STACK EMISSIONS MONITORING REPORT

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Operator & Address:
Energy Pyrolysis West Factory Bale Store Great Coates Industrial Estate Moody Lane Grimsby DN31 2SS

Permit:
EPR Permit: EP20140001

Release Point:
Main Process Exhaust

Sampling Date(s):
5th - 7th December 2017

ESG Job Number: Report Date: Version:	LNO 13348 / Q4 16th January 2018 1
Report By: MCERTS Number: MCERTS Level: Technical Endorsements:	Dominic Houghton MM 04 529 MCERTS Level 2 - Team Leader 1, 2, 3 & 4
Report Approved By: MCERTS Number: Business Title: Technical Endorsements: Signature:	Keith Bird MM 07 825 MCERTS Level 2 - Team Leader 1, 2, 3 & 4 

UKAS TESTING
1015

mCERTS
THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

CONTENTS

EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Energy Pyrolysis operates a rubber recycling process at Grimsby which is subject to EPR Permit EP20140001, under the Environmental Permitting Regulations 2010.

ESG were commissioned by Mabbett & Associates 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, EP20140001.

Plant

Main Process Exhaust

Operator

Energy Pyrolysis
West Factory Bale Store
Great Coates Industrial Estate
Moody Lane
Grimsby
DN31 2SS

EPR Permit: EP20140001

Stack Emissions Monitoring Test House

ESG - Stockport Laboratory
Unit 5 Crown Industrial Estate
Kenwood Road
Stockport
SK5 6PH
UKAS and MCERTS Accreditation Number: 1015

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Limit**	**MCERTS accredited result**
Dioxins & Furans - UPPER Limits					
Dioxins & Furans (NATO I-TEQ)	ng/m³	0.0014	0.0019	0.1	✓
Dioxins & Furans (NATO I-TEQ) Emission Rate	µg/hr	0.0014	0.0019	-	
Dioxins & Furans (WHO TEQ Humans / Mammals)	ng/m³	0.0014	0.0020	-	✓
Dioxins & Furans (WHO TEQ H / M) Emission Rate	µg/hr	0.0014	0.0020	-	
Dioxins & Furans (WHO TEQ Fish)	ng/m³	0.0015	0.0022	-	✓
Dioxins & Furans (WHO TEQ Fish) Emission Rate	µg/hr	0.0015	0.0022	-	
Dioxins & Furans (WHO TEQ Birds)	ng/m³	0.0022	0.0031	-	✓
Dioxins & Furans (WHO TEQ Birds) Emission Rate	µg/hr	0.0022	0.0031	-	
Dioxins & Furans - LOWER Limits					
Dioxins & Furans (NATO I-TEQ)	ng/m³	0.0008	0.0012	-	✓
Dioxins & Furans (NATO I-TEQ) Emission Rate	µg/hr	0.0008	0.0012	-	
Dioxins & Furans (WHO TEQ Humans / Mammals)	ng/m³	0.0007	0.0010	-	✓
Dioxins & Furans (WHO TEQ H / M) Emission Rate	µg/hr	0.0007	0.0010	-	
Dioxins & Furans (WHO TEQ Fish)	ng/m³	0.0007	0.0010	-	✓
Dioxins & Furans (WHO TEQ Fish) Emission Rate	µg/hr	0.0007	0.0010	-	
Dioxins & Furans (WHO TEQ Birds)	ng/m³	0.0016	0.0022	-	✓
Dioxins & Furans (WHO TEQ Birds) Emission Rate	µg/hr	0.0016	0.0022	-	
Cadmium & Thallium	mg/m³	0.00065	0.00096	0.05	✓
Cadmium & Thallium Emission Rate	g/hr	0.00068	0.00100	-	
Heavy Metals	mg/m³	0.093	0.0102	0.5	✓
Heavy Metals Emission Rate	g/hr	0.097	0.0107	-	
Mercury	mg/m³	0.00027	0.00046	0.05	✓
Mercury Emission Rate	g/hr	0.00028	0.00048	-	
Hydrogen Chloride	mg/m³	0.30	0.035	20	✓
Hydrogen Chloride Emission Rate	g/hr	0.29	0.034	-	
Hydrogen Fluoride	mg/m³	***0.03***	0.004	2	✓
Hydrogen Fluoride Emission Rate	g/hr	***0.03***	0.004	-	
Oxides of Nitrogen (as NO_2)	mg/m³	5.7	12	400	✓
Oxides of Nitrogen (as NO_2) Emission Rate	g/hr	5.6	12	-	
Sulphur Dioxide	mg/m³	5.7	14	100	✓
Sulphur Dioxide Emission Rate	g/hr	5.6	14	-	
Carbon Monoxide	mg/m³	3.5	3.4	150	✓
Carbon Monoxide Emission Rate	g/hr	3.4	3.3	-	
Nitrous Oxide	mg/m³	0.35	1.3	-	✓
Nitrous Oxide Emission Rate	g/hr	0.34	1.3	-	
Moisture	%	2.5	1.33	-	✓
Stack Gas Temperature	°C	50	-	-	✓
Stack Gas Velocity	m/s	6.5	0.17	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	1150	60	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	979	51	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	955	50	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	979	51	-	

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 without correction for water vapour

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
Dioxins & Furans Run 1	07 December	09:25 - 15:25	360 minutes
Cadmium & Thallium Run 1	05 December	12:40 - 14:40	120 minutes
Heavy Metals Run 1	05 December	12:40 - 14:40	120 minutes
Mercury Run 1	05 December	12:40 - 14:40	120 minutes
Hydrogen Chloride Run 1	05 December	11:05 - 12:05	60 minutes
Hydrogen Fluoride Run 1	05 December	15:15 - 16:15	60 minutes
Combustion Gases	06 December	11:30 - 15:30	240 minutes
Preliminary Stack Traverse	05 December	10:40	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Rubber recycling
Continuous or batch	Batch
Product Details	Diesel and Carbon
Part of batch to be monitored (if applicable)	When operating at temperature
Normal load, throughput or continuous rating	Normal Load
Fuel used during monitoring	LPG and recycled process gas
Abatement	None
Plume Appearance	Plume Visible

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by ESG is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency Technical Guidance Note (Monitoring) M2. i.e. CEN, ISO, BS, US EPA etc.

MONITORING METHODS						
Species	**Method** Standard Reference Method / Alternative Method	**ESG Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Limit of Detection (LOD)**	**Calculated MU +/- %**
PCDD/PCDF	SRM - BS EN 1948-1	AE 109	1015	Yes	0.001 ng/m³	141%
Cd & Tl	SRM - BS EN 14385	AE 108	1015	Yes	0.00047 mg/m³	147%
Heavy Metals	SRM - BS EN 14385	AE 108	1015	Yes	0.002 mg/m³	11%
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	Yes	0.0002 mg/m³	173%
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	0.0007 mg/m³	11.7%
Hydrogen Fluoride	SRM - BS ISO 15713	AE 113	1015	Yes	0.01 mg/m³	14%
NO_X	AM - M22/FTIR	AE 063	1015	Yes	3.5 mg/m³	210.4%
SO_2	AM - M22/FTIR	AE 063	1015	Yes	0.4 mg/m³	245.1%
CO	AM - M22/FTIR	AE 063	1015	Yes	0.1 mg/m³	96.2%
N_2O	AM - M22/FTIR	AE 063	1015	Yes	0.3 mg/m³	372.9%
H_2O	AM - M22/FTIR	AE 063	1015	Yes	0.1 %	53.93%
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	5 Pa	2.6%
Volumetric Flow Rate	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	-	5.2%

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**
PCDD/PCDF	Gas Chromatography - High Resolution Mass Spectometry	MSOP1	1549	Yes	SAL	SAL	8 Weeks
Cd & Tl	Inductively coupled Plasma - Mass Spectrometry	ASC/SOP/117	ESG - Bretby	Yes	ESG - Bretby	ESG - Bretby	8 Weeks
Heavy Metals	Inductively coupled Plasma - Mass Spectrometry	ASC/SOP/117	ESG - Bretby	Yes	ESG - Bretby	ESG - Bretby	8 Weeks
Mercury	Inductively coupled Plasma - Mass Spectrometry	ASC/SOP/117	ESG - Bretby	Yes	ESG - Bretby	ESG - Bretby	8 Weeks
Hydrogen Chloride	Ion Chromatography	ASC/SOP/110	1015	Yes	ESG Bretby	ESG Bretby	8 Weeks
Hydrogen Fluoride	Ion Chromatography	ASC/SOP/110	1015	Yes	ESG Bretby	ESG Bretby	8 Weeks

ON-SITE TESTING							
Species	**Analytical Technique**	**Analytical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Analysis**	**Laboratory**	**Data Archive Location**	**Archive Period**
NO_X	Fourier Transform - Infra Red	AE 102	1015	Yes	ESG Stockport	ESG Stockport	5 years
SO_2	Fourier Transform - Infra Red	AE 063	1015	Yes	ESG Stockport	ESG Stockport	5 years
CO	Fourier Transform - Infra Red	AE 063	1015	Yes	ESG Stockport	ESG Stockport	5 years
N_2O	Fourier Transform - Infra Red	AE 063	1015	Yes	ESG Stockport	ESG Stockport	5 years
H_2O	Fourier Transform - Infra Red	AE 063	1015	Yes	ESG Stockport	ESG Stockport	5 years

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	31	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	6.5	m/s	-	-	-
Highest Gas Velocity	6.5	m/s	-	-	-
Ratio of Gas Velocities	1.0	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	6.5	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	0.25	m
Width	-	m
Area	0.05	m^2
Port Depth	60	mm

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

SAMPLING PLATFORM	
General Platform Information	
Permanent / Temporary Platform / Ground level / Floor Level / Roof	Floor 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)	No
Platform has vertical base boards (approximately 0.25 m high)	No
Platform has removable chains / self closing gates at the top of ladders	No
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)

A sampling platform with sufficient depth should be constructed to meet the requirements of 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

CONTENTS

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	**Method** Standard Reference Method / Alternative Method	**ESG Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Number of Samples**
PCDD/PCDF	SRM - BS EN 1948-1	AE 109	1015	Yes	1
Cd & Tl	SRM - BS EN 14385	AE 108	1015	Yes	1
Heavy Metals	SRM - BS EN 14385	AE 108	1015	Yes	1
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	Yes	1
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	1
Hydrogen Fluoride	SRM - BS ISO 15713	AE 113	1015	Yes	1
NOx	AM - M22/FTIR	AE 063	1015	Yes	1
SO_2	AM - M22/FTIR	AE 063	1015	Yes	1
CO	AM - M22/FTIR	AE 063	1015	Yes	1
Nitrous Oxide	AM - M22/FTIR	AE 063	1015	Yes	1
H_2O	AM - M22/FTIR	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	LNO 13-08	Horiba PG-250 Analyser	-	Laboratory Balance	LNO 00-12/00-13
Box Thermocouples	LNO 03-08	FT-IR Protea	LNO Protea	Tape Measure	LNO 24-DJH
Meter In Thermocouple	LNO 03-08	FT-IR Oven Box	-	Stopwatch	LNO 17-DJH
Meter Out Thermocouple	LNO 03-08	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17-01	Signal 3030 FID	-	Barometer	LNO 08-DJH
Oven Box	LNO 13-12	Servomex	-	Digital Micromanometer	LNO 01-DJH
Probe	LNO 11-25	JCT Heated Head Filter	-	Digital Temperature Meter	LNO 03-DJH
Probe Thermocouple	LNO 10-25	Thermo FID	LNO 21-10	Stack Thermocouple	-
Probe	-	Stackmaster	-	Mass Flow Controller	LNO 29-13
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	LNO 29-11
S-Pitot	LNO 06-DJH	Anemometer	-	1m Heated Line (1)	-
L-Pitot	LNO 10-104 / 06-10	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LNO 14-DJH	Chiller (JCT/MAK 10)	-	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	LNO 03-91	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	LNO 31-DJH	Site temperature Logger	LNO 12-JO	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	LNO 18-65
Heater Controller	-		-	20m Heated Line (1)	-
Inclinometer (Swirl Device)	LNO 23-DJH		-	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 +/- %**
Methane	120876	BOC	105	-	2.0
Carbon Monoxide	221325	BOC	78	-	2.0
Nitric Oxide	HPC882	BOC	79.8	-	2.0
Oxides of Nitrogen	HPC882	BOC	79.8	-	2.0
Sulphur Dioxide	245944	BOC	404	-	2.0
Nitrous Oxide	249413	BOC	41.8	-	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**
Dominic Houghton	MM 04 529	MCERTS Level 2	Mar-18	Dec-21	Dec-21	Mar-18	Dec-21	Sep-19
Mike Howell	MM 13 1226	MCERTS Level 1	Jul-19	Jul-20	Mar-21	-	-	Jun-20

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS SUMMARY - UPPER LIMIT

NATO I-TEQ					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	09:25 - 15:25 07 December 2017	0.0014	0.0013	0.1	0.001
Field Blanks Run 1	-	0.00107	-	-	-

WHO TEQ (Humans / Mammals)					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	09:25 - 15:25 07 December 2017	0.0014	0.0012	-	0.001
Field Blanks Run 1	-	0.0011	-	-	-

WHO TEQ (Fish)					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	09:25 - 15:25 07 December 2017	0.0015	0.0014	-	0.002
Field Blanks Run 1	-	0.0012	-	-	-

WHO TEQ (Birds)					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	09:25 - 15:25 07 December 2017	0.0022	0.0014	-	0.002
Field Blanks Run 1	-	0.0017	-	-	-

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS SUMMARY - LOWER LIMIT

NATO I-TEQ					
Test	**Sampling Times**	**Concentration ng/m³**	**LOD ng/m³**	**Limit ng/m³**	**Emission Rate µg/hr**
Run 1	09:25 - 15:25 07 December 2017	0.00084	-	0.1	0.0008
Field Blanks Run 1	-	0.00036	-	-	-

WHO TEQ (Humans / Mammals)					
Test	**Sampling Times**	**Concentration ng/m³**	**LOD ng/m³**	**Limit ng/m³**	**Emission Rate µg/hr**
Run 1 07 December 2017	09:25 - 15:25 07 December 2017	0.00071	-	-	0.0007
Field Blanks Run 1	-	0.00035	-	-	-

WHO TEQ (Fish)					
Test	**Sampling Times**	**Concentration ng/m³**	**LOD ng/m³**	**Limit ng/m³**	**Emission Rate µg/hr**
Run 1	09:25 - 15:25 07 December 2017	0.00073	-	-	0.0007
Field Blanks Run 1	-	0.00026	-	-	-

WHO TEQ (Birds)					
Test	**Sampling Times**	**Concentration ng/m³**	**LOD ng/m³**	**Limit ng/m³**	**Emission Rate µg/hr**
Run 1	09:25 - 15:25 07 December 2017	0.0016	-	-	0.0016
Field Blanks Run 1	-	0.00073	-	-	-

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS ANALYSIS SUMMARY - RUN 1

NATO I-TEQ & WHO TEQ (Humans / Mammals)					
Congener	Result	NATO I-TEQ	WHO TEQ Humans / Mammals	Extraction Recovery	
				Actual	Permitted
	ng	ng	ng	%	%
Dioxins					
2378 Tetra CDD	< 0.002	0.002	0.002	98	50 - 130
12378 Penta CDD	< 0.002	0.001	0.002	106	50 - 130
123478 Hexa CDD	< 0.003	0.0003	0.0003	95	50 - 130
123678 Hexa CDD	< 0.0033	0.00033	0.00033	94	50 - 130
123789 Hexa CDD	0.003	0.0003	0.0003		
1234678 Hepta CDD	0.025	0.00025	0.00025	102	50 - 130
OCDD Octa CDD	0.048	0.000048	0.0000144	94	20 - 150
Total -Dioxins	**0.0863**	**0.00423**	**0.00519**		
Furans					
2378 Tetra CDF	0.0044	0.00044	0.00044	102	50 - 130
12378 Penta CDF	0.0032	0.00016	0.000096	0	>=50
23478 Penta CDF	0.0038	0.0019	0.00114	103	50 - 130
123478 Hexa CDF	0.0072	0.00072	0.00072	96	50 - 130
123678 Hexa CDF	0.0055	0.00055	0.00055	99	50 - 130
234678 Hexa CDF	0.0092	0.00092	0.00092	92	50 - 130
123789 Hexa CDF	0.0037	0.00037	0.00037	0	>=50
1234678 Hepta CDF	0.013	0.00013	0.00013	92	20 - 150
1234789 Hepta CDF	< 0.01	0.0001	0.0001	0	>=50
OCDF Octa CDF	< 0.01	0.00001	0.000003	95	20 - 150
Total -Furans	**0.07**	**0.00530**	**0.00447**		
Mean Recoveries (%)				**98**	
Total Isomers	**0.1563**	**0.00953**	**0.00966**		
Total ITEQ (<LOD = 0)		**0.00579**	**0.00493**		

NOTE: The Total Isomers result includes all isomers below the limit of detection. This gives a "worst case" Dioxins & Furans result.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS ANALYSIS SUMMARY - RUN 1

WHO TEQ (Fish) & WHO TEQ (Birds)					
Congener	Result	WHO TEQ Fish	WHO TEQ Birds	Extraction Recovery	
				Actual	Permitted
	ng	ng	ng	%	%
Dioxins					
2378 Tetra CDD	< 0.002	0.002	0.002	98	50 - 130
12378 Penta CDD	< 0.002	0.002	0.002	106	50 - 130
123478 Hexa CDD	< 0.003	0.0015	0.00015	95	50 - 130
123678 Hexa CDD	< 0.0033	0.000033	0.000033	94	50 - 130
123789 Hexa CDD	0.003	0.00003	0.00003		
1234678 Hepta CDD	0.025	0.000025	0.000025	102	50 - 130
OCDD Octa CDD	0.048	-	-	94	20 - 150
Total -Dioxins	**0.0863**	**0.00559**	**0.00424**		
Furans					
2378 Tetra CDF	0.0044	0.00022	0.0044	102	50 - 130
12378 Penta CDF	0.0032	0.00016	0.000032	0	>=50
23478 Penta CDF	0.0038	0.0019	0.0038	103	50 - 130
123478 Hexa CDF	0.0072	0.00072	0.00072	96	50 - 130
123678 Hexa CDF	0.0055	0.00055	0.00055	99	50 - 130
234678 Hexa CDF	0.0092	0.00092	0.00092	92	50 - 130
123789 Hexa CDF	0.0037	0.00037	0.00037	0	>=50
1234678 Hepta CDF	0.013	0.00013	0.00013	92	20 - 150
1234789 Hepta CDF	< 0.01	0.0001	0.0001	0	>=50
OCDF Octa CDF	< 0.01	0.000001	0.000001	95	20 - 150
Total -Furans	**0.07**	**0.00507**	**0.01102**		
Mean Recoveries (%)				**98**	
Total Isomers	**0.1563**	**0.01066**	**0.01526**		
Total ITEQ (<LOD = 0)		**0.00503**	**0.01098**		

NOTE: The Total Isomers result includes all isomers below the limit of detection. This gives a "worst case" Dioxins & Furans result.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS ANALYSIS SUMMARY - FIELD BLANK RUN 1

NATO I-TEQ & WHO TEQ (Humans / Mammals)					
Congener	Result	NATO I-TEQ	WHO TEQ Humans / Mammals	Extraction Recovery	
				Actual	Permitted
	ng	ng	ng	%	%
Dioxins					
2378 Tetra CDD	< 0.002	0.002	0.002	77	50 - 130
12378 Penta CDD	< 0.002	0.001	0.002	91	50 - 130
123478 Hexa CDD	< 0.003	0.0003	0.0003	73	50 - 130
123678 Hexa CDD	< 0.0033	0.00033	0.00033	76	50 - 130
123789 Hexa CDD	0.003	0.0003	0.0003		
1234678 Hepta CDD	0.017	0.00017	0.00017	84	50 - 130
OCDD Octa CDD	0.039	0.000039	0.0000117	84	20 - 150
Total -Dioxins	**0.0693**	**0.00414**	**0.00511**		
Furans					
2378 Tetra CDF	0.0034	0.00034	0.00034	83	50 - 130
12378 Penta CDF	< 0.002	0.0001	0.00006	0	>=50
23478 Penta CDF	< 0.002	0.001	0.0006	90	50 - 130
123478 Hexa CDF	0.004	0.0004	0.0004	79	50 - 130
123678 Hexa CDF	0.004	0.0004	0.0004	77	50 - 130
234678 Hexa CDF	0.004	0.0004	0.0004	77	50 - 130
123789 Hexa CDF	0.004	0.0004	0.0004	0	>=50
1234678 Hepta CDF	< 0.01	0.0001	0.0001	79	20 - 150
1234789 Hepta CDF	< 0.01	0.0001	0.0001	0	>=50
OCDF Octa CDF	0.015	0.000015	0.0000045	90	20 - 150
Total -Furans	**0.0584**	**0.003255**	**0.0028045**		
Mean Recoveries (%)				**82**	
Total Isomers	**0.1277**	**0.00739**	**0.00792**		
Total ITEQ (<LOD = 0)		**0.00246**	**0.00243**		

NOTE: The Total Isomers result includes all isomers below the limit of detection. This gives a "worst case" Dioxins & Furans result.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS ANALYSIS SUMMARY - FIELD BLANK RUN 1

WHO TEQ (Fish) & WHO TEQ (Birds)					
Congener	Result	WHO TEQ Fish	WHO TEQ Birds	Extraction Recovery	
				Actual	Permitted
	ng	ng	ng	%	%
Dioxins					
2378 Tetra CDD	< 0.002	0.002	0.002	77	50 - 130
12378 Penta CDD	< 0.002	0.002	0.002	91	50 - 130
123478 Hexa CDD	< 0.003	0.0015	0.00015	73	50 - 130
123678 Hexa CDD	< 0.0033	0.000033	0.000033	76	50 - 130
123789 Hexa CDD	0.003	0.00003	0.00003		
1234678 Hepta CDD	0.017	0.000017	0.000017	84	50 - 130
OCDD Octa CDD	0.039	-	-	84	20 - 150
Total -Dioxins	**0.0693**	**0.00558**	**0.00423**		
Furans					
2378 Tetra CDF	0.0034	0.00017	0.0034	83	50 - 130
12378 Penta CDF	< 0.002	0.0001	0.00002	0	>=50
23478 Penta CDF	< 0.002	0.001	0.002	90	50 - 130
123478 Hexa CDF	0.004	0.0004	0.0004	79	50 - 130
123678 Hexa CDF	0.004	0.0004	0.0004	77	50 - 130
234678 Hexa CDF	0.004	0.0004	0.0004	77	50 - 130
123789 Hexa CDF	0.004	0.0004	0.0004	0	>=50
1234678 Hepta CDF	< 0.01	0.0001	0.0001	79	20 - 150
1234789 Hepta CDF	< 0.01	0.0001	0.0001	0	>=50
OCDF Octa CDF	0.015	0.0000015	0.0000015	90	20 - 150
Total -Furans	**0.0584**	**0.00307**	**0.00722**		
Mean Recoveries (%)				**82**	
Total Isomers	**0.1277**	**0.00865**	**0.01145**		
Total ITEQ (<LOD = 0)		**0.00182**	**0.00505**		

NOTE: The Total Isomers result includes all isomers below the limit of detection. This gives a "worst case" Dioxins & Furans result.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 1 — Dioxins & Furans

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	757.51
Stack static pressure, P_{static}	mm H_2O	1.22
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	757.60
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H 0 by FTIR
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		7.52
Gas meter correction factor, Y_d		0.97198
Mean dry gas meter temperature, T_m		22.50
Mean pressure drop across orifice, DH	mmH_2O	31.33
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		6.75
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.9232
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		20.95
% oxygen reference condition		21
O_2 Reference Factor: $O2\ Ref = \frac{21.0 - act\%O2}{21.0 - ref\%O2}$		No O2 Ref
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	No O2 Ref
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0200
	%	2.46
Moisture by FTIR	%	2.463143963

Molecular weight of dry gas, M_d		
CO_2	%	1.57
O_2	%	20.95
Total	%	22.52
N_2 (100 -Total)	%	77.48
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.09
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.87
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.84
Mean of velocity heads, DP_{avg}	mm H_2O	3.41
Mean square root of velocity heads, ÖDP		1.85
Mean stack gas temperature, T_s	°C	43
$V_s = \frac{(K_p)(C_p)(\ddot{O}DP)(\ddot{O}(T_s + 273))}{(M_s)(P_s)}$	m/s	6.51
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.05
$Q_a = (60)(A_s)(V_s)$	m^3/min	19.2
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	16.2
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	17
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	8.5
Nozzle area, A_n	mm^2	56.8
Total sampling time, q	min	360.0
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	100.1
Acceptable isokinetic range 95% to 115%		Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS QUALITY ASSURANCE 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	20.31	0.10	0.12	-355.6	1.02	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	100.1	Yes

Acceptable isokinetic range 95% to 115%

Filtration	Filter Material	Filter Size mm	Maximum Filtration Temperature °C
Run 1	Quartz Fibre	90	120

Critical Sampling Requirement	Maximum Temperature at Condenser / Adsorber °C	Acceptable Temperature?	Maximum Temperature during storage / transit °C	Acceptable Temperature?
Run 1	15	Yes	21	Yes
Acceptance Criteria	< 20°C	-	< 25°C	-

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS SOLID & VAPOUR PHASES COMBINED

CADMIUM & THALLIUM COMBINED					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	12:40 - 14:40 05 December 2017	0.0007	0.0005	0.05	0.0007
Field Blank	-	0.0006	-	-	-
TOTAL HEAVY METALS COMBINED					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	12:40 - 14:40 05 December 2017	0.0931	0.0016	0.5	0.10
Field Blank	-	0.0031	-	-	-

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

INDIVIDUAL METALS SUMMARY - SOLID & VAPOUR PHASES COMBINED

Metals	LOD mg/m³	Concentration mg/m³	Emission Rate g/hr	Uncertainty (%)	UKAS Accredited
Cadmium	0.00022	0.00039	0.000404	107%	✓
Thallium	0.00026	0.00027	0.000278	148%	✓
Cadmium & Thallium	0.00047	0.00065	0.000682	147%	-

Metals	LOD mg/m³	Concentration mg/m³	Emission Rate g/hr	Uncertainty (%)	UKAS Accredited
Arsenic	0.00018	0.00018	0.000190	148%	✓
Antimony	0.00018	0.00019	0.000202	197%	✓
Chromium	0.00015	0.06439	0.067314	16%	✓
Cobalt	0.00009	0.00018	0.000190	99%	✓
Copper	0.00022	0.00400	0.004179	25%	✓
Lead	0.00022	0.00184	0.001927	37%	✓
Manganese	0.00018	0.00318	0.003325	197%	✓
Nickel	0.00018	0.01869	0.019542	17%	✓
Vanadium	0.00026	0.00044	0.000460	119%	✓
Total Other Heavy Metals	0.00163	0.09310	0.097328	11%	-

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS - RUN 1 SUMMARY

Metals	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³
Cadmium	0.00	0.50	0.00021	0.000006	0.41	0.00017
Thallium	0.00	0.60	0.00025	0.000006	0.03	0.00001
Cadmium & Thallium	0.00	1.10	0.00047	0.000006	0.44	0.00019
Volume Sampled m^3		2.3621			2.3621	

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

Metals	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³
Arsenic	0.00017	0.400	0.00017	0.00001	0.02871	0.00001
Antimony	0.00017	0.400	0.00017	0.00001	0.05742	0.00002
Chromium	0.00013	150.000	0.06350	0.00002	2.09991	0.00089
Cobalt	0.00008	0.400	0.00017	0.00001	0.02871	0.00001
Copper	0.00021	5.000	0.00212	0.00001	4.44260	0.00188
Lead	0.00021	3.000	0.00127	0.00001	1.35447	0.00057
Manganese	0.00017	6.900	0.00292	0.00001	0.61384	0.00026
Nickel	0.00017	32.000	0.01355	0.00001	12.15520	0.00515
Vanadium	0.00025	1.000	0.00042	0.00001	0.03862	0.00002
Total Other Heavy Metals	0.00157	199.10000	0.08429	0.00007	20.81948	0.00881
Volume Sampled m^3		2.3621			2.3621	

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS - BLANK SUMMARY

Metals	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³
Cadmium	0.00021	0.50	0.00021	0.00001	0.23500	0.00010
Thallium	0.00021	0.60	0.00025	0.00001	0.02350	0.00001
Cadmium & Thallium	0.00042	1.10	0.00047	0.00001	0.25850	0.00011
Volume Sampled m^3		2.3621			2.3621	

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

Metals	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³
Arsenic	0.00017	0.40000	0.00017	0.00001	0.02350	0.00001
Antimony	0.00017	0.40000	0.00017	0.00001	0.02350	0.00001
Chromium	0.00013	0.60000	0.00025	0.00002	0.23500	0.00010
Cobalt	0.00008	0.20000	0.00008	0.00001	0.02350	0.00001
Copper	0.00021	0.50000	0.00021	0.00001	1.26900	0.00054
Lead	0.00021	0.70000	0.00030	0.00001	0.77550	0.00033
Manganese	0.00017	0.40000	0.00017	0.00001	0.37600	0.00016
Nickel	0.00017	0.50000	0.00021	0.00001	0.16450	0.00007
Vanadium	0.00025	0.60000	0.00025	0.00001	0.02350	0.00001
Total Other Heavy Metals	0.00157	4.30000	0.00182	0.00007	2.91400	0.00123
Volume Sampled m^3		2.3621			2.3621	

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MERCURY SUMMARY - PARTICULATE & VAPOUR PHASES COMBINED

Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	12:40 - 14:40 05 December 2017	0.00027	0.00022	0.05	0.00028
Field Blank	-	0.00027	-	-	-

Mercury	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mean mg/m³	Lab Result ug	Concentration mg/m³	Stack LOD mean mg/m³	Lab Result ug	Concentration mg/m³
Run 1	0.00021	0.50	0.00021	0.00001	0.13	0.00005
Volume Sampled m^3		2.3621			2.3621	

Field Blank	-	0.50	0.00021	-	0.14	0.0001
Volume Sampled m^3		2.3621			2.3621	

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1 — Cd, Tl, Heavy Metals & Mercury

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	765.0
Stack static pressure, P_{static}	mm H_2O	1.2
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	765.1
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H 0 by FTIR
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		2.506
Gas meter correction factor, Y_d		0.97198
Mean dry gas meter temperature, T_m		18.46
Mean pressure drop across orifice, DH	mm	33.56
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		2.30
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	2.3621
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		21.0
% oxygen reference condition		21
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		No O2 Ref
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	No O2 Ref
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0246
	%	2.46
Moisture by FTIR	%	2.463143963

Molecular weight of dry gas, M_d		
CO_2	%	1.57
O_2	%	20.95
Total	%	22.52
N_2 (100 -Total)	%	77.48
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.09
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.82
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.84
Mean of velocity heads, DP_{avg}	mm H_2O	3.62
Mean square root of velocity heads, ÖDP		1.90
Mean stack gas temperature, T_s	°C	33
$V_s = \frac{(K_p)(C_p)(\ddot{O}DP)(\ddot{O}(T_s + 273))}{(M_s)(P_s)}$	m/s	6.58
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.05
$Q_a = (60)(A_s)(V_s)$	m^3/min	19.4
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	17.0
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	17.4
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	8.50
Nozzle area, A_n	mm^2	56.75
Total sampling time, q	min	120
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	97.7
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	20.3	0.10	0.20	-355.6	0.41	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	97.7	Yes

Filtration / Temp	Filter Material	Filter Size mm	Maximum Filtration Temperature °C	Maximum storage / transit Temperature °C
Run 1	Quartz Fibre	47	180	21

Metals	Type of Absorbers - Metals	Absorption Solutions - Metals
Run 1	PTFE	3.3% Nitric Acid, 1.5% Hydrogen Peroxide

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS ABSORBTION EFFICIENCY

Parameter		Total ug	3rd Absorber ug	Absorption Efficiency (%)	Required %	Pass / Fail
Cadmium	Run 1	0.913	0.17	82	90	N/A <30% ELV
Thallium	Run 1	1.542	ND	100	90	N/A <30% ELV
Arsenic	Run 1	0.429	ND	100	90	N/A <30% ELV
Antimony	Run 1	0.457	0.02	96	90	N/A <30% ELV
Chromium	Run 1	152.100	0.80	99	90	N/A <30% ELV
Cobalt	Run 1	0.429	ND	100	90	N/A <30% ELV
Copper	Run 1	9.443	3.77	60	90	N/A <30% ELV
Lead	Run 1	4.354	0.56	87	90	N/A <30% ELV
Manganese	Run 1	7.514	0.24	97	90	N/A <30% ELV
Nickel	Run 1	44.155	11.89	73	90	N/A <30% ELV
Vanadium	Run 1	1.03862	0.02	98	90	N/A <30% ELV

Parameter		Total ug	5th Absorber ug	Absorption Efficiency	Required	Pass / Fail
Mercury	Run 1	0.63	ND	100	95	N/A <30% ELV

HYDROGEN CHLORIDE SUMMARY					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	11:05 - 12:05 05 December 2017	0.30	0.0007	20	0.29
Field Blank	-	0.0019	-	-	-

Please note figures in bold italic font are at the limit of detection
Reference conditions are 273K, 101.3kPa without correction for water vapour

HYDROGEN CHLORIDE QUALITY ASSURANCE CHECKLIST

Leak Test Results	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	18.9	0.12	0.20	0.38	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Max. Storage / Transit Temp. °C	Type of Absorbers	Absorption Solutions
Run 1	Quartz Fibre	47	160	21	Glass	HPLC Water

HYDROGEN CHLORIDE ABSORPTION EFFICIENCY

Parameter	**Total ug**	**IMP C ug**	**Absorption Efficiency %**	**Acceptable Absorption Efficiency %**	**Absorption Efficiency Acceptable ?**
Run 1	333.062	8.162	98	95	Yes

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS 1 — Hydrogen Chloride

Absolute pressure of stack gas, P_s			**Velocity of stack gas, V_s**		
Barometric pressure, P_b	mm Hg	765	Pitot tube velocity constant, K_p		34.97
Stack static pressure, P_{static}	mm H_2O	1	Velocity pressure coefficient, C_p		0.84
$P_s = P_b + (P_{static}/13.6)$	mm Hg	765	Mean of velocity heads, DP_{avg}	mm H_2O	3.37
			Mean square root of velocity heads, ÖDP		1.83
Vol. of water vapour collected, V_{wstd}			Mean stack gas temperature, T_s	°C	52
Moisture trap weight increase,Vlc	g	H 0 by FTIR			
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$V_s = (K_p)(C_p)(ÖDP)(Ö(T_s + 273))/(M_s)(P_s)$	m/s	6.5
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		1.1690	Area of stack, A_s	m^2	0.05
Gas meter correction factor, Y_d		0.97198	$Q_a = (60)(A_s)(V_s)$	m^3/min	19
Mean dry gas meter temperature, T_m		13.33	**Dry total flow of stack gas, Q_{std}**		
Mean pressure drop across orifice, DH	mmH_2O	29.15	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = (0.3592)(V_m)(P_b+(DH/13.6))(Y_d)/(T_m + 273)$		1.09	$Q_{std} = (Q_a)P_s(0.3592)(1-B_{wo})/(T_s) +273$	m^3/min	16
Volume of gas metered wet, V_{mstw}			**Wet total flow of stack gas, Q_{stw}**		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.1211	$Q_{stw} = (Q_a)P_s(0.3592)/(T_s) +273$	m^3/min	16
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	$Q_{stdO2} = (Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)/(T_s) +273$	m^3/min	No O2 Ref
% oxygen measured in gas stream, act%O_2		20.9			
% oxygen reference condition		21	**Percent isokinetic, %I**		
O_2 Reference Factor: O2 Ref = 21.0 - act%O2 / 21.0 - ref%O2		No O2 Ref	Nozzle diameter, D_n	mm	8.50
			Nozzle area, A_n	mm^2	56.75
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	No O2 Ref	Total sampling time, q	min	60
Moisture content, B_{wo}			$\%I = (4.6398E6)(T_s+273)(V_{mstd})/(P_s)(V_s)(A_n)(q)(1-B_{wo})$	%	99
$B_{wo} = V_{wstd}/(V_{mstd} + V_{wstd})$		0.0246			
	%	2.46	Acceptable isokinetic range 95% to 115%		Yes
Moisture by FTIR	%	2.463143963	**Hydrogen Chloride Concentration, C**		
Molecular weight of dry gas, M_d			Mass collected , M	ug	333
CO_2		1.57	$C_{wet} = M_n/V_{mstw}$	mg/m^3	0.297
O_2		20.9			
Total		22.47	$C_{dry} = M_n/V_{mstd}$	mg/m^3	0.305
N_2 (100 -Total)		77.53			
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.09	$C_{dry@X\%O2} = M_n/V_{mstd@X\%oxygen}$	mg/m^3	No O2 Ref
Molecular weight of wet gas, M_s			**Hydrogen Chloride 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	0.29

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HYDROGEN FLUORIDE SUMMARY					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	15:15 - 16:15 05 December 2017	***0.03***	0.01	2	***0.03***
Field Blank	-	0.024	-	-	-

Please note figures in bold italic font are at the limit of detection
Reference conditions are 273K, 101.3kPa without correction for water vapour

HYDROGEN FLUORIDE QUALITY ASSURANCE CHECKLIST

Leak Test Results	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	3.0	0.02	0.03	0.06	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Max. Storage / Transit Temp. °C	Type of Absorbers	Absorption Solutions
Run 1	Quartz Fibre	47	150	21	PE	0.1N Sodium Hydroxide

HYDROGEN FLUORIDE ABSORPTION EFFICIENCY

Parameter	**Total ug**	**IMP C ug**	**Absorption Efficiency %**	**Acceptable Absorption Efficiency %**	**Absorption Efficiency Acceptable ?**
Run 1	ND	ND	100	95	Yes

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GAS SUMMARY

Test	Sampling Times	Concentration mg/m³	Analysis Areas	Interference (%) *	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Oxides of Nitrogen	11:30 - 15:30 06 December 2017	5.7	1875 - 2130 / 2700 - 2950	3.48	3.483	400	5.59
Sulphur Dioxide	11:30 - 15:30 06 December 2017	5.7	1100 - 1380	3.8	0.371	100	5.59
Carbon Monoxide	11:30 - 15:30 06 December 2017	3.5	2000 - 2200 / 2540 - 2590	1.8	0.075	150	3.42
Nitrous Oxide	11:30 - 15:30 06 December 2017	0.4	2100 - 2223 / 2540 - 2600	2.1	0.277	-	0.34

*M22 Specifies interference must be <5%.

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

*M22 Specifies interference must be <5%.

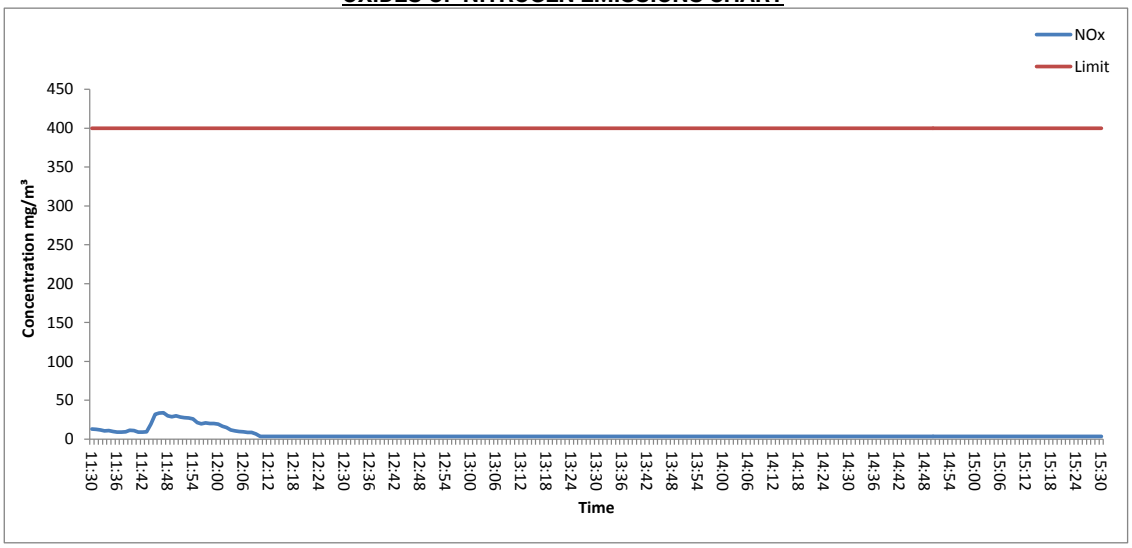
FTIR CALIBRATION CHECKS

Pre - Sampling Checks - System			Date of Checks	06 December 2017		Time of Checks	10:30	
Post Sampling Checks - System			Date of Checks	06 December 2017		Time of Checks	15:35	
Compound	Pre - Test Zero Reading	Post Test Zero Reading	Zero Drift as a % of Range	Span Gas (ppm)	Pre - Test Span Reading	% Variation from Actual	Post Test Span Reading	% Span Drift
CO	-0.01	-0.10	-0.09	78.0	80.0	2.61	80.3	0.37
NOx	1.53	0.00	-1.53	79.8	79.3	-0.63	80.1	1.06
SO_2	0.08	0.21	0.43	404.0	405.3	0.33	404.0	-0.33
N_2O	0.01	0.02	0.10	41.8	42.2	0.88	41.7	-1.19

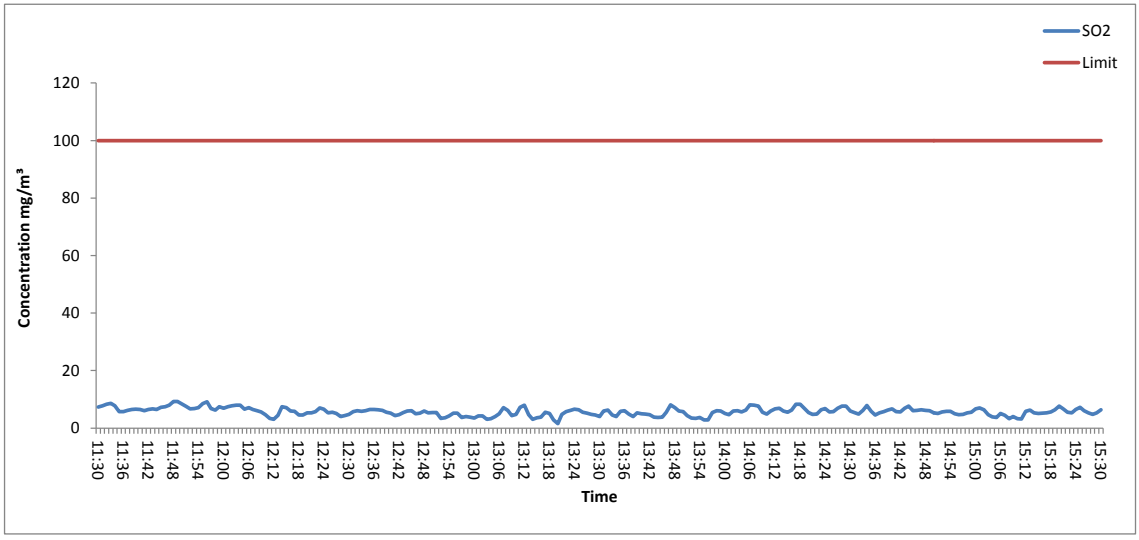
Note - Methane was used as a surrogate span check for moisture. All other surrogates are listed in the individual measurement uncertainty budgets.
Acceptance criteria for initial span check variation is +/-5% of certified reading for all gases, except HCl and NH_3 which are +/- 10% of certified reading.
Acceptance criteria for % zero drift across the test is +/-2% of range for all gases.
Acceptance criteria for % span drift across the test is +/-5% for all gases, except very reactive gases, such as HCl and NH_3 which are exempt.
M22 also states that if the gas with the narrowest peak width (Methane) has to be drift corrected and that correction should also apply to all gases.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

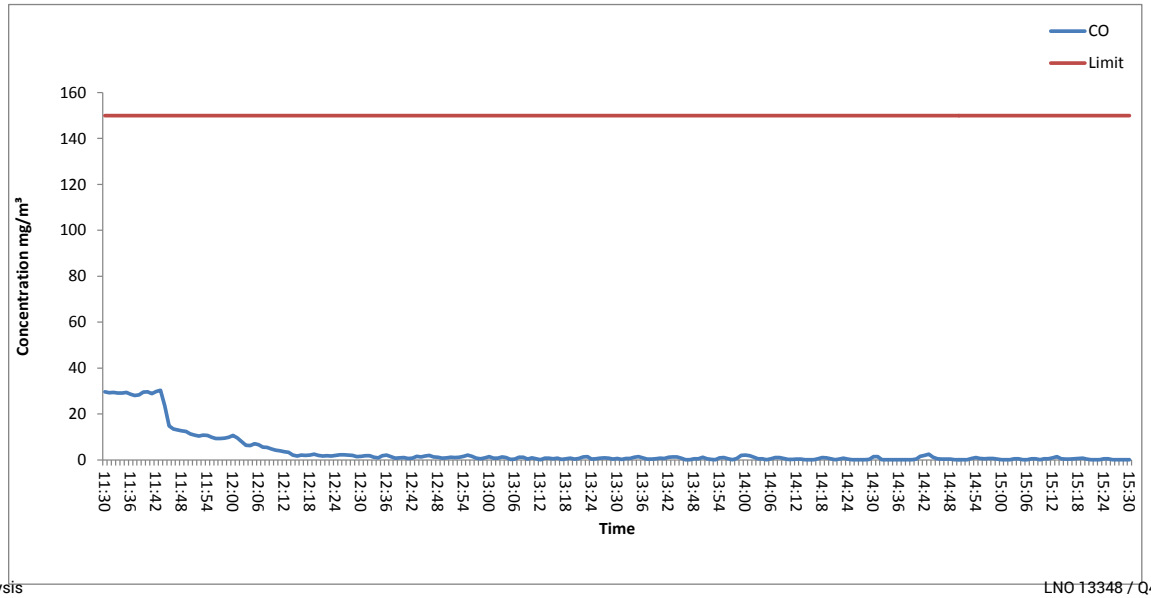
OXIDES OF NITROGEN EMISSIONS CHART



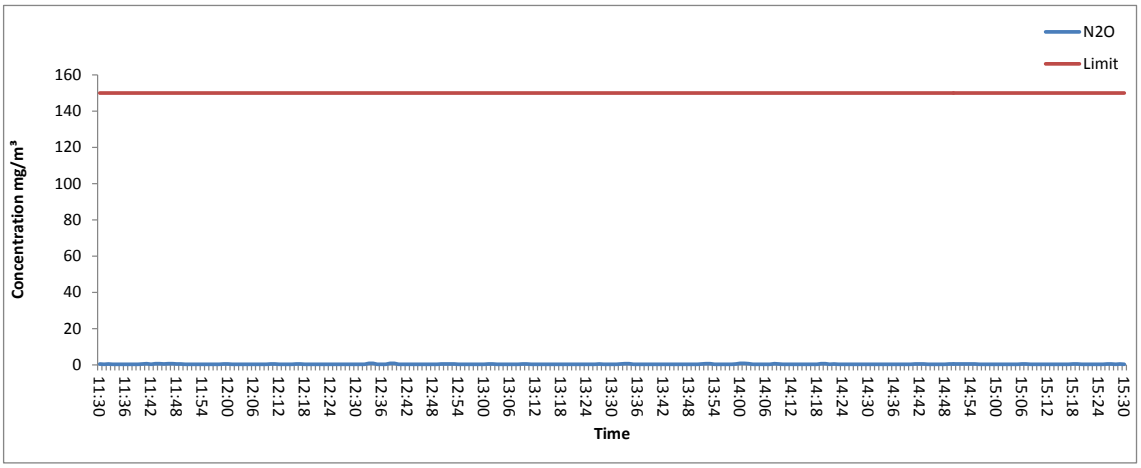
SULPHUR DIOXIDE EMISSIONS CHART



CARBON MONOXIDE EMISSIONS CHART



NITROUS OXIDE EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.25	m
Stack Width, W	-	m
Stack Area, A	0.05	m^2
Average stack gas temperature	50	^oC
Stack static pressure	0.012	kPa
Barometric Pressure	102	kPa

Stack Gas Composition & Molecular Weights								
Component	Molar Mass M	Density kg/m³ p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m³ pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m³ pi
CO_2	44	1.963059	0.161847	0.001618	0.003177	0.157860	0.001579	0.003099
O_2	32	1.427679	16.134135	0.161341	0.230344	15.736728	0.157367	0.224670
N_2	28	1.249219	83.704018	0.837040	1.045647	81.642268	0.816423	1.019891
H_2O	18	0.803070	-	-	-	2.463144	0.024631	0.019781

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2792	kg/m^3
Wet Density (STP), P_{STW}	1.2674	kg/m^3
Dry Density (Actual), P_{Actual}	1.0888	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	1.079	kg/m^3

Where:

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

P_{STW} = (P_{STD} + pi of H_2O) / (1 + (pi 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	05 December 2017
Time of Survey	10:40
Velocity Measurement Device:	S-Type Pitot

Sampling Line A								
Traverse Point	Distance into duct (m)	DP pt mmH_2O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
1	0.13	3.3	33	50	6.5	0.32	-	<15
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	3.3	33	50	6.5	0.32	-	-

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt mmH_2O (average of 3 readings)	DP pt Pa (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 Pa	End Value Pa	Difference %	Outcome	Start Value Pa	End Value Pa	Difference %	Outcome
Run 1	164	158	3.7	Pass	182	176	3.3	Pass

To complete a compliant pitot leak check a pressure of over 80 mmH 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	12	10	2.0	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	33	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	6.5	m/s	-	-
Highest Gas Velocity	6.5	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	**6.5**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	50	0	°C
Total Pressure	102.012	101.3	kPa
Oxygen	21.0	21	%
Moisture	2.46	2.46	%
Pitot tube calibration coefficient, K_{pt}	0.84		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	6.51	m/s
Stack Area (A)	0.05	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	1150	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	979	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	955	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	979	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 ((20.9 - O_2a) / (20.9 - O_2s))

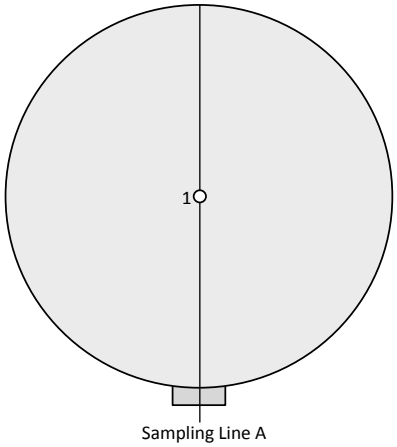
Nomenclature:
Ts = Absolute Temperature, Standard Conditions, 273 K
Ps = Absolute Pressure, Standard Conditions, 101.3 kPa
Ta = Absolute Temperature, Actual Conditions, K
Pa = Absolute Pressure, Actual Conditions, kPa
Ma = Water vapour, Actual Conditions, % Vol
Ms = Water vapour, Reference Conditions, % 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	0.25	m
Stack Width	-	m
Area	0.05	m^2

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	50	0.13	m



- ○ 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	50.0	0.13	< 15
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

SAMPLING LOCATION

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - DIOXINS & FURANS

Run	Sampled Volume m³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 2%**
Run 1	0.001	2.0	0.50	1.0	N/A	-
as a %	0.01	0.7	0.49	1.0	N/A	0.59
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	O2 Correction -	Mass of Dioxin & Furan ng	Leak ng/m³	Laboratory analysis -	Combined uncertainty
Run 1	6.3779	1.0	0.1563	0.0000047	-	-
MU as ng/m³	0.00002	-	0.0009	0.0000047	0.0001	**0.0010**
MU as %	1.3051	-	67.0505	0.3411	7.50	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.002**	**ng/m³**	**140.8**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CADMIUM & THALLIUM

Run	Sampled Volume m³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Leak %
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**<=2%**
Run 1	0.001	2.0	0.50	1.0	0.1	0.00005	-
as a %	0.04	0.69	0.49	1.0	-	3.00	0.99
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**

Run	Volume (STP) m³	O2 Correction -	Mass of Cadmium & Thallium mg	Leak mg/m³	Lab Uncertainty mg	Combined uncertainty
Run 1	2.2304	-	1.5416	0.000004	-	-
MU as mg	0.000009	-	0.0005	0.000004	0.00003	**0.0005**
MU as %	1.3087	-	73.2177	0.5689	5.00000	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.0010**	**mg/m³**	**146.80**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - HEAVY METALS

Run	Sampled Volume m³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Leak %
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**<=2%**
Run 1	0.001	2.0	0.50	1.0	0.10	0.0022	-
as a %	0.04	0.73	0.49	1.0	-	3.00	0.99
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**

Run	Volume (STP) m³	O2 Correction -	Mass of Heavy Metals mg	Leak mg/m³	Lab Uncertainty mg	Combined uncertainty
Run 1	2.3812	-	219.9195	0.0005	-	-
MU as mg/m³	0.0012	-	0.0016	0.0005	0.00466	**0.0051**
MU as %	1.3335	-	1.7542	0.5689	5.00000	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.01**	**mg/m³**	**10.99**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MERCURY

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Concentration in impinger	Leak
	m^3	K	kPa	% by volume	% by volume	mg	%
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**<=2%**
Run 1	0.001	2.0	0.50	1.0	0.10	0.000009	-
as a %	0.04	0.7	0.49	1.0	-	3.00	0.99
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**

Run	Volume (STP)	O2 Correction	Mass of Mercury	Leak	Lab Uncertainty	Combined
	m^3	-	mg	mg/m^3	mg	
Run 1	2.2304	-	0.6276	0.0000015	-	-
MU as mg/m^3	0.000003	-	0.0002	0.0000015	0.00001	**0.0002**
MU as %	1.3087	-	86.5838	0.5689	5.00000	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.00046**	**mg/m^3**	**173.48**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - ISOKINETIC HYDROGEN CHLORIDE

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Concentration in impinger	Limit of Detection	Leak
	m^3	K	kPa	% by volume	% by volume	mg	% by mass	%
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**≤ 5% of ELV**	**<=2%**
Run 1	1.121	286.33	102.12	1.0	-	0.0082	0.00201	-
as a %	0.09	0.70	0.49	1.0	-	3.00	0.04	1.06
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**

Run	Volume (STP)	Mass of Hydrogen Chloride	O2 Correction	Leak	Lab Uncertainty	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	1.078	0.0020	-	0.0018	-	-
MU as mg/m^3	0.0039	0.0090	-	0.0018	0.0143	**0.0174**
MU as %	1.3177	3.0276	-	0.6097	4.8	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**mg/m^3**	**11.72**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - NON-ISOKINETIC HYDROGEN FLUORIDE

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Concentration in impinger	Limit of Detection	Leak
	m^3	K	kPa	% by volume	% by volume	mg	% by mass	%
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**≤ 5% of ELV**	**<=2%**
Run 1	0.00006	2.000	0.500	1.000	0.100	0.001	0.00017	-
as a %	0.033	0.694	0.439	1.000	-	3.000	3.021	1.000
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**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	0.1923	0.0057	-	0.0002	-	-
MU as mg/m^3	0.0004	0.0009	-	0.0002	0.0019	**0.0022**
MU as %	1.2944	3.0207	-	0.5774	6.1	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.004**	**mg/m^3**	**13.91**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXIDES OF NITROGEN

Actual Measured Concentration	5.71	mg/m^3
Measured Concentration at Reference Conditions	5.71	mg/m^3
Emission Limit Value	400	mg/m^3
Instrument Range	205	mg/m^3
Check Gas Concentration (Nitric Oxide was used as a Surrogate)	106.93	mg/m^3

Performance Characteristics & Source of Value	Values	Requirement	Compliant
Deviation from linearity as a % of the range (taken from worst case figure in MCERTS certificate)	1.900	<2%	Yes
Zero drift (calculated from start and end readings)	-1.530	<5%	Yes
Span drift (calculated from start and end readings).	1.059	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	1.280	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.200	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	0.270	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	0.001	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	3.480	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	1.230	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	mg/m^3
Uncertainty of linearity (lack of fit) U_{fit}	2.249
Uncertainty of zero drift $U_{0,dr}$	-1.811
Uncertainty of span drift $U_{s,dr}$	1.254
Uncertainty of volume or pressure flow dependence U_{spress}	1.515
Uncertainty in Ambient Temperature U_{temp}	0.398
Uncertainty in Voltage U_{volt}	0.001
Uncertainty of interferents U_i	4.118
Uncertainty of Repeatability U_r	2.522
Uncertainty of Certified Reference Material U_{cal}	0.617

Measurement Uncertainty	mg/m^3
Combined uncertainty	6.01
Expanded uncertainty at a 95% Confidence Interval	12.01

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

Expanded Measurement Uncertainty at a 95% Confidence Interval	%
Expressed as a % of the Measured Concentration	210.37
Expressed as a % of the Measured Concentration at Reference Conditions	210.37
Expressed as a % of the Emission Limit Value	3.00

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - SULPHUR DIOXIDE BY FTIR

Actual Measured Concentration	5.71	mg/m³
Measured Concentration at Reference Conditions	5.71	mg/m³
Emission Limit Value	100	mg/m³
Instrument Range	86	mg/m³
Check Gas Concentration	1155.44	mg/m³

Performance Characteristics & Source of Value	Values	Requirement	Compliant
Deviation from linearity as a % of the range (taken from worst case figure in MCERTS certificate)	0.800	<2%	Yes
Zero drift (calculated from start and end readings)	0.433	<5%	Yes
Span drift (calculated from start and end readings).	-0.329	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	1.280	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.200	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	0.140	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	0.001	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	3.780	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.620	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	mg/m^3
Uncertainty of linearity (lack of fit) U_{fit}	0.396
Uncertainty of zero drift $U_{0,dr}$	0.215
Uncertainty of span drift $U_{s,dr}$	-0.163
Uncertainty of volume or pressure flow dependence U_{spress}	0.634
Uncertainty in Ambient Temperature U_{temp}	0.121
Uncertainty in Voltage U_{volt}	0.0005
Uncertainty of interferents U_i	1.872
Uncertainty of Repeatability U_r	0.532
Uncertainty of Certified Reference Material U_{cal}	6.671

Measurement Uncertainty	mg/m^3
Combined uncertainty	7.00
Expanded uncertainty at a 95% Confidence Interval	13.99

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

Expanded Measurement Uncertainty at a 95% Confidence Interval	%
Expressed as a % of the Measured Concentration	245.13
Expressed as a % of the Measured Concentration at Reference Conditions	245.13
Expressed as a % of the Emission Limit Value	13.99

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CARBON MONOXIDE BY FTIR

Actual Measured Concentration	3.49	mg/m^3
Measured Concentration at Reference Conditions	3.49	mg/m^3
Emission Limit Value	150	mg/m^3
Instrument Range	125	mg/m^3
Check Gas Concentration	97.50	mg/m^3

Performance Characteristics & Source of Value	Values	Requirement	Compliant
Deviation from linearity as a % of the range (taken from worst case figure in MCERTS certificate)	0.950	<2%	Yes
Zero drift (calculated from start and end readings)	-0.090	<5%	Yes
Span drift (calculated from start and end readings).	0.371	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	-0.570	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.050	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	0.070	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	0.001	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	1.760	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.330	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	mg/m^3
Uncertainty of linearity (lack of fit) U_{fit}	0.686
Uncertainty of zero drift $U_{0,dr}$	-0.065
Uncertainty of span drift $U_{s,dr}$	0.268
Uncertainty of volume or pressure flow dependence U_{spress}	-0.411
Uncertainty in Ambient Temperature U_{temp}	0.062
Uncertainty in Voltage U_{volt}	0.001
Uncertainty of interferents U_i	1.270
Uncertainty of Repeatability U_r	0.413
Uncertainty of Certified Reference Material U_{cal}	0.563

Measurement Uncertainty	mg/m^3
Combined uncertainty	1.68
Expanded uncertainty at a 95% Confidence Interval	3.36

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

Expanded Measurement Uncertainty at a 95% Confidence Interval	%
Expressed as a % of the Measured Concentration	96.23
Expressed as a % of the Measured Concentration at Reference Conditions	96.23
Expressed as a % of the Emission Limit Value	2.24

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - NITROUS OXIDE BY FTIR

Actual Measured Concentration	0.35	mg/m^3
Measured Concentration at Reference Conditions	0.35	mg/m^3
Emission Limit Value	-	mg/m^3
Instrument Range	20	mg/m^3
Check Gas Concentration	82.11	mg/m^3

Performance Characteristics & Source of Value	Values	Requirement	Compliant
Deviation from linearity as a % of the range (taken from worst case figure in MCERTS certificate)	1.900	<2%	Yes
Zero drift (calculated from start and end readings)	0.100	<5%	Yes
Span drift (calculated from start and end readings).	-1.186	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	1.280	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.200	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	0.270	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	0.001	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	2.110	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	1.230	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	mg/m^3
Uncertainty of linearity (lack of fit) U_{fit}	0.215
Uncertainty of zero drift $U_{0,dr}$	0.011
Uncertainty of span drift $U_{s,dr}$	-0.134
Uncertainty of volume or pressure flow dependence U_{spress}	0.145
Uncertainty in Ambient Temperature U_{temp}	0.038
Uncertainty in Voltage U_{volt}	0.000
Uncertainty of interferents U_i	0.239
Uncertainty of Repeatability U_r	0.241
Uncertainty of Certified Reference Material U_{cal}	0.474

Measurement Uncertainty	mg/m^3
Combined uncertainty	0.65
Expanded uncertainty at a 95% Confidence Interval	1.31

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

Expanded Measurement Uncertainty at a 95% Confidence Interval	%
Expressed as a % of the Measured Concentration	372.89
Expressed as a % of the Measured Concentration at Reference Conditions	372.89
Expressed as a % of the Emission Limit Value	-

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	6.5	m/s
Measured Volumetric Flow rate at Actual Conditions	1150	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	-	0.34		
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	2.44	<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	1.65	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	520		
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	0.09
Expanded uncertainty at a 95% Confidence Interval	0.17

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 Concentration	1.3
Expanded uncertainty at a 95% Confidence Interval	2.6

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	31
Expanded uncertainty at a 95% Confidence Interval	60

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 Concentration	2.7
Expanded uncertainty at a 95% Confidence Interval	5.2

END OF REPORT

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