STACK EMISSIONS MONITORING REPORT

Units C & D
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Operator & Address:
Babcock & Wilcox Vølund Limited Land Off Longlands Lane (Heol Cae'r Bont) Margam Neath Port Talbot

Permit Reference:
EPR Permit: EPR/DP3137EG

Release Point:
A1 - Main Stack

Sampling Date(s):
25th August 2022

SOCOTEC Job Number:	LSO 220613
Report Date:	29th September 2022
Version:	1
Report By:	Jose Navarro
MCERTS Number:	MM 19 1542
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
Technical Endorsements:	1, 2, 3 & 4
Signature:	

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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Babcock & Wilcox Vølund Limited operates a wood fired incineration process at Margam Green Energy Plant which is subject to EPR Permit EPR/DP3137EG, under the Environmental Permitting Regulations 2010.

SOCOTEC LTD were commissioned by David Appleby 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, EPR/DP3137EG.

Plant

A1 - Main Stack

Operator

Babcock & Wilcox Vølund Limited
Land Off Longlands Lane (Heol Cae'r Bont)
Margam
Neath
Port Talbot
SA13 2NU

Stack Emissions Monitoring Test House

SOCOTEC - 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.
The results of this testing relate only to the emission release point(s) listed in the report.
MCERTS accredited results will only be claimed where both the sampling and analytical stages are MCERTS accredited.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Emission Limit Value (ELV)**	**Accreditation**
Mercury Mercury Emission Rate	mg/m³ g/hr	0.0016 0.2840	0.0008 0.1355	0.05 -	MCERTS
Oxygen	% v/v	9.46	0.40	-	MCERTS
Moisture	%	18.2	0.6	-	MCERTS
Stack Gas Temperature	°C	126	-	-	MCERTS
Stack Gas Velocity	m/s	23.6	0.57	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	383666.4	19726.1	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	262187.4	13480.3	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	214530.9	11030.0	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	214530.9	11030.0	-	

ND = None Detected,

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

The above volumetric flow rate is an average of the data collected during the isokinetic tests. Mass emissions for non isokinetic tests are also calculated using these 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	25 August 2022	09:00 - 10:05	60 minutes
Mercury Run 2	25 August 2022	10:20 - 11:25	60 minutes
Mercury Run 3	25 August 2022	11:45 - 12:50	60 minutes
Preliminary Stack Traverse	24 August 2022	09:15	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Wood Fired Incineration
Continuous or batch	Continuous
Product Details	Power
Part of batch to be monitored (if applicable)	N/A
Normal load, throughput or continuous rating	0.95
Fuel used during monitoring	Wood grade 2-4 and Fuel oil
Abatement	PAC, Lime SNCR injection, NH3
Plume Appearance	Steam plume visible

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by SOCOTEC is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency technical Guidance 'Monitoring stack emissions: techniques and standards for periodic monitoring'.

MONITORING METHODS							
Species	**Method** Standard Reference Method / Alternative Method	**SOCOTEC Technical Procedure**	**UKAS Lab Number**	**Method Accreditation**	**Limit of Detection (LOD)**	**Calculated MU +/- % Result**	**Calculated MU +/- % ELV**
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	MCERTS	0.0004 mg/m³	47.7%	1.5%
Oxygen	AM - BS EN 14789:2017	AE 102	1015	MCERTS	0.01%	4.3%	N/A - No ELV
Moisture	SRM - BS EN 14790	AE 105	1015	MCERTS	0.05%	3.5%	N/A - No ELV
Velocity	SRM - EN ISO 16911-1	AE 154	1015	MCERTS	5 Pa	2.4%	N/A - No ELV
Volumetric Flow Rate	SRM - EN ISO 16911-1	AE 154	1015	MCERTS	-	5.1%	N/A - No ELV

EXECUTIVE SUMMARY

Analytical Methods

The following tables list the analytical methods employed together with the custody details. Unless otherwise stated the samples are archived at the analysis lab location.

SAMPLING METHODS WITH SUBSEQUENT ANALYSIS							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	Analysis Accreditation	Analysis Lab	Analysis Report number	Archive Period
Mercury	Inductively coupled Plasma - Mass Spectrometry	ASC/SOP/117	1252	MCERTS	SOCOTEC (Bretby)	ASC/55039	8 Weeks

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	Accreditation	Laboratory	Data Archive Location	Archive Period
Oxygen	Zirconia Cell	AE 102	1015	MCERTS	SOCOTEC - (Cirencester)	SOCOTEC - (Cirencester)	5 years
Moisture	Gravimetric	AE 105	1015	MCERTS	SOCOTEC - (Cirencester)	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	284	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	22.4	m/s	-	-	-
Highest Gas Velocity	24.6	m/s	-	-	-
Ratio of Gas Velocities	1.1	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	23.6	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	°	< 15°	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Circular	-
Depth	2.40	m
Width	-	m
Area	4.52	m^2
Port Depth	90	mm

SAMPLING LINES & POINTS		
	Isokinetic	**Non-Iso & Gases**
Sample port size	4 " BSP	2 " Port
Number of lines used	2	1
Number of points / line	4	1
Duct orientation	Vertical	Vertical
Filtration	Out Stack	Out Stack

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

M1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	Yes
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)	Yes
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	Yes

Sampling Platform Improvement Recommendations (if applicable)

The sampling location meets all the requirements as specified in EA Guidance Note M1.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

In this instance there were no deviations from the sampling and analytical methods employed.

APPENDICES

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APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	**Method** Standard Reference Method / Alternative Method	**SOCOTEC Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Number of Samples**
Moisture	SRM - BS EN 14790	AE 105	1015	MCERTS	1
Velocity	SRM - EN ISO 16911-1	AE 154	1015	MCERTS	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	P2947	Horiba PG-250 Analyser	P2659	Laboratory Balance	P3225
Box Thermocouples	P2947	FT-IR Gasmet	-	Tape Measure	P3136
Meter In Thermocouple	P2947	FT-IR Oven Box	-	Stopwatch	P1343
Meter Out Thermocouple	P2947	Bernath 3006 FID	-	Protractor	-
Control Box Timer	P2947	Signal 3030 FID	-	Barometer	P341
Oven Box	P1375	Servomex	-	Digital Micromanometer	P1940
Probe		JCT Heated Head Filter	-	Digital Temperature Meter	P2675
Probe Thermocouple	P2971	Thermo FID	-	Stack Thermocouple	P2322
Probe		Stackmaster	P9808	Mass Flow Controller	P2816
Probe Thermocouple		FTIR Heater Box for Heated Line	P2418	MFC Display module	-
S-Pitot	P1587	Anemometer	-	1m Heated Line (1)	-
L-Pitot		Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	P2769	Chiller	P3263	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	P1897	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	-	Site temperature Logger	P2215	10m Heated Line (2)	-
Small DGM	-			15m Heated Line (1)	-
Heater Controller	-			20m Heated Line (1)	P2546
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 GASES					
Gas (traceable to ISO 17025)	Cylinder I.D Number	Supplier	ppm	%	Analytical Tolerance +/- %
Oxygen	CG 58	BOC	-	9.9	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
Jose Navarro	MM 19 1542	MCERTS Level 2	Jul-24	Oct-25	Dec-25	Dec-25	Nov-25	Jul-24
Alistair Holmes	MM 13 1218	MCERTS Level 1	Mar-23	-	-	-	-	Mar-23

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1 — Mercury

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	kPa	102.00
Stack static pressure, P_{static}	Pa	100.00
$P_s = P_b + (P_{static})$	kPa	102.10
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 by Non Iso
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m	m^3	1.54
Gas meter correction factor, Y_d		1.12
Mean dry gas meter temperature, T_m	K	301.69
Mean pressure drop across orifice, DH	mmH_2O	60.06
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$	m^3	1.59
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.9414
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		8.43
% oxygen reference condition		6
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		0.84
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	1.33
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1818
	%	18.18
Moisture by FTIR	%	-

Molecular weight of dry gas, M_d		
CO_2	%	9.85
O_2	%	8.43
Total	%	18.28
N_2 (100 -Total)	%	81.72
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.91
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.75
Velocity of stack gas, V_s		
Velocity pressure coefficient, C_p		0.84
Mean of velocity heads, DP_{avg}	Pa	310.54
Mean stack gas temperature, T_s	K	393.00
Gas density (wet, ambient), p		
p=(Ms*Ps)/(8.314*Ts)	kg/m^3	0.867
Stack Velocity, Vs $V_s = Cp\sqrt{\frac{\Delta DPavg}{p}}$	m/s	22.48
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	4.52
$Q_a = (60)(A_s)(V_s)$	m^3/min	6103.0
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(Ts)}$	Dry	3495.1
$Q_{std02} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(Ts)}$	@O2ref	2929
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(Ts)}$	Wet	4272
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	6.4
Nozzle area, A_n	mm^2	32.3
Total sampling time, q	min	64.0
$\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	99.5
Acceptable isokinetic range 95% to 115%		Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 2 — Mercury

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	kPa	102.00
Stack static pressure, P_{static}	Pa	100.00
$P_s = P_b + (P_{static})$	kPa	102.10
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 by Non Iso
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m	m^3	1.51
Gas meter correction factor, Y_d		1.12
Mean dry gas meter temperature, T_m	K	301.75
Mean pressure drop across orifice, DH	mmH_2O	57.65
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$	m^3	1.56
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.9028
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		8.43
% oxygen reference condition		6
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		0.84
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	1.30
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1818
	%	18.18
Moisture by FTIR	%	-

Molecular weight of dry gas, M_d		
CO_2	%	9.85
O_2	%	8.43
Total	%	18.28
N_2 (100 -Total)	%	81.72
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.91
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.75
Velocity of stack gas, V_s		
Velocity pressure coefficient, C_p		0.84
Mean of velocity heads, DP_{avg}	Pa	299.51
Mean stack gas temperature, T_s	K	395.00
Gas density (wet, ambient), p		
p=(Ms*Ps)/(8.314*Ts)	kg/m^3	0.863
Stack Velocity, Vs $V_s = Cp\sqrt{\frac{\Delta DPavg}{p}}$	m/s	22.13
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	4.52
$Q_a = (60)(A_s)(V_s)$	m^3/min	6008.9
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(Ts)}$	Dry	3423.8
$Q_{std02} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(Ts)}$	@O2ref	2869
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(Ts)}$	Wet	4184
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	6.4
Nozzle area, A_n	mm^2	32.3
Total sampling time, q	min	64.0
$\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	99.6
Acceptable isokinetic range 95% to 115%		Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 3 — Mercury

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	kPa	102.00
Stack static pressure, P_{static}	Pa	100.00
$P_s = P_b + (P_{static})$	kPa	102.10
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 by Non Iso
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m	m^3	1.57
Gas meter correction factor, Y_d		1.12
Mean dry gas meter temperature, T_m	K	305.06
Mean pressure drop across orifice, DH	mmH_2O	60.39
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$	m^3	1.59
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.9448
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		8.43
% oxygen reference condition		6
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		0.84
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	1.33
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1818
	%	18.18
Moisture by FTIR	%	-

Molecular weight of dry gas, M_d		
CO_2	%	9.85
O_2	%	8.43
Total	%	18.28
N_2 (100 -Total)	%	81.72
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.91
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.75
Velocity of stack gas, V_s		
Velocity pressure coefficient, C_p		0.84
Mean of velocity heads, DP_{avg}	Pa	311.15
Mean stack gas temperature, T_s	K	396.00
Gas density $_{(wet, ambient)}$, p		
p=(Ms*Ps)/(8.314*Ts)	kg/m^3	0.860
Stack Velocity, Vs $V_s = Cp\sqrt{\frac{\Delta DPavg}{p}}$	m/s	22.59
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	4.52
$Q_a = (60)(A_s)(V_s)$	m^3/min	6132.3
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(Ts)}$	Dry	3485.3
$Q_{std02} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(Ts)}$	@O2ref	2921
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(Ts)}$	Wet	4259
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	6.4
Nozzle area, A_n	mm^2	32.3
Total sampling time, q	min	64.0
$\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	100.0
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	27.1	0.32	0.33	-381	0.54	Yes
Run 2	26.6	0.35	0.33	-381	0.53	Yes
Run 3	27.4	0.35	0.36	-381	0.55	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	99.5	Yes
Run 2	99.6	Yes
Run 3	100.0	Yes

Filtration / Temp	Filter Material	Filter Size mm	Maximum Filtration Temperature °C	Temperature during storage / transit <25°C
Run 1	Quartz Fibre	90	182	Yes
Run 2	Quartz Fibre	90	180	Yes
Run 3	Quartz Fibre	90	181	Yes

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

DAILY OXYGEN SUMMARY

Sampling Times	Concentration %	LOD %
08:40 - 15:00 25 August 2022	8.43	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 %
25 August 2022	08:35 - 08:45	25	0.00	10.02	0.03	0.01	10.00	-0.20

POST SAMPLING CALIBRATION DATA					
Date	Time of Analyser Checks	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
25 August 2022	15:05 - 15:15	0.01	10.02	-0.20	0.20

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Non Isokinetic							
Test Number	Sampling Time and Date	Start Weight kg	End Weight kg	Total gain kg	Concentration %	LOD %	Uncertainty %
Run 1	09:40 - 15:45 24th August 2022	3.0134	3.0587	0.0453	18.2	0.05	3.5

Moisture Quality Assurance							
Test Number	Sampling Duration mins	Total Volume Sampled l	Sampling Rate l/min	Start Leak Rate l/min	End Leak Rate l/min	Acceptable Leak Rate l/min	Leak Tests Acceptable?
Run 1	360	254	0.7	0.01	0.01	0.01	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	2.40	m
Stack Width, W	-	m
Stack Area, A	4.52	m^2
Average stack gas temperature	126	^oC
Stack static pressure	0.1	kPa
Barometric Pressure	101	kPa

Stack Gas Composition & Molecular Weights								
Component	Molar Mass M	Density kg/m^3 p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m^3 pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m^3 pi
CO_2	44	1.963059	9.850000	0.098500	0.193361	8.059615	0.080596	0.158215
O_2	32	1.427679	9.464655	0.094647	0.135125	7.744312	0.077443	0.110564
N_2	28	1.249219	80.685345	0.806853	1.007937	66.019577	0.660196	0.824729
H_2O	18	0.803070	-	-	-	18.176496	0.181765	0.145970

Where: p = M / 22.41 pi = r x p

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3364	kg/m^3
Wet Density (STP), P_{STW}	1.2395	kg/m^3
Dry Density (Actual), P_{Actual}	0.9133	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.847	kg/m^3

Where:

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

$P_{STW} = (P_{STD} + pi \text{ of } H_2O) / (1 + (pi \text{ of } H_2O / 0.8036))$

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

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	24 August 2022
Time of Survey	09:15
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	*DP* pt Pa (average of 3 readings)	*DP* pt mmH_2O (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
1	0.06	303.8	31.0	124	22.5	101.8	-	<15
2	0.20	323.4	33.0	124	23.2	105.0	-	<15
3	0.35	320.1	32.7	126	23.1	104.5	-	<15
4	0.54	343.0	35.0	126	23.9	108.1	-	<15
5	0.82	343.0	35.0	126	23.9	108.1	-	<15
6	1.58	343.0	35.0	126	23.9	108.1	-	<15
7	1.86	349.5	35.7	127	24.1	109.2	-	<15
8	2.05	352.8	36.0	126	24.2	109.7	-	<15
9	2.20	323.4	33.0	126	23.2	105.0	-	<15
10	2.34	300.5	30.7	126	22.4	101.2	-	<15
Mean	-	330.3	33.7	126	23.4	106.1	-	-

Sampling Line B

Traverse Point	Distance into duct (m)	*DP* pt Pa (average of 3 readings)	*DP* pt mmH_2O (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
1	0.06	316.9	32.3	123	23.0	103.9	-	<15
2	0.20	343.0	35.0	124	23.9	108.1	-	<15
3	0.35	339.7	34.7	126	23.8	107.6	-	<15
4	0.54	343.0	35.0	126	23.9	108.1	-	<15
5	0.82	349.5	35.7	126	24.1	109.2	-	<15
6	1.58	329.9	33.7	126	23.4	106.1	-	<15
7	1.86	349.5	35.7	127	24.1	109.2	-	<15
8	2.05	362.6	37.0	128	24.6	111.2	-	<15
9	2.20	320.1	32.7	126	23.1	104.5	-	<15
10	2.34	310.3	31.7	125	22.7	102.9	-	<15
Mean	-	336.5	34.3	126	23.7	107.1	-	-

PRELIMINARY STACK SURVEY QUALITY ASSURANCE CHECKLIST

PITOT LEAK CHECK

Run	Pre Traverse Leak Rate				Post Traverse Leak Rate			
	Start Value mmH2O	End Value mmH2O	Difference %	Outcome	Start Value mmH2O	End Value mmH2O	Difference %	Outcome
Run 1	112	114	-1.8	Pass	113	113	0.0	Pass

To complete a compliant pitot leak check a pressure of over 80 mmH_2O (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	100	100	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 Average Differential Pressure	301	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	22.4	m/s	-	-
Highest Gas Velocity	24.6	m/s	-	-
Ratio of Gas Velocities	1.1	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	°	< 15°	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, V = K_{pt} x (1-e) * Ö(2 * DP_{pt} / $P_{ActualW}$)		
Where: K_{pt} = Pitot tube calibration coefficient (1-e) = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, Va	**23.6**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	126	0	°C
Total Pressure	101.1	101.3	kPa
Oxygen	6.0	6	%
Moisture	18.18	0.00	%
Pitot tube calibration coefficient, K_{pt}	0.84		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	23.55	m/s
Stack Area (A)	4.52	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	383666.4	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	262187.4	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	214530.9	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	214530.9	m^3/hr

Where:
Q_{Actual} = Va x A x 3600
Q_{STP} = Q (Actual) x (Ts / Ta) x (Pa / Ps) x 3600
$Q_{STP,Dry}$ = Q (STP) / (100 - (100 / Ma)) x 3600
Q_{Ref} = Q (STP) x ((100 - Ma) / (100 - Ms)) x ((21 - O_2a) / (21 - O_2s))

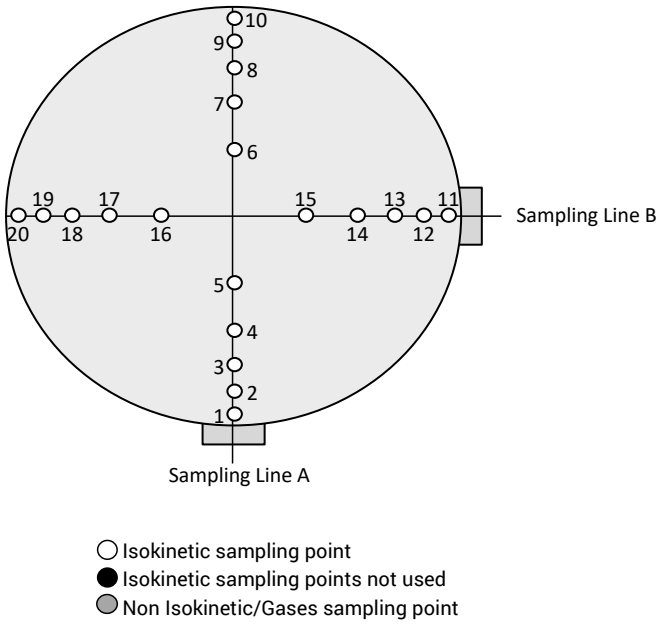
Nomenclature:
Ts = Absolute Temperature, Standard Conditions, 273 K
Ps = Absolute Pressure, Standard Conditions, 101.3 kPa
Ta = Absolute Temperature, Actual Conditions, K
Pa = Absolute Pressure, Actual Conditions, kPa
Ma = Water vapour, Actual Conditions, % Vol
Ms = Water vapour, Reference Conditions, % Vol
O_2a = Oxygen, Actual Conditions, % Vol
O_2s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK DIAGRAM

	Value	Units
Stack Depth	2.40	m
Stack Width	-	m
Area	4.52	m^2

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	50	1.20	m



Isokinetic Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	2.6	0.06	< 15
2	8.2	0.20	< 15
3	14.6	0.35	< 15
4	22.6	0.54	< 15
5	34.2	0.82	< 15
6	65.8	1.58	< 15
7	77.4	1.86	< 15
8	85.4	2.05	< 15
9	91.8	2.20	< 15
10	97.4	2.34	< 15
11	2.6	0.06	< 15
12	8.2	0.20	< 15
13	14.6	0.35	< 15
14	22.6	0.54	< 15
15	34.2	0.82	< 15
16	65.8	1.58	< 15
17	77.4	1.86	< 15
18	85.4	2.05	< 15
19	91.8	2.20	< 15
20	97.4	2.34	< 15

SAMPLING LOCATION

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

Day 1 - 25 August 2022

Reference	6	%vol
Measured concentration	8.43	%vol
Calibration gas	9.9	%vol
Analyser Full Scale	25	%vol

	Value	Units	specification	MU Met?
Response time	34	seconds	180	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	380	minutes	-	-
Number of readings in measurement	380	-	-	-
Repeatability at zero	0.25	% full scale	<1 % range	Yes
Repeatability at span level	0.15	% full scale	<2 % range	Yes
Deviation from linearity	0.1	% of value	<2 % range	Yes
Zero drift	-0.20	% full scale	<2% range / 24hr	Yes
Span drift	0.20	% 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	0.01	% full scale/10V	< 0.1%vol /10 volt	Yes
losses in the line (leak)	-0.20	% 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	$U_{d,z}$	-0.1157
short term span drift	$U_{d,s}$	0.1166
influence of Ambient Temp at Zero	$U_{t,z}$	0.0000
influence of Ambient Temp at Span	$U_{t,s}$	0.0001
influence of sample gas pressure	U_p	0.0000
influence of sample gas flow	U_{fit}	-0.0294
influence of supply voltage	U_v	0.0003
Combined Interfence	U_i	0.0000
Uncertainty of Cal gas	U_{adj}	0.0495

Measurement uncertainty (Concentration Measured)	8.43	%
Combined Interfence	0.18	%
Uncertainty of Cal gas	0.36	%

Expanded uncertainty expressed with a level of confidence of 95%	**0.36**	**%**

Expanded uncertainty as percentage of the result	**4.27**	**% vol**

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	23.6	m/s
Measured Volumetric Flow rate at Actual Conditions	383666	m³/hr

Performance Characteristics & Source of Value	Units	Values	Requirement	Compliant
Uncertainty of Local Gas Velocity Determination				
Uncertainty of pitot tube coefficient	-	0.010		
Uncertainty of mean local dynamic pressures	-	2.57		
Factor loading, function of the number of measurements.	3 readings	0.591	minimum 3	Yes
Range of measurment device	pa	1000		
Resolution	pa	1.00		
Calibration uncertainty	pa	49.98	<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	0.00002		
Uncertainty of temperature measurement	K	2.03	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	516		
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	0.29
Expanded uncertainty at a 95% Confidence Interval	0.57

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	m³/hr
Combined uncertainty	10064
Expanded uncertainty at a 95% Confidence Interval	19726

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 Technical Procedure AE150 Estimation of Uncertainty of Measurement

END OF REPORT

Thank you for choosing SOCOTEC 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