sub>d</sub> (1 - B <sub>wo</sub> ) + 18(B <sub>wo</sub> )	g/gmol 30.15
V <sub>wstd</sub> = (0.001246)(V <sub>lc</sub> )	m <sup>3</sup>	-	<b>Velocity of stack gas, V<sub>s</sub></b>	
<b>Volume of gas metered dry, V<sub>mstd</sub></b>			Pitot tube velocity constant, K <sub>p</sub>	34.97
Volume of gas sample through gas meter, V <sub>m</sub>		1.39	Velocity pressure coefficient, C <sub>p</sub>	0.84
Gas meter correction factor, Y <sub>d</sub>		0.99	Mean of velocity heads, DP <sub>avg</sub>	mm H <sub>2</sub> O 34.00
Mean dry gas meter temperature, T <sub>m</sub>		17.58	Mean square root of velocity heads, ÖDP	5.83
Mean pressure drop across orifice, DH	mmHg	48.49	Mean stack gas temperature, T <sub>s</sub>	°C 56
V <sub>mstd</sub> = $\frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m + 273}$		1.26	V <sub>s</sub> = $\frac{(K_p)(C_p)(\ddot{O}DP)(\ddot{O}(T_s + 273))}{(M_s)(P_s)}$	m/s 20.88
<b>Volume of gas metered wet, V<sub>mstw</sub></b>			<b>Actual flow of stack gas, Q<sub>a</sub></b>	
V <sub>mstw</sub> = V <sub>mstd</sub> + V <sub>wstd</sub>	m <sup>3</sup>	1.2767	Area of stack, A <sub>s</sub>	m <sup>2</sup> 30.19
<b>Vol. of gas metered at O<sub>2</sub> Ref. Cond., V<sub>mstd@X%O<sub>2</sub></sub></b>			Q <sub>a</sub> = (60)(A <sub>s</sub> )(V <sub>s</sub> )	m <sup>3</sup> /min 37833.0
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)	No		<b>Total flow of stack gas, Q</b>	
% oxygen measured in gas stream, act%O <sub>2</sub>	8.0		Conversion factor (K/mm.Hg)	0.3592
% oxygen reference condition	6		Q <sub>std</sub> = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) + 273}$	Dry 29839.5
O <sub>2</sub> Reference	O <sub>2</sub> Ref = 21.0 - act%O <sub>2</sub>	0.87	Q <sub>stdO2</sub> = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) + 273}$	@O2ref 25860.9
Factor	21.0 - ref%O <sub>2</sub>		Q <sub>stw</sub> = $\frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet 30322.9
V <sub>mstd@X%oxygen</sub> = (V <sub>mstd</sub> ) (O <sub>2</sub> Ref)	m <sup>3</sup>	1.089	<b>Percent isokinetic, %I</b>	
<b>Moisture content, B<sub>wo</sub></b>			Nozzle diameter, D <sub>n</sub>	mm 5.05
B <sub>wo</sub> = $\frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0159	Nozzle area, A <sub>n</sub>	mm <sup>2</sup> 20.03
		1.59	Total sampling time, q	min 60
<b>Moisture by FTIR</b>			%I = $\frac{(4.6398E6)(T_s + 273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	% 105.8
		-	Acceptable isokinetic range 95% to 115%	
			Yes	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 2			Mercury	
<b>Absolute pressure of stack gas, P<sub>s</sub></b>			<b>Molecular weight of dry gas, M<sub>d</sub></b>	
Barometric pressure, P <sub>b</sub>	mm Hg	735.0	CO <sub>2</sub>	% 12.67
Stack static pressure, P <sub>static</sub>	mm H <sub>2</sub> O	-12.2	O <sub>2</sub>	% 9.00
$P_s = P_b + (P_{static})$	mm Hg		Total	% 21.67
13.6		734.1	N <sub>2</sub> (100 -Total)	% 78.33
			$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2)$	30.39
<b>Vol. of water vapour collected, V<sub>wstd</sub></b>			<b>Molecular weight of wet gas, M<sub>s</sub></b>	
Moisture trap weight increase, V <sub>lc</sub>	g	H <sub>2</sub> O by Non Iso	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol 30.19
$V_{wstd} = (0.001246)(V_{lc})$	m <sup>3</sup>	-	<b>Velocity of stack gas, V<sub>s</sub></b>	
<b>Volume of gas metered dry, V<sub>mstd</sub></b>			Pitot tube velocity constant, K <sub>p</sub>	34.97
Volume of gas sample through gas meter, V <sub>m</sub>		1.333	Velocity pressure coefficient, C <sub>p</sub>	0.84
Gas meter correction factor, Y <sub>d</sub>		0.99	Mean of velocity heads, DP <sub>avg</sub>	mm H <sub>2</sub> O 34.58
Mean dry gas meter temperature, T <sub>m</sub>		17.58	Mean square root of velocity heads, ÖDP	5.88
Mean pressure drop across orifice, DH	mmHg	49.62	Mean stack gas temperature, T <sub>s</sub>	°C 54
$V_{mstd} = \frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m + 273}$		1.20	$V_s = \frac{(K_p)(C_p)(\ddot{O}DP)(\ddot{O}(T_s + 273))}{(M_s)(P_s)}$	m/s 20.98
<b>Volume of gas metered wet, V<sub>mstw</sub></b>			<b>Actual flow of stack gas, Q<sub>a</sub></b>	
$V_{mstw} = V_{mstd} + V_{wstd}$	m <sup>3</sup>	1.2245	Area of stack, A <sub>s</sub>	m <sup>2</sup> 30.19
<b>Vol. of gas metered at O<sub>2</sub> Ref. Cond., V<sub>mstd@X%O2</sub></b>			$Q_a = (60)(A_s)(V_s)$	m <sup>3</sup> /min 38015.2
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)	No		<b>Total flow of stack gas, Q</b>	
% oxygen measured in gas stream, act%O <sub>2</sub>	9.0		Conversion factor (K/mm.Hg)	0.3592
% oxygen reference condition	6		$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) + 273}$	Dry 30166.6
O <sub>2</sub> Reference O <sub>2</sub> Ref = 21.0 - act%O <sub>2</sub>	0.80		$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) + 273}$	@O2ref 24133.3
Factor 21.0 - ref%O <sub>2</sub>			$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet 30655.3
$V_{mstd@X\%oxygen} = (V_{mstd})(O_2 Ref)$	m <sup>3</sup>	0.964	<b>Percent isokinetic, %I</b>	
<b>Moisture content, B<sub>wo</sub></b>			Nozzle diameter, D <sub>n</sub>	mm 5.1
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0159	Nozzle area, A <sub>n</sub>	mm <sup>2</sup> 20.0
		1.59	Total sampling time, q	min 60
<b>Moisture by FTIR</b>			$\%I = \frac{(4.6398E6)(T_s + 273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	% 100.3
		-	Acceptable isokinetic range 95% to 115%	
			Yes	



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 3			Mercury	
<b>Absolute pressure of stack gas, P<sub>s</sub></b>			<b>Molecular weight of dry gas, M<sub>d</sub></b>	
Barometric pressure, P <sub>b</sub>	mm Hg	741.8	CO <sub>2</sub>	% 12.67
Stack static pressure, P <sub>static</sub>	mm H <sub>2</sub> O	-12.2	O <sub>2</sub>	% 8.70
$P_s = P_b + (P_{static})$	mm Hg	740.9	Total	% 21.37
13.6			N <sub>2</sub> (100 -Total)	% 78.63
			$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2)$	30.37
<b>Vol. of water vapour collected, V<sub>wstd</sub></b>			<b>Molecular weight of wet gas, M<sub>s</sub></b>	
Moisture trap weight increase, V <sub>lc</sub>	g	H <sub>2</sub> O by Non Iso	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol 30.18
$V_{wstd} = (0.001246)(V_{lc})$	m <sup>3</sup>	-	<b>Velocity of stack gas, V<sub>s</sub></b>	
<b>Volume of gas metered dry, V<sub>mstd</sub></b>			Pitot tube velocity constant, K <sub>p</sub>	34.97
Volume of gas sample through gas meter, V <sub>m</sub>		1.166	Velocity pressure coefficient, C <sub>p</sub>	0.84
Gas meter correction factor, Y <sub>d</sub>		0.9900	Mean of velocity heads, DP <sub>avg</sub>	mm H <sub>2</sub> O 27.17
Mean dry gas meter temperature, T <sub>m</sub>		20.92	Mean square root of velocity heads, ÖDP	5.21
Mean pressure drop across orifice, DH	mmHg	39.07	Mean stack gas temperature, T <sub>s</sub>	°C 57
$V_{mstd} = \frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m + 273}$		1.050	$V_s = \frac{(K_p)(C_p)(\ddot{O}DP)(\ddot{O}(T_s + 273))}{(M_s)(P_s)}$	m/s 18.60
<b>Volume of gas metered wet, V<sub>mstw</sub></b>			<b>Actual flow of stack gas, Q<sub>a</sub></b>	
$V_{mstw} = V_{mstd} + V_{wstd}$	m <sup>3</sup>	1.0675	Area of stack, A <sub>s</sub>	m <sup>2</sup> 30.19
<b>Vol. of gas metered at O<sub>2</sub> Ref. Cond., V<sub>mstd@X%O<sub>2</sub></sub></b>			$Q_a = (60)(A_s)(V_s)$	m <sup>3</sup> /min 33699.43
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)	No		<b>Total flow of stack gas, Q</b>	
% oxygen measured in gas stream, act%O <sub>2</sub>	8.7		Conversion factor (K/mm.Hg)	0.3592
% oxygen reference condition	6		$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) + 273}$	Dry 26742.44
O <sub>2</sub> Reference O <sub>2</sub> Ref = 21.0 - act%O <sub>2</sub>	0.82		$Q_{stdO_2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) + 273}$	@O2ref 21928.80
Factor 21.0 - ref%O <sub>2</sub>			$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet 27175.6
$V_{mstd@X\%oxygen} = (V_{mstd})(O_2 Ref)$	m <sup>3</sup>	0.861	<b>Percent isokinetic, %I</b>	
<b>Moisture content, B<sub>wo</sub></b>			Nozzle diameter, D <sub>n</sub>	mm 5.05
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0159	Nozzle area, A <sub>n</sub>	mm <sup>2</sup> 20.03
		1.59	Total sampling time, q	min 60
<b>Moisture by FTIR</b>			$\%I = \frac{(4.6398E6)(T_s + 273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	% 98.7
			Acceptable isokinetic range 95% to 115%	
			Yes	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

**HEAVY METALS QA CHECKLIST**

Leak Test Results	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable litre/min
Run 1	22.9	0.13	0.11	-381	0.46	Yes
Run 2	22.0	0.17	0.15	-381	0.44	Yes
Run 3	19.2	0.17	0.18	-381	0.38	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	105.8	Yes
Run 2	100.3	Yes
Run 3	98.7	Yes

Filtration / Temp	Filter Material	Filter Size mm	Maximum Filtration Temperature °C	Maximum storage / transit Temperature °C
Run 1	Quartz Fibre	90	184	7
Run 2	Quartz Fibre	90	185	7
Run 3	Quartz Fibre	90	186	7

Mercury	Type of Absorbers - Mercury	Absorption Solutions - Mercury
Run 1	Glass	4% Potassium Dichromate, 20% Nitric Acid
Run 2	Glass	4% Potassium Dichromate, 20% Nitric Acid
Run 3	Glass	4% Potassium Dichromate, 20% Nitric Acid

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

**HEAVY METALS ABSORPTION EFFICIENCY**

Parameter		Total ug	5th Absorber ug	Absorption Efficiency	Required	Pass / Fail
Mercury	Run 1	0.99	ND	100	95	N/A <30% ELV
	Run 2	1.42	0.15	89	95	N/A <30% ELV
	Run 3	0.91	0.07	93	95	N/A <30% ELV

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

**DAILY OXYGEN SUMMARY**

Sampling Times	Concentration %	LOD %
10:00 - 18:00 22 January 2019	7.98	0.01
09:30 - 17:25 23 January 2019	9.01	0.01
09:30 - 16:30 24 January 2019	8.69	0.01

PRE SAMPLING CALIBRATION DATA								
Date	Time of Analyser Checks	Range (%)	Zero Reading at analyser	Span Reading at analyser	Zero Check at analyser	Zero Check down line	Span Check down line	Leak Rate %
22 January 2019	09:00 - 09:30	25	0.00	10.15	0.10	0.11	10.23	0.78
23 January 2019	09:10 - 09:25	25	0.00	10.15	0.10	0.10	10.25	0.98
24 January 2019	09:10 - 09:25	25	0.00	10.15	0.12	0.14	10.31	1.55

POST SAMPLING CALIBRATION DATA					
Date	Time of Analyser Checks	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
22 January 2019	18:00 - 18:20	0.14	10.27	0.12	0.04
23 January 2019	17:30 - 17:45	0.11	10.20	0.04	-0.24
24 January 2019	16:40 - 16:50	0.14	10.30	0.00	-0.04

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

**MOISTURE CALCULATIONS**

Moisture Determination - Non Isokinetic							
Test Number	Sampling Time and Date	Start Weight	End Weight	Total gain	Concentration	LOD	Uncertainty
		kg	kg	kg	%	%	%
Run 1	16:43 - 17:53 22 January 2019	1.0000	1.0140	0.0140	1.6	0.01	3.5

Moisture Quality Assurance							
Test Number	Sampling Duration	Total Volume Sampled	Sampling Rate	Start Leak Rate	End Leak Rate	Acceptable Leak Rate	Leak Tests Acceptable?
	mins	l	l/min	l/min	l/min	l/min	
Run 1	60	1077	17.9	0.11	0.12	0.36	Yes

**PRELIMINARY STACK SURVEY**

Stack Characteristics		
Stack Diameter / Depth, D	6.20	m
Stack Width, W	-	m
Stack Area, A	30.19	m <sup>2</sup>
Average stack gas temperature	57	°C
Stack static pressure	-0.12	kPa
Barometric Pressure	98.1	kPa

Stack Gas Composition & Molecular Weights								
Component	Molar Mass M	Density kg/m <sup>3</sup> p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m <sup>3</sup> pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m <sup>3</sup> pi
CO <sub>2</sub>	44	1.963059	12.666667	0.126667	0.248654	12.464754	0.124648	0.244690
O <sub>2</sub>	32	1.427679	7.983222	0.079832	0.113975	7.855966	0.078560	0.112158
N <sub>2</sub>	28	1.249219	79.350111	0.793501	0.991257	78.085236	0.780852	0.975456
H <sub>2</sub> O	18	0.803070	-	-	-	1.594043	0.015940	0.012801

Where:  $p = M / 22.41$   $pi = r \times p$

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), $P_{STD}$	1.3539	kg/m <sup>3</sup>
Wet Density (STP), $P_{STW}$	1.3451	kg/m <sup>3</sup>
Dry Density (Actual), $P_{Actual}$	1.0841	kg/m <sup>3</sup>
Average Wet Density (Actual), $P_{ActualW}$	1.077	kg/m <sup>3</sup>

Where:

$P_{STD}$  = sum of component concentrations, kg/m<sup>3</sup> (not including water vapour)

$P_{STW} = (P_{STD} + pi \text{ of H}_2\text{O}) / (1 + (pi \text{ of H}_2\text{O} / 0.8036))$

$P_{Actual} = P_{STD} \times (Ts / Ps) \times (Pa / Ta)$

$P_{ActualW} = P_{STW} \times (Ts / Ps) \times (Pa / Ta)$

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

**PRELIMINARY STACK SURVEY**

**TRAVERSE 1**

Date of Survey	21 January 2019
Time of Survey	12:46
Velocity Measurement Device:	S-Type Pitot

Sampling Line A								
Traverse Point	Distance into duct (m)	DP pt mmH <sub>2</sub> O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m <sup>3</sup> /s	O <sub>2</sub> % Vol	Angle of Swirl °
1	0.30	36.3	356	56	21.5	649.4	-	<15
Mean	-	36.3	356	56	21.5	649.4	-	-

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt mmH <sub>2</sub> O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m <sup>3</sup> /s	O <sub>2</sub> % Vol	Angle of Swirl °
1	0.30	37.7	369	57	21.9	662.2	-	<15
Mean	-	37.7	369	57	21.9	662.2	-	-

Sampling Line C								
Traverse Point	Distance into duct (m)	DP pt mmH <sub>2</sub> O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m <sup>3</sup> /s	O <sub>2</sub> % Vol	Angle of Swirl °
1	0.30	37.00	363	58.00	21.8	657.3	-	<15
Mean	-	37.00	363	58.00	21.8	657.3	-	-

Sampling Line D								
Traverse Point	Distance into duct (m)	DP pt mmH <sub>2</sub> O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m <sup>3</sup> /s	O <sub>2</sub> % Vol	Angle of Swirl °
1	0.30	35.00	343	56.00	21.1	637.4	-	<15
Mean	-	35.00	343	56.00	21.1	637.4	-	-

**PRELIMINARY STACK SURVEY QUALITY ASSURANCE CHECKLIST**

PITOT LEAK CHECK								
Run	Pre Traverse Leak Rate				Post Traverse Leak Rate			
	Start Value Pa	End Value Pa	Difference %	Outcome	Start Value Pa	End Value Pa	Difference %	Outcome
Run 1	87	88	-1.1	Pass	88	87	1.1	Pass

To complete a compliant pitot leak check a pressure of over 80 mmH<sub>2</sub>O (or 800 Pa) is applied and the pressure drop monitored over 5 mins. A drop of less than 5% must be observed.

S-Type Pitot Stagnation Check				
Run	Stagnation (Pa)	Reference (Pa)	Difference (Pa)	Outcome (Permitted +/- 10 Pa)
Run 1	-150	-150	0.0	Pass

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

**PRELIMINARY STACK SURVEY (CONTINUED)**

Sampling Plane Validation Criteria				
EA Technical Guidance Note (Monitoring) M1	Result	Units	Requirement	Compliant
Lowest Differential Pressure	343	Pa	$\geq 5 \text{ Pa}$	Yes
Lowest Gas Velocity	21.1	m/s	-	-
Highest Gas Velocity	21.9	m/s	-	-
Ratio of Gas Velocities	1.0	-	$< 3 : 1$	Yes
Maximum angle of flow with regard to duct axis	$< 15$	$^{\circ}$	$< 15^{\circ}$	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, $V = K_{pt} \times (1-e) \times \sqrt{2 \times DP_{pt} / \rho_{ActualW}}$		
<b>Where:</b> $K_{pt}$ = Pitot tube calibration coefficient $(1-e)$ = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, Va	21.6	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	57	0	$^{\circ}\text{C}$
Total Pressure	97.98	101.3	kPa
Oxygen	8.6	6	%
Moisture	1.59	0.00	%
Pitot tube calibration coefficient, $K_{pt}$	0.84		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	21.58	m/s
Stack Area (A)	30.19	$\text{m}^2$
Gas Volumetric Flowrate (Actual), $Q_{Actual}$	2345699	$\text{m}^3/\text{hr}$
Gas Volumetric Flowrate (STP, Wet), $Q_{STP}$	1878357	$\text{m}^3/\text{hr}$
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	1848415	$\text{m}^3/\text{hr}$
Gas Volumetric Flowrate (REF), $Q_{Ref}$	1532653	$\text{m}^3/\text{hr}$

**Where:**

$$Q_{Actual} = V_a \times A \times 3600$$

$$Q_{STP} = Q_{Actual} \times (T_s / T_a) \times (P_a / P_s) \times 3600$$

$$Q_{STP,Dry} = Q_{STP} / (100 - (100 / Ma)) \times 3600$$

$$Q_{Ref} = Q_{STP} \times ((100 - Ma) / (100 - Ms)) \times ((20.9 - O_{2a}) / (20.9 - O_{2s}))$$

**Nomenclature:**

$T_s$  = Absolute Temperature, Standard Conditions, 273 K

$P_s$  = Absolute Pressure, Standard Conditions, 101.3 kPa

$T_a$  = Absolute Temperature, Actual Conditions, K

$P_a$  = Absolute Pressure, Actual Conditions, kPa

$Ma$  = Water vapour, Actual Conditions, % Vol

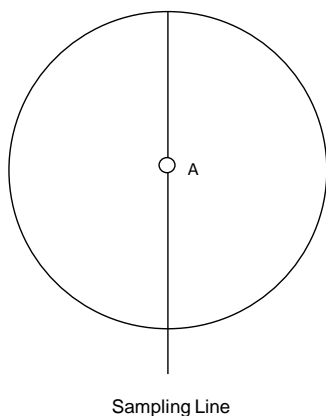
$Ms$  = Water vapour, Reference Conditions, % Vol

$O_{2a}$  = Oxygen, Actual Conditions, % Vol

$O_{2s}$  = Oxygen, Reference Conditions, % Vol

### STACK DIAGRAM

	Value	Units
Stack Depth	6.20	m
Stack Width	-	m
Area	30.19	m <sup>2</sup>



- Isokinetic sampling point
- Isokinetic sampling points not used
- Non Isokinetic/Gases sampling point

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	30	1.86	m

[illegible]



APPENDIX 3 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - MERCURY**

Run	Sampled Volume m <sup>3</sup>	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Leak %
<b>MU required</b>	<b>&lt;=2%</b>	<b>&lt;2.5 k</b>	<b>&lt;=1%</b>	<b>&lt;=1%</b>	<b>&lt;=5%</b>	<b>&lt;5%</b>	<b>&lt;=2%</b>
Run 1	0.001	2.0	0.50	1.0	0.10	3.05353E-05	-
as a %	0.08	0.7	0.52	1.0	1.25	3.00	0.48
<b>compliant?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Run 2	0.0	2.0	0.50	1.0	0.10	5.46932E-05	-
as a %	0.10	0.7	0.51	1.0	1.11	3.00	0.68
<b>compliant?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Run 3	0.0	2.0	0.50	1.0	0.10	2.24918E-05	-
as a %	0.12	0.7	0.51	1.0	1.15	3.00	0.94
<b>compliant?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>

Run	Volume (STP) m <sup>3</sup>	O2 Correction -	Mass of Mercury mg	Leak mg/m <sup>3</sup>	Lab Uncertainty mg	Combined
Run 1	1.1279	1.1538	0.9906	0.0000	-	-
MU as mg/m <sup>3</sup>	0.0000	0.0000	0.0005	0.0000	0.00005	<b>0.0005</b>
MU as %	1.3223	0.7692	50.4846	0.2769	5.00000	-
Run 2	0.883	1.250	1.128	0.000	-	-
MU as mg/m <sup>3</sup>	0.000	0.000	0.001	0.000	0.00007	<b>0.001</b>
MU as %	1.320	0.833	44.339	0.394	5.00000	-
Run 3	0.772	1.220	0.912	0.000	-	-
MU as mg/m <sup>3</sup>	0.000	0.000	0.001	0.000	0.00005	<b>0.001</b>
MU as %	1.320	0.813	54.860	0.540	5.00000	-

<b>R1 - Uncertainty expressed at a 95% confidence level (where k = 2)</b>	<b>0.0009</b>	<b>mg/m<sup>3</sup></b>	<b>101.51</b>	<b>%</b>
<b>R2 - Uncertainty expressed at a 95% confidence level (where k = 2)</b>	<b>0.0013</b>	<b>mg/m<sup>3</sup></b>	<b>89.30</b>	<b>%</b>
<b>R3 - Uncertainty expressed at a 95% confidence level (where k = 2)</b>	<b>0.0012</b>	<b>mg/m<sup>3</sup></b>	<b>110.22</b>	<b>%</b>

(k is a coverage factor which gives a 95% confidence in the quoted figures)

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - MOISTURE**

Run	Sampled Volume m <sup>3</sup>	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Leak %
<b>MU required</b>	<b>≤ 2%</b>	<b>≤ 2%</b>	<b>≤ 1%</b>	<b>≤ 1%</b>	<b>≤ 10%</b>	<b>≤ 2%</b>
Run 1	0.000	2.0	0.50	1.0	0.1	-
as a %	0.03	0.61	0.51	1.0	1.17	0.61
<b>compliant?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>

Run	Volume (STP) m <sup>3</sup>	Mass Gained mg	O2 Correction -	Leak mg/m <sup>3</sup>	Uncollected Mass mg	Combined uncertainty
Run 1	0.9	14000	1.2	46.0	58	-
MU as % v/v	0.02	0.01	0.00	0.01	0.01	<b>0.03</b>
MU as %	1.3	0.7	0.80	0.4	0.4	-

<b>R1 - Uncertainty expressed at a 95% confidence level (where k = 2)</b>	<b>0.05</b>	<b>% v/v</b>	<b>3.51</b>	<b>%</b>
---	-------------	--------------	-------------	----------

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - OXYGEN**

DAY 1 - 22 January 2019

Reference	6	%vol
Measured concentration	7.98	%vol
Calibration gas	10.15	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	23	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	480	minutes	-	-
Number of readings in measurement	480	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	No
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.1	% of value	<2 % range	Yes
Zero drift	0.12	% full scale	<2% range / 24hr	Yes
Span drift	0.04	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	-0.0425	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.0475	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	0.0025	% full scale/10K	<3% range / 10 K	Yes
Combined interference	0.00	% range	<4% of Range	Yes
dependence on voltage	0.18	% full scale/10V	< 0.1%vol /10 volt	No
losses in the line (leak)	0.78	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.00	% of value	< 2% of value	Yes

losses in the line (leak)	Uncertainty	< 2% of value
repeatability	$U_r = S_r$	0.0083
lack of fit	$U_{lof}$	0.0577
short term zero drift	$U_{d,z}$	0.07
short term span drift	$U_{d,s}$	0.02
influence of Ambient Temp at Zero	$U_{t,z}$	-2.45904E-05
influence of Ambient Temp at Span	$U_{t,s}$	0.000131149
influence of sample gas pressure	$U_p$	0
influence of sample gas flow	$U_{fit}$	-0.029444864
influence of supply voltage	$U_v$	0.010255184
Combined Interference	$U_i$	0.00
Uncertainty of Cal gas	$U_{adj}$	0.05075

Measurement uncertainty (Concentration Measured)	7.98	%
Combined Interference	0.11	%
Uncertainty of Cal gas	1.39	%

Expanded uncertainty expressed with a level of confidence of 95%	1.39	%
--	------	---

Expanded uncertainty as percentage of the result	0.11	% vol
--	------	-------

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - OXYGEN**

day 2 - 23 January 2019

Reference	6	%vol
Measured concentration	9.01	%vol
Calibration gas	10.15	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	23	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	475	minutes	-	-
Number of readings in measurement	475	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	No
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.1	% of value	<2 % range	Yes
Zero drift	0.04	% full scale	<2% range / 24hr	Yes
Span drift	-0.24	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	-0.0425	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.0475	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	0.0025	% full scale/10K	<3% range / 10 K	Yes
Combined interference	0.00	% range	<4% of Range	Yes
dependence on voltage	0.18	% full scale/10V	< 0.1%vol /10 volt	No
losses in the line (leak)	0.98	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.00	% of value	< 2% of value	Yes

losses in the line (leak)	Uncertainty	< 2% of value
repeatability	$U_r = S_r$	0.0083
lack of fit	$U_{lof}$	0.0577
short term zero drift	$U_{d,z}$	0.02
short term span drift	$U_{d,s}$	-0.14
influence of Ambient Temp at Zero	$U_{t,z}$	-8.77971E-06
influence of Ambient Temp at Span	$U_{t,s}$	-0.000175594
influence of sample gas pressure	$U_p$	0
influence of sample gas flow	$U_{fit}$	-0.029444864
influence of supply voltage	$U_v$	0.010255184
Combined Interference	$U_i$	0.00
Uncertainty of Cal gas	$U_{adj}$	0.05075

Measurement uncertainty (Concentration Measured)	9.01	%
Combined Interference	0.16	%
Uncertainty of Cal gas	1.81	%

Expanded uncertainty expressed with a level of confidence of 95%	1.81	%
--	------	---

Expanded uncertainty as percentage of the result	0.16	% vol
--	------	-------

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - OXYGEN**

day 3 - 24 January 2019

Reference	6	%vol
Measured concentration	8.69	%vol
Calibration gas	10.15	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	23	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	420	minutes	-	-
Number of readings in measurement	420	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	No
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.1	% of value	<2 % range	Yes
Zero drift	0.00	% full scale	<2% range / 24hr	Yes
Span drift	-0.04	% full scale	<2% range/24hr	Yes
volume or pressure flow dependence	-0.0425	% of full scale/3 kPa	<2 % / 3 kPa	Yes
atmospheric pressure dependence	0.0475	% of full scale/2 kPa	<3% / 2 kPa	Yes
ambient temperature dependence	0.0025	% full scale/10K	<3% range / 10 K	Yes
Combined interference	0.00	% range	<4% of Range	Yes
dependence on voltage	0.18	% full scale/10V	< 0.1%vol /10 volt	No
losses in the line (leak)	1.55	% of value	< 2% of value	Yes
Uncertainty of calibration gas	1.00	% of value	< 2% of value	Yes

losses in the line (leak)	Uncertainty	< 2% of value
repeatability	$U_r = S_r$	0.0083
lack of fit	$U_{lof}$	0.0577
short term zero drift	$U_{d,z}$	0.00
short term span drift	$U_{d,s}$	-0.02
influence of Ambient Temp at Zero	$U_{t,z}$	0
influence of Ambient Temp at Span	$U_{t,s}$	-4E-05
influence of sample gas pressure	$U_p$	0
influence of sample gas flow	$U_{fit}$	-0.029444864
influence of supply voltage	$U_v$	0.010255184
Combined Interference	$U_i$	0.00
Uncertainty of Cal gas	$U_{adj}$	0.05075

Measurement uncertainty (Concentration Measured)	8.69	%
Combined Interference	0.09	%
Uncertainty of Cal gas	1.00	%

Expanded uncertainty expressed with a level of confidence of 95%	1.00	%
--	------	---

Expanded uncertainty as percentage of the result	0.09	% vol
--	------	-------

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

**MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE**

Measured Velocity at Actual Conditions	21.6	m/s
Measured Volumetric Flow rate at Actual Conditions	2345699	m <sup>3</sup> /hr

Performance Characteristics & Source of Value	Units	Values	Requirement	Compliant
<b>Uncertainty of Local Gas Velocity Determination</b>				
Uncertainty of pitot tube coefficient	-	0.010		
Uncertainty of mean local dynamic pressures	-	0.49		
Factor loading, function of the number of measurements.	3 readings	0.591	minimum 3	Yes
Range of measurement device	pa	1000		
Resolution	pa	1.00		
Calibration uncertainty	pa	7.22	<1% of Value or 20 Pa whichever is greater	Yes
Drift	% range	0.10		
Linearity	% range	0.06	<2% of value	Yes
Uncertainty of gas density determination				
Uncertainty of molar mass determination	kg/mol	0.00006		
Uncertainty of temperature measurement	K	1.68	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	500		
Uncertainty associated with the estimate of density	-	0.008		
Uncertainty associated with the measurement of local velocity	-	0.0001		
Uncertainty associated with the measurement of mean velocity	-	0.0002		

Measurement Uncertainty - Velocity	m/s
Combined uncertainty	0.27
Expanded uncertainty at a 95% Confidence Interval	0.53

Note - The expanded uncertainty uses a coverage factor of  $k = 2$ .

Expanded Measurement Uncertainty of Velocity at a 95% Confidence Interval	%
Expressed as a % of the Measured Velocity	1.2
Expanded uncertainty at a 95% Confidence Interval	2.4

Measurement Uncertainty Volumetric Flow Rate	m <sup>3</sup> /hr
Combined uncertainty	61533
Expanded uncertainty at a 95% Confidence Interval	120604

Note - The expanded uncertainty uses a coverage factor of  $k = 2$ .

Expanded Measurement Uncertainty of Volumetric Flow Rate at a 95% Confidence Interval	%
Expressed as a % of the Measured Volumetric Flow Rate	2.6
Expanded uncertainty at a 95% Confidence Interval	5.1

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

## END OF REPORT

*Thank you for choosing SOCOTEC UK for your environmental monitoring needs. We hope our services have met your requirements and that you are fully satisfied with your experience of working with us, we really do value your custom and would welcome your feedback. We would appreciate it if you could take a moment to complete a short online questionnaire so that we can improve our operations and address any areas that have not met with your expectations, by clicking on the following*

[https://www.surveymonkey.co.uk/r/CAE\\_customer\\_feedback\\_weblink](https://www.surveymonkey.co.uk/r/CAE_customer_feedback_weblink)