STACK EMISSIONS MONITORING REPORT

Unit 5 Crown Industrial Estate
Kenwood Road
Stockport
SK5 6PH
Tel: 0161 443 0980
Fax: 0161 443 0989

Your contact at SOCOTEC LTD
Mark Woodruff Business Manager - North Tel: 0161 443 0982 Fax: 0161 443 0989 Email: mark.woodruff@socotec.com

Operator & Address:
Less Common Metals Ltd Unit 2 Vauxhall Supply Park North Road Ellesmere Port Cheshire CH65 1BL

Permit Reference:
EPR Permit: EPR/RP3233CZ/V002

Release Point:
Electrolysis

Sampling Date(s):
27th November 2020

SOCOTEC Job Number:	LNO 16148
Report Date:	14th January 2021
Version:	1
Report By: MCERTS Number: MCERTS Level: Technical Endorsements:	Mark Derbyshire MM 02 022 MCERTS Level 2 - Team Leader 1, 2, 3 & 4
Report Approved By: MCERTS Number: Business Title: Technical Endorsements: Signature:	Jonathon Orley MM 08 983 MCERTS Level 2 - Team Leader 1, 2, 3 & 4 

UKAS TESTING 1015

mCERTS THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

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EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Less Common Metals Ltd operates a vacuum furnaces process at Ellesmere Port which is subject to EPR Permit EPR/RP3233CZ/V002, under the Environmental Permitting Regulations 2010.

SOCOTEC LTD were commissioned by Less Common Metals 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, EPR/RP3233CZ/V002.

Plant

Electrolysis

Operator

Less Common Metals Ltd
Unit 2 Vauxhall Supply Park
North Road
Ellesmere Port
Cheshire
CH65 1BL

Stack Emissions Monitoring Test House

SOCOTEC - Stockport Laboratory
Unit 5 Crown Industrial Estate
Kenwood Road
Stockport
SK5 6PH
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.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Emission Limit Value (ELV)**	**Accrediation**
Total Particulate Matter	mg/m³	0.80	0.16	5	MCERTS
Particulate Emission Rate	g/hr	4.8	1.0	-	
Hydrogen Fluoride	mg/m³	0.11	0.01	0.5	MCERTS
Hydrogen Fluoride Emission Rate	g/hr	0.64	0.08	-	
Moisture	%	0.55	0.02	-	MCERTS
Stack Gas Temperature	°C	15	-	-	MCERTS
Stack Gas Velocity	m/s	10	0.24	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	6532	336	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	6033	310	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	5999	308	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	6033	310	-	

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 without correction for water vapour

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
Total Particulate Matter Run 1	27 November 2020	10:35 - 14:35	240 minutes
Hydrogen Fluoride Run 1	27 November 2020	10:35 - 14:35	240 minutes
Preliminary Stack Traverse	27 November 2020	10:10	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Vacuum Furnaces
Continuous or batch	Continuous
Product Details	Non ferrous metals
Part of batch to be monitored (if applicable)	N/A
Normal load, throughput or continuous rating	Normal Load
Fuel used during monitoring	N/A
Abatement	Wet Scrubber
Plume Appearance	None 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**	**MCERTS Accredited Method**	**Limit of Detection (LOD)**	**Calculated MU +/- % Result**	**Calculated MU +/- % ELV**
Total Particulate Matter	SRM - BS EN 13284-1	AE 104	1015	MCERTS	0.08 mg/m³	20%	3.2%
Hydrogen Fluoride	SRM - ISO 15713	AE 113	1015	MCERTS	0.001 mg/m³	13%	2.7%
Moisture	SRM - BS EN 14790	AE 105	1015	MCERTS	0.003%	3.4%	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

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

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	UKAS Accredited Lab Analysis	Analysis Lab	Analysis Report number	Archive Period
Total Particulate Matter	Gravimetric	AE 106	1015	MCERTS	SOCOTEC (Stockport)	N/A	8 Weeks
Hydrogen Fluoride	Ion Chromatography	ASC/SOP/110	1252	MCERTS	SOCOTEC (Bretby)	ASC 47913	8 Weeks

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	MCERTS Accredited Analysis	Laboratory	Data Archive Location	Archive Period
Moisture	Gravimetric	AE 105	1015	MCERTS	SOCOTEC (Stockport)	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	82	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	9.9	m/s	-	-	-
Highest Gas Velocity	10.2	m/s	-	-	-
Ratio of Gas Velocities	1.0	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	10.0	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	0.48	m
Width	-	m
Area	0.18	m^2
Port Depth	40	mm

SAMPLING LINES & POINTS		
	Isokinetic	**Non-Iso & Gases**
Sample port size	4 inch BSP	-
Number of lines used	1	-
Number of points / line	4	-
Duct orientation	Horizontal	-
Filtration	Out Stack	-
Filtration for TPM	Out Stack	-

SAMPLING PLATFORM	
General Platform Information	
Permanent / Temporary Platform / Ground level / Floor Level / Roof	Ground Level
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)	N/A
Platform has vertical base boards (approximately 0.25 m high)	N/A
Platform has removable chains / self closing gates at the top of ladders	N/A
Handrail / obstructions do not hamper insertion of sampling equipment	N/A
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

Nozzle Size

To maintain an isokinetic ratio a nozzle smaller than the recommended 6mm was used.

Sample Lines

Only one sample line available. The number of points were doubled along the remaining line as recommended by EA MID 13284.

APPENDICES

CONTENTS

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**
Total Particulate Matter	SRM - BS EN 13284-1	AE 104	1015	MCERTS	1
Hydrogen Fluoride	SRM - ISO 15713	AE 113	1015	MCERTS	1
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	LNO 13 - 23	Horiba PG-250 Analyser	-	Laboratory Balance	LNO 00-12/00-13
Box Thermocouples	LNO 03 - 23	FT-IR Gasmet	-	Tape Measure	LNO 24 - MD
Meter In Thermocouple	LNO 03 - 23	FT-IR Oven Box	-	Stopwatch	LNO 17 - MD
Meter Out Thermocouple	LNO 03 - 23	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17 - 23	Signal 3030 FID	-	Barometer	LNO 08 - MD
Oven Box	LNO 09 - 11	Servomex	-	Digital Micromanometer	LNO 01 - MD
Probe	LNO 11 - 03	JCT Heated Head Filter	-	Digital Temperature Meter	LNO 03 - MD
Probe Thermocouple	LNO 10 - 03	Thermo FID	-	Stack Thermocouple	LNO 01 - MD
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LNO 06 - MD	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LNO 14 - MD	Chiller (JCT/MAK 10)	-	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	-	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	-	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-			15m Heated Line (1)	-
Heater Controller	-			20m Heated Line (1)	-
Inclinometer (Swirl Device)	LNO 23-MD			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 +/- %
-	-	-	-	-	-

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
Mark Derbyshire	MM 02 022	MCERTS Level 2	Nov-22	Nov-22	Dec-22	Nov-23	Dec-22	Apr-24
Joe Saxton	MM 18 1501	MCERTS Level 1	Apr-24	-	-	-	-	Apr-24

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY					
Parameter	**Sampling Times**	**Concentration mg/m³**	**Uncertainty mg/m³**	**ELV mg/m³**	**Emission Rate g/hr**
Run 1	10:35 - 14:35 27 November 2020	0.80	0.16	5	4.8
Blank	-	0.35	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour

Acetone Blank Value mg/l	Acceptable Value mg/l
0.3	10

FILTER INFORMATION

SAMPLES								
Test	Filter & Probe Rinse Number	Filter Start Weight g	Filter End Weight g	Mass Gained on Filter g	Probe Rinse Start Weight g	Probe Rinse End Weight g	Mass Gained on Probe g	Combined Total Mass Gained g
Run 1	Q1866	0.14072	0.14278	0.00206	61.16080	61.16160	0.00080	0.00286

If total mass gained is less than the LOD then the LOD is reported

BLANKS								
Test	Filter & Probe Number	Filter Start Weight g	Filter End Weight g	Mass Gained Filter g	Probe Start Weight g	Probe End Weight g	Mass Gained Probe g	Combined Total Mass Gained g
Run 1	Q1865	0.14456	0.14513	0.00057	71.58440	71.58510	0.00070	0.00127

If total mass gained is less than the LOD then the LOD is reported

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 1 — TPM

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	Kpa	99.5	CO_2	%	0.03
Stack static pressure, P_{static}	pa	-150.0	O_2	%	21.00
$P_s = P_b + P_{static}$	Kpa	99.4	Total	%	21.03
			N_2 (100 -Total)	%	78.97
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.84
Moisture trap weight increase,Vlc	g	16.0	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.019936	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.78
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		3.765	Area of stack, A_s	m^2	0.18
Gas meter correction factor, Y_d		1.024	$Q_a = (60)(A_s)(V_s)$	m³/min	108.7
Mean dry gas meter temperature, T_m		290	**Total flow of stack gas, Q**		
Mean pressure drop across orifice, DH	mmH_2O	30.199	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$	m^3	3.573	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$	Dry	100.0
Volume of gas metered wet, V_{mstw}			$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$	@O_2ref	No O2 Ref
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	3.5934	$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$	Wet	100.59
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	**Percent isokinetic, %I**		
			Nozzle diameter, D_n	mm	5.97
% oxygen measured in gas stream, act%O_2		21.0	Nozzle area, A_n	mm^2	28.03
% oxygen reference condition		21	Total sampling time, q	min	240
O_2 Reference Factor O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		No O2 Ref	$\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	96.1
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$	m^3	No O2 Ref	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			**Particulate Concentration, C**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0055	Mass collected on filter, M_f	g	0.00206
	%	0.55	Mass collected in probe, M_p	g	0.00080
Moisture by FTIR	%	-	Total mass collected, M_n	g	0.00286
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.796
Velocity pressure coefficient, C_p		0.84	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.800
Mean of velocity heads, DP_{avg}	Pa	84.04	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	No O2 Ref
Mean stack gas temperature, T_s	K	289			
Gas density (wet, ambient), ρ			**Particulate Emission Rates, E**		
ρ=(Ms*Ps)/(8.314*Ts)	kg/m^3	1.190			
Stack Velocity, Vs $V_s = Cp\sqrt{\frac{\Delta DPavg}{p}}$	m/s	10.01	E = [(C_{wet})(Q_{stw})(60)] / 1000		4.80

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER QUALITY ASSURANCE CHECKLIST

LEAK RATE						
Run	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?
Run 1	16.06	0.23	-	-457.2	0.32	Yes

In BS EN 13284-1:2017 a post sampling leak check is not required.

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	96.11	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m³	5% ELV mg/m³	LOD < 5% ELV
Run 1	0.08	0.25	N/A - ELV <5 mg/m³

The above is based on both the Filter and rinse uncertainty
Where installations have ELVs of 5 mg/m³ or less, it may not be practical to meet the 5% of ELV requirement. Under these circumstances, a minimum one hour sample time shall used.

BLANK VALUE				
Run	Overall Blank Value mg/m^3	Daily Emission Limit Value mg/m^3	Acceptable Blank Value mg/m^3	Overall Blank Acceptable mg/m^3
Blank 1	0.35	5	1.0	Yes

*For ELVs of 5 mg/m3 and lower a blank value must be <20% of the ELV

FILTERS					
Run	Filter Material	Filter Size mm	Max Filtration Temperature °C	Pre-use Filter Conditioning Temperature °C	Post-use Filter Conditioning Temperature °C
Run 1	Quartz Fibre	47	150	180	160

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HYDROGEN FLUORIDE SUMMARY					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**ELV mg/m³**	**Emission Rate g/hr**
Run 1	10:35 - 14:35 27 November 2020	0.11	0.001	0.5	0.64
Field Blank	-	0.005	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour

HYDROGEN FLUORIDE QUALITY ASSURANCE CHECKLIST

Leak Test Results	Total Sample Volume @ ref Conditions m³	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	3.6	16.1	0.23	0.23	0.32	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Temperature during storage / transit <25°C	Type of Absorbers	Absorption Solutions
Run 1	Quartz Fibre	47	150	N/A	PTFE	0.1N Sodium Hydroxide

HYDROGEN FLUORIDE ABSORPTION EFFICIENCY

Parameter	**Total ug**	**IMP C ug**	**Absorption Efficiency %**	**Acceptable Absorption Efficiency %**	**Absorption Efficiency Acceptable ?**
Run 1	383.3	14.3	96	95	Yes

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS 1 — Hydrogen Fluoride

Absolute pressure of stack gas, P_s			**Velocity of stack gas, V_s**		
Barometric pressure, P_b	kPa	100	Velocity pressure coefficient, C_p		0.842
Stack static pressure, P_{static}	Pa	-150	Mean of velocity heads, DP_{avg}	Pa	84.04
$P_s = P_b + (P_{static})$	kPa	99.35	Mean stack gas temperature, T_s	K	289.17
			Gas density $_{(wet, ambient)}$, p		
Vol. of water vapour collected, V_{wstd}			p=(Ms*Ps)/(8.314*Ts)	kg/m^3	1.190
Moisture trap weight increase,Vlc	g	-	Stack Velocity, Vs $V_s = Cp\sqrt{\frac{\Delta DPavg}{p}}$	m/s	10.01
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-			
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m	m^3	3.7650	Area of stack, A_s	m^2	0.18
Gas meter correction factor, Y_d		1.0237	$Q_a = (60)(A_s)(V_s)$	m^3/min	109
Mean dry gas meter temperature, T_m	K	289.98	**Dry total flow of stack gas, Q_{std}**		
Mean pressure drop across orifice, DH	mmH_2O	30.20	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$	m^3	3.57	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$	m^3/min	100
Volume of gas metered wet, V_{mstw}			**Wet total flow of stack gas, Q_{stw}**		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	3.5934	$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$	m^3/min	101
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Dry total flow of stack gas at X% O_2, Q_{stdO2}**		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$	m^3/min	No O2 Ref
% oxygen measured in gas stream, act%O_2		21.00	**Percent isokinetic, %I**		
% oxygen reference condition		21	Nozzle diameter, D_n	mm	5.97
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		No O2 Ref	Nozzle area, A_n	mm^2	28.03
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	No O2 Ref	Total sampling time, q	min	240
Moisture content, B_{wo}			$\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	96
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0055 0.55	Acceptable isokinetic range 95% to 115%		Yes
Moisture by FTIR	%	-	**Hydrogen Fluoride Concentration, C**		
Molecular weight of dry gas, M_d			Mass collected , M	ug	383
CO_2		0.03	$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m^3	0.107
O_2		21.00			
Total		21.03	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m^3	0.107
N_2 (100 -Total)		78.97	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m^3	No O2 Ref
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.84			
Molecular weight of wet gas, M_s			**Hydrogen Fluoride Emission Rates, E**		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.8	$E = [(C_{wet})(Q_{stw})(60)] / 1000$	g/hr	0.64

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Isokinetic							
Test Number	Sampling Time and Date	Start Weight kg	End Weight kg	Total gain kg	Concentration %	LOD %	Uncertainty %
Run 1	10:35 - 14:35 27 November 2020	3.3495	3.3655	0.0160	0.55	0.003	3.4

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	240	3593	16.1	0.23	-	0.32	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.48	m
Stack Width, W	-	m
Stack Area, A	0.18	m^2
Average stack gas temperature	15	^oC
Stack static pressure	-1	kPa
Barometric Pressure	99.7	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	0.028571	0.000286	0.000561	0.028413	0.000284	0.000558
O_2	32	1.427679	21.000000	0.210000	0.299813	20.883492	0.208835	0.298149
N_2	28	1.249219	78.971429	0.789714	0.986526	78.533296	0.785333	0.981053
H_2O	18	0.803070	-	-	-	0.554799	0.005548	0.004455

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2869	kg/m^3
Wet Density (STP), P_{STW}	1.2842	kg/m^3
Dry Density (Actual), P_{Actual}	1.1886	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	1.186	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	27 November 2020
Time of Survey	10:10
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	0.05	83.0	8.5	15	10.0	1.8	-	<15
2	0.12	84.3	8.6	15	10.0	1.8	-	<15
3	0.36	86.9	8.9	15	10.2	1.8	-	<15
4	0.43	82.3	8.4	15	9.9	1.8	-	<15
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	84.1	8.6	15	10.0	1.8	-	-

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 °
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	-	-

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	145	143	1.4	Pass	150	149	0.7	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	-1000	-1000	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	82	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	9.9	m/s	-	-
Highest Gas Velocity	10.2	m/s	-	-
Ratio of Gas Velocities	1.0	-	< 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	**10.0**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	15	0	°C
Total Pressure	98.7	101.3	kPa
Oxygen	21.0	21	%
Moisture	0.55	0.55	%
Pitot tube calibration coefficient, K_{pt}	0.84		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	10.03	m/s
Stack Area (A)	0.18	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	6532	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	6033	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	5999	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	6033	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))

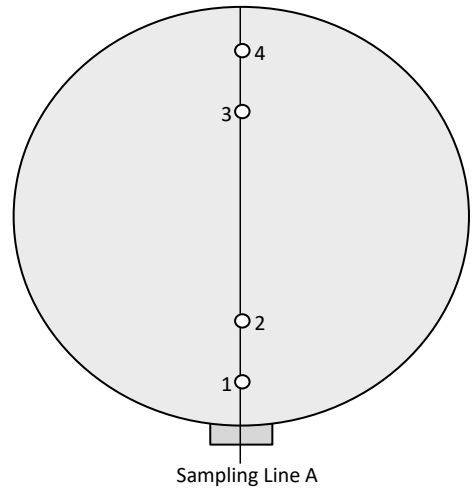
Nomenclature:
Ts = Absolute Temperature, Standard Conditions, 273 K
Ps = Absolute Pressure, Standard Conditions, 101.3 kPa
Ta = Absolute Temperature, Actual Conditions, K
Pa = Absolute Pressure, Actual Conditions, kPa
Ma = Water vapour, Actual Conditions, % Vol
Ms = Water vapour, Reference Conditions, % 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	0.48	m
Stack Width	-	m
Area	0.18	m^2

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



○ Isokinetic sampling point
● Isokinetic sampling points not used
◍ Non Isokinetic/Gases sampling point

Isokinetic Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	10.4	0.05	< 15
2	25.0	0.12	< 15
3	75.0	0.36	< 15
4	89.6	0.43	< 15
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

SAMPLING LOCATION

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - TOTAL PARTICULATE MATTER

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Limit of Detection	Leak	Uncollected Mass
	m^3	K	kPa	% by volume	% by volume	% by mass	%	mg
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**	**≤ 10% of ELV**
Run 1	0.001	2.0	0.50	1.0	N/A	0.28	-	-
as a %	0.03	0.69	0.50	1.0	N/A	1.56	1.43	0.025
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**

*Where installations have ELVs of 5 mg/m³ or less, it may not be practical to meet the 5% of ELV requirement. Under these circumstances, a minimum one hour sample time shall used.

Run	Volume (STP)	Mass of particulate	O_2 Correction	Leak	Uncollected Mass	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	3.31	2.8600	1.0	0.0066	0.0007	-
MU as mg/m^3	0.01	0.0779	-	0.0066	0.0002	**0.08**
MU as %	1.32	9.7902	-	0.827	0.0256	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.16**	**mg/m^3**	**20**	**% Result**	**3.2**	**% ELV**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - ISOKINETIC HYDROGEN FLUORIDE

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Limit of Detection	Leak
	m^3	K	kPa	% by volume	% by volume	% by mass	%
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**≤ 5% of ELV**	**<=2%**
Run 1	3.593	290	98	1.0	-	0.66	-
as a %	0.03	0.69	0.51	1.0	-	0.23	1.43
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**

Run	Volume (STP)	Mass of Hydrogen Fluoride	O2 Correction	Leak	Lab Uncertainty	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	3.2728	0.6612	-	0.0009	-	-
MU as mg/m^3	0.0014	0.0012	-	0.0009	0.0065	**0.0068**
MU as %	1.3179	1.0911	-	0.8269	6.1	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.01**	**mg/m^3**	**13**	**% Result**	**2.7**	**% ELV**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	10.0	m/s
Measured Volumetric Flow rate at Actual Conditions	6532	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	-	0.78		
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	14.08	<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	0.00003		
Uncertainty of temperature measurement	K	1.47	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	504		
Uncertainty associated with the estimate of density	-	0.007		
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	0.12
Expanded uncertainty at a 95% Confidence Interval	0.24

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	171
Expanded uncertainty at a 95% Confidence Interval	336

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