

STACK EMISSIONS MONITORING REPORT



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Glascoed Road
St Asaph
Denbighshire
LL17 0LL

Permit:

EPR Permit: EPR/BX4666IZ/V002

Release Point:

A10 - Ultra Precision Machining Centre

Sampling Date(s):

16th November 2015

ESG Job Number:	LNO 12696
Report Date:	23rd December 2015
Version:	1
Report By:	Dominic Houghton
MCERTS Number:	MM 04 529
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
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Technical Endorsements:	1, 2, 3 & 4
Signature:	



CONTENTS

EXECUTIVE SUMMARY

Stack Emissions Monitoring Objectives

- Plant
- Operator
- Stack Emissions Monitoring Test House

Emissions Summary

Monitoring Times

Process Details

Monitoring Methods

Analytical Methods

- Sampling Methods with Subsequent Analysis
- On-Site Testing

Sampling Location

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

Sampling and Analytical Method Deviations

APPENDICES

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

APPENDIX 3 - Measurement Uncertainty Budget Calculations

EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Qioptiq Ltd operates a lens turning /cutting accompanied by a mist of white spirit process at St Asaph which is subject to EPR Permit EPR/BX4666IZ/V002, under the Environmental Permitting Regulations 2010.

ESG were commissioned by Qioptiq 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/BX4666IZ/V002.

Plant

A10 - Ultra Precision Machining Centre

Operator

Qioptiq Ltd
Glascoed Road
St Asaph
Denbighshire
LL17 0LL

EPR Permit: EPR/BX4666IZ/V002

Stack Emissions Monitoring Test House

ESG - 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.
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EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	Units	Result	Calculated Uncertainty +/-	Limit	MCERTS accredited result
Total Particulate Matter	mg/m ³	0.14	0.29	1	✓
Particulate Emission Rate	g/hr	0.13	0.27	-	
Heavy Metals	mg/m ³	0.0003	0.00003	-	✓
Heavy Metals Emission Rate	g/hr	0.0002	0.00003	-	
White Spirit	mg/m ³	28	7.0	-	✗
White Spirit Emission Rate	g/hr	27	6.8	-	
Moisture	%	0.11	0.02	-	✓
Stack Gas Temperature	°C	26	-	-	✓
Stack Gas Velocity	m/s	6.1	0.15	-	
Gas Volumetric Flow Rate (Actual)	m ³ /hr	1079	56	-	
Gas Volumetric Flow Rate (STP, Wet)	m ³ /hr	977	51	-	
Gas Volumetric Flow Rate (STP, Dry)	m ³ /hr	976	51	-	
Gas Volumetric Flow Rate at Reference Conditions	m ³ /hr	977	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
Total Particulate Matter Run 1	16 November 2015	11:45 - 12:45	60 minutes
Heavy Metals Run 1	16 November 2015	11:45 - 12:45	60 minutes
White Spirit Run 1	16 November 2015	11:45 - 12:15	30 minutes
Preliminary Stack Traverse	16 November 2015	11:30	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Lens turning /cutting accompanied by a mist of white spirit
Continuous or batch	Batch
Product Details	Infra Red Lenses
Part of batch to be monitored (if applicable)	Any
Normal load, throughput or continuous rating	Normal throughput
Fuel used during monitoring	N/A
Abatement	Coarse and HEPA Filter
Plume Appearance	None 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 +/- %
TPM	SRM - BS EN 13284-1	AE 104	1015	Yes	0.14 mg/m ³	200 %
Heavy Metals	SRM - BS EN 14385	AE 108	1015	Yes	0 mg/m ³	10.4 %
White Spirit	SRM - BS EN 13649	AE 118	1015	Yes	0.133 mg/m ³	25 %
H ₂ O	SRM - BS EN 14790	AE 105	1015	Yes	0.01%	18%
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	5 Pa	2.5 %
Volumetric Flow Rate	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	-	5.2 %

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

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 (ESG or Subcontract)	Sample Archive Location	Archive Period
TPM	Gravimetric	AE 106	1015	Yes	ESG Stockport	ESG Stockport	3 months
Heavy Metals	Inductively coupled Plasma - Mass Spectrometry	ANU/SOP/117, 101,102	1015	Yes	ESG Bretby	ESG Bretby	3 months
White Spirit	ATD-GC-MS	ASC	1015	No	ESG - Bretby	ESG - Bretby	3 months

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	MCERTS Accredited Analysis	Laboratory	Data Archive Location	Archive Period
H ₂ O	Gravimetric	AE 105	1015	Yes	ESG Stockport	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	Value	Units	Requirement	Compliant	Method
Lowest Differential Pressure	25	Pa	≥ 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	6.10	m/s	-	-	-
Highest Gas Velocity	6.10	m/s	-	-	-
Ratio of Gas Velocities	1.00	: 1	$< 3 : 1$	Yes	BS EN 15259
Mean Velocity	6.10	m/s	-	-	-
Maximum angle of flow with regard to duct axis	< 15	$^{\circ}$	$< 15^{\circ}$	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259

DUCT CHARACTERISTICS		
	Value	Units
Shape	Circular	-
Depth	0.25	m
Width	-	m
Area	0.05	m ²
Port Depth	0	mm

SAMPLING LINES & POINTS		
	Isokinetic	Non-Iso & Gases
Sample port size	1.5 inch Hole	1.5 inch Hole
Number of lines used	1	1
Number of points / line	1	1
Duct orientation	Vertical	Vertical
Filtration	Out Stack	Out Stack
Filtration for TPM	Out Stack	-

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

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	No
Depth of Platform = $\geq$ Stack depth / diameter + wall and port thickness + 1.5m	Yes

Sampling Platform Improvement Recommendations (if applicable)

The sampling location ports should ideally be increased to meet all the requirements as specified in EA Guidance Note M1.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

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

APPENDICES

CONTENTS

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

APPENDIX 3 - Measurement Uncertainty Budget Calculations

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	Method Standard Reference Method / Alternative Method	ESG Technical Procedure	UKAS Lab Number	MCERTS Accredited Method	Number of Samples
TPM	SRM - BS EN 13284-1	AE 104	1015	Yes	1
Heavy Metals	SRM - BS EN 14385	AE 108	1015	Yes	1
White Spirit	SRM - BS EN 13649	AE 118	1015	Yes	1
H ₂ O	SRM - BS EN 14790	AE 105	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 13-01	Horiba PG-250 Analyser	-	Laboratory Balance	LNO 00-12/00-13
Box Thermocouples	LNO 03-01	FT-IR	-	Tape Measure	LNO 24-DJH
Meter In Thermocouple	LNO 03-01	FT-IR Oven Box	-	Stopwatch	LNO 17-DJH
Meter Out Thermocouple	LNO 03-01	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	-	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	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)	-	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	LNO 31-DJH	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
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 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
Dominic Houghton	MM 04 529	MCERTS Level 2	Dec-16	Dec-16	Dec-16	Mar-18	Dec-16	Sep-19
Mark Derbyshire	MM 07 824	MCERTS Level 1	Dec-17	-	-	-	-	Nov-18

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY					
Parameter	Sampling Times	Concentration mg/m ³	Uncertainty mg/m ³	Limit mg/m ³	Emission Rate g/hr
Run 1	11:45 - 12:45 16 November 2015	0.14	0.29	1	0.13
Blank	-	0.14	-	-	-

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

Acetone Blank Value mg/l	Acceptable Value mg/l
2.0	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	Q8634	0.13899	0.13868	-0.00031	142.85220	142.85130	-0.00090	0.00022

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	Q8633	0.14373	0.14357	-0.00016	145.24220	145.24190	-0.00030	0.00022

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				
Barometric pressure, P _b	mm Hg	753.01		
Stack static pressure, P _{static}	mm H ₂ O	3.06		
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	753.23		
Vol. of water vapour collected, V_{wstd}				
Moisture trap weight increase, V _{lc}	g	1.3		
$V_{wstd} = (0.001246)(V_{lc})$	m ³	0.0016198		
Volume of gas metered dry, V_{mstd}				
Volume of gas sample through gas meter, V _m		1.644		
Gas meter correction factor, Y _d		1.00701		
Mean dry gas meter temperature, T _m		20.250		
Mean pressure drop across orifice, DH	mmH ₂ O	65.429		
$V_{mstd} = \frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m + 273}$		1.537		
Volume of gas metered wet, V_{mstw}				
$V_{mstw} = V_{mstd} + V_{wstd}$	m ³	1.5384		
Vol. of gas metered at O₂ 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	O ₂ Ref = 21.0 - act%O ₂	No O2 Ref		
Factor	21.0 - ref%O ₂			
$V_{mstd@X\%oxygen} = (V_{mstd}) (O_2 \text{ Ref})$	m ³	No O2 Ref		
Moisture content, B_{wo}				
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0011		
	%	0.11		
Moisture by FTIR				
	%	-		
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 ₂ O	2.83		
Mean square root of velocity heads, ÖDP		1.68		
Mean stack gas temperature, T _s	°C	27		
$V_s = \frac{(K_p)(C_p)(\ddot{O}DP)(\ddot{O}(T_s + 273))}{(M_s)(P_s)}$	m/s	5.81		
Molecular weight of dry gas, M_d				
CO ₂	%	0.03		
O ₂	%	20.95		
Total	%	20.98		
N ₂ (100 - Total)	%	79.02		
$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2)$		28.84		
Molecular weight of wet gas, M_s				
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.83		
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	17.1		
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	15.4		
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2 \text{ REF})}{(T_s) + 273}$	@O ₂ ref	No O2 Ref		
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet	15.45		
Percent isokinetic, %I				
Nozzle diameter, D _n	mm	9.75		
Nozzle area, A _n	mm ²	74.67		
Total sampling time, q	min	60		
$\%I = \frac{(4.6398E6)(T_s + 273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	109.1		
Acceptable isokinetic range 95% to 115%				Yes
Particulate Concentration, C				
Mass collected on filter, M _f	g	-0.00031		
Mass collected in probe, M _p	g	-0.00090		
Total mass collected, M _n	g	0.00022		
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m ³	0.143		
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m ³	0.143		
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m ³	No O2 Ref		
Particulate Emission Rates, E				
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.13		

As the total mass gained was less than the LOD, the LOD has been reported

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	27.59	0.00	0.04	-355.6	0.55	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	109.09	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m ³	5% ELV mg/m ³	LOD < 5% ELV
Run 1	0.14	0.05	N/A - ELV < 5 mg/m ³

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	0.14	1	0.2	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	QF	47	160	180	160

GF = Glass Fibre

QF = Quartz Fibre

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS SOLID & VAPOUR PHASES COMBINED

TOTAL HEAVY METALS COMBINED					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	Limit mg/m ³	Emission Rate g/hr
Run 1	11:45 - 12:45 16 November 2015	0.0003	0.0003	-	0.0002
Field Blank	-	0.0003	-	-	-

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/m ³	Laboratory Result ug	Concentration mg/m ³	Stack LOD mg/m ³	Laboratory Result ug	Concentration mg/m ³
Arsenic	0.00026	0.40000	0.00026	-	-	-
Total Heavy Metals	0.00026	0.40000	0.00026	-	-	-
Volume Sampled m ³		1.5384				-

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/m ³	Laboratory Result ug	Concentration mg/m ³	Stack LOD mg/m ³	Laboratory Result ug	Concentration mg/m ³
Arsenic	0.00026	0.40000	0.00026	-	-	-
Total Other Heavy Metals	0.00026	0.40000	0.00026	-	-	-
Volume Sampled m ³	1.5384			-		

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1			Heavy Metals		
Absolute pressure of stack gas, P_s			Molecular weight of dry gas, M_d		
Barometric pressure, P _b	mm Hg	753.0	CO ₂	%	0.03
Stack static pressure, P _{static}	mm H ₂ O	3.1	O ₂	%	20.95
P _s = $\frac{P_b + (P_{static})}{13.6}$	mm Hg	753.2	Total	%	20.98
			N ₂ (100 -Total)	%	79.02
			M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)		28.84
Vol. of water vapour collected, V_{wstd}			Molecular weight of wet gas, M_s		
Moisture trap weight increase, V _{lc}	g	-	M _s = M _d (1 - B _{wo}) + 18(B _{wo})	g/gmol	28.83
V _{wstd} = (0.001246)(V _{lc})	m ³	-	Velocity of stack gas, V_s		
Volume of gas metered dry, V_{mstd}			Pitot tube velocity constant, K _p		34.97
Volume of gas sample through gas meter, V _m		1.644	Velocity pressure coefficient, C _p		0.84
Gas meter correction factor, Y _d		1.00701	Mean of velocity heads, DP _{avg}	mm H ₂ O	2.83
Mean dry gas meter temperature, T _m		20.25	Mean square root of velocity heads, ÖDP		1.68
Mean pressure drop across orifice, DH	mm	65.43	Mean stack gas temperature, T _s	°C	27
V _{mstd} = $\frac{(0.3592)(V_m)(P_b + (DH/13.6))(Y_d)}{T_m + 273}$		1.54	V _s = $\frac{(K_p)(C_p)(\text{ÖDP})(\text{Ö}(T_s + 273))}{(M_s)(P_s)}$	m/s	5.81
Volume of gas metered wet, V_{mstw}			Actual flow of stack gas, Q_a		
V _{mstw} = V _{mstd} + V _{wstd}	m ³	1.5384	Area of stack, A _s	m ²	0.05
Vol. of gas metered at O₂ Ref. Cond., V_{mstd@X%O2}			Q _a = (60)(A _s)(V _s)	m ³ /min	17.1
Is the process burning hazardous waste? (If yes, no favourable oxygen correction)	No		Total flow of stack gas, Q		
% oxygen measured in gas stream, act%O ₂	21.0		Conversion factor (K/mm.Hg)		0.3592
% oxygen reference condition	21		Q _{std} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) + 273}$	Dry	15.4
O ₂ Reference	O ₂ Ref = 21.0 - act%O ₂	No O ₂ Ref	Q _{stdO2} = $\frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2\text{REF})}{(T_s) + 273}$	@O2ref	No O ₂ Ref
Factor	21.0 - ref%O ₂	No O ₂ Ref	Q _{stw} = $\frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet	15.5
V _{mstd@X%oxygen} = (V _{mstd}) (O ₂ Ref)	m ³	No O ₂ Ref	Percent isokinetic, %I		
Moisture content, B_{wo}			Nozzle diameter, D _n	mm	9.75
B _{wo} = $\frac{V_{wstd}}{V_{mstd} + V_{wstd}}$	%	0.0011	Nozzle area, A _n	mm ²	74.67
		0.11	Total sampling time, q	min	60
Moisture by FTIR			%I = $\frac{(4.6398E6)(T_s + 273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	109.1
	%	-	Acceptable isokinetic range 95% to 115%		
			Yes		

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS QA CHECKLIST

Leak Test Results	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable litre/min
Run 1	27.6	0.00	0.04	-355.6	0.55	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	109.1	Yes

Filtration / Temp	Filter Material	Filter Size mm	Maximum Filtration Temperature °C	Maximum storage / transit Temperature °C
Run 1	QF	47	160	16

GF = Glass Fibre

QF = Quartz Fibre

Metals	Type of Absorbers - Metals	Absorption Solutions - Metals
Run 1	Glass	Quartz Filter

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

WHITE SPIRIT SUMMARY					
Test	Sampling Times	Concentration mg/m ³	LOD mg/m ³	Limit mg/m ³	Emission Rate g/hr
Run 1	11:45 - 12:15 16 November 2015	28	0.13	-	27
Field Blank	-	0.13	-	-	-

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

WHITE SPIRIT 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	0.05	0.0001	0.0001	0.00	Yes

	Type of tube	Max. Tube Temperature °C	Max. Storage / Transit Temp. °C
Run 1	Tenax ATD	18	16

Tube sampling temperature should be < 40°C

WHITE SPIRIT ADSORPTION EFFICIENCY

Parameter	Total ug	Back ug	Adsorption Efficiency %	Acceptable Adsorption Efficiency %	Adsorption Efficiency Acceptable ?
Run 1	42	1	98	95	N/A - No ELV

N/A - As White Spirit does not have an emission limit an absorption efficiency is not required.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Isokinetic							
Test Number	Sampling Time and Date	Start Weight	End Weight	Total gain	Concentration	LOD	Uncertainty
		kg	kg	kg	%	%	%
Run 1	11:45 - 12:45 16 November 2015	3.7832	3.7845	0.0013	0.11	0.008	18.0

Moisture Quality Assurance							
Test Number	Sampling Duration	Total Volume Sampled	Sampling Rate	Start Leak Rate	End Leak Rate	Acceptable Leak Rate	Leak Tests Acceptable?
	mins	l	l/min	l/min	l/min	l/min	
Run 1	60	1538	27.6	0.00	0.04	0.55	Yes

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	26	°C
Stack static pressure	0.03	kPa
Barometric Pressure	100.4	kPa

Stack Gas Composition & Molecular Weights								
Component	Molar Mass	Density	Conc	Dry Volume	Dry Conc	Conc	Wet Volume	Wet Conc
	M	kg/m ³	Dry	Fraction	kg/m ³	Wet	Fraction	kg/m ³
		p	% Vol	r	pi	% Vol	r	pi
CO ₂	44	1.963059	0.030000	0.000300	0.000589	0.029968	0.000300	0.000588
O ₂	32	1.427679	20.950000	0.209500	0.299099	20.927941	0.209279	0.298784
N ₂	28	1.249219	79.020000	0.790200	0.987133	78.936796	0.789368	0.986094
H ₂ O	18	0.803070	-	-	-	0.105294	0.001053	0.000846

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

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2868	kg/m ³
Wet Density (STP), P_{STW}	1.2863	kg/m ³
Dry Density (Actual), P_{Actual}	1.1648	kg/m ³
Average Wet Density (Actual), $P_{ActualW}$	1.164	kg/m ³

Where:

P_{STD} = sum of component concentrations, kg/m³ (not including water vapour)

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

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

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	16 November 2015
Time of Survey	11:30
Velocity Measurement Device:	L-Type Pitot

Sampling Line A								
Traverse Point	Distance into duct (m)	DP pt mmH ₂ O (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	2.7	27	26	6.10	0.30	-	<15
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	2.7	27	26	6.10	0.30	-	

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt mmH ₂ O (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 mmH ₂ O	End Value mmH ₂ O	Difference %	Outcome	Start Value mmH ₂ O	End Value mmH ₂ O	Difference %	Outcome
Run 1	124	124	0.0	Pass	136	132	2.9	Pass

To complete a compliant pitot leak check a pressure of over 80 mmH₂O (or 800 Pa) is applied and the pressure drop monitored over 5 mins. A drop of ≤ 5% must be observed.

L-Type Pitot Blockage Test				
Run	Final Reading (Pa)	Reading After Purge (Pa)	Difference (%)	Outcome (Permitted +/- 5%)
Run 1	30	30	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	27	Pa	$\geq 5 \text{ Pa}$	Yes
Lowest Gas Velocity	6.10	m/s	-	-
Highest Gas Velocity	6.10	m/s	-	-
Ratio of Gas Velocities	1.00	-	$< 3 : 1$	Yes
Maximum angle of flow with regard to duct axis	0	°	$< 15^\circ$	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, $V = K_{pt} \times (1-e) \times \sqrt{2 \times DP_{pt} / \rho_{ActualW}}$		
Where: K_{pt} = Pitot tube calibration coefficient $(1-e)$ = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, V_a	6.10	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	26	0	°C
Total Pressure	100.43	101.3	kPa
Oxygen	21.0	21	%
Moisture	0.11	0.11	%
Pitot tube calibration coefficient, K_{pt}	0.90		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (V_a)	6.10	m/s
Stack Area (A)	0.05	m ²
Gas Volumetric Flowrate (Actual), Q_{Actual}	1079	m ³ /hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	977	m ³ /hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	976	m ³ /hr
Gas Volumetric Flowrate (REF), Q_{Ref}	977	m ³ /hr

Where:

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

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

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

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

Nomenclature:

T_s = Absolute Temperature, Standard Conditions, 273 K

P_s = Absolute Pressure, Standard Conditions, 101.3 kPa

T_a = Absolute Temperature, Actual Conditions, K

P_a = Absolute Pressure, Actual Conditions, kPa

Ma = Water vapour, Actual Conditions, % Vol

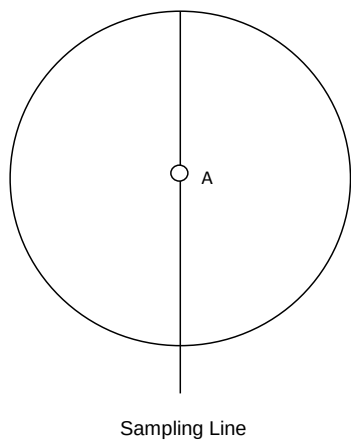
Ms = Water vapour, Reference Conditions, % Vol

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

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

STACK DIAGRAM

	Value	Units
Stack Depth	0.25	m
Stack Width	-	m
Area	0.05	m ²



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

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	30	0.08	m

[illegible]

SAMPLING LOCATION



APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - TOTAL PARTICULATE MATTER

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %	Uncollected Mass mg
MU required	≤ 2%	≤ 2%	≤ 1%	≤ 1%	≤ 10%	≤ 5% of ELV	≤ 2%	≤ 10% of ELV
Run 1	0.001	2	0.5	1	N/A	0.22	-	-
as a %	0.07	0.68	0.50	1.00	N/A	14.30	0.14	0.022
compliant?	Yes	Yes	Yes	Yes	N/A	No	Yes	Yes

Run	Volume (STP) m ³	Mass of particulate mg	O ₂ Correction -	Leak mg/m ³	Uncollected Mass mg	Combined uncertainty
Run 1	1.42	0.2200	1.00	0.000	0.0001	-
MU as mg/m ³	0.00	0.1430	-	0.000	0.0001	0.14
MU as %	1.31	100.0000	-	0.084	0.0577	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.29	mg/m³	200.02	%
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(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 m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in imminner mg	Leak %
MU required	<=2%	<2.5 k	<=1%	<=1%	<=5%	<5%	<=2%
Run 1	0.001	2.00	0.50	1.00	0.10	-	-
as a %	0.07	0.73	0.50	1.00	-	-	0.14
compliant?	Yes	Yes	Yes	Yes	N/A	No	Yes

Run	Volume (STP) m ³	O2 Correction -	Leak mg/m ³	Lab Uncertainty mg	Combined uncertainty
Run 1	1.5292	-	0.0000002	-	-
MU as mg/m ³	0.000003	-	0.0000002	0.00001	0.00001
MU as %	1.3370	-	0.0837	5.00000	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.00	mg/m³	10.35	%
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(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 - WHITE SPIRIT

Run	Sampled Volume m ³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Limit of Detection % by mass	Leak %	Uncollected Mass mg
MU required	≤ 2%	≤ 2%	≤ 1%	≤ 1%	≤ 10%	≤ 5% of ELV	≤ 2%	≤ 10% of ELV
Run 1	0.000001	2	0.5	1	N/A	0.0002	-	-
as a %	0.0667	0.6873	0.4979	1.0000	N/A	N/A	0.2000	N/A
compliant?	Yes	Yes	Yes	Yes	N/A	N/A	Yes	N/A

Run	Volume (STP) m ³	Mass of White Spirit mg	O ₂ Correction -	Leak mg/m ³	Uncollected Mass mg	Lab Uncertainty mg	Combined uncertainty
Run 1	0.001	0.042	1.000	0.032	0.000	-	-
MU as mg/m ³	0.000	0.133	-	0.032	0.077	3.504	3.507
MU as %	0.000	0.476	-	0.115	0.275	12.500	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	7.014	mg/m³	25.03	%
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE

Run	Sampled Volume m ³	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	0.5	1	N/A	-
as a %	0.07	0.68	0.50	1.00	N/A	0.14
compliant?	Yes	Yes	Yes	Yes	N/A	Yes
Run	Volume (STP) m ³	Mass Gained mg	O ₂ Correction -	Leak mg/m ³	Uncollected Mass mg	Combined uncertainty
Run 1	1.42	1300.00	1.00	0.71	57.74	-
MU as % v/v	0.00	0.01	-	0.00	0.005	0.01
MU as %	1.31	7.69	-	0.08	4.44	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	0.02	% v/v	17.96	%
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APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	6.1	m/s
Measured Volumetric Flow rate at Actual Conditions	1079	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 measurement device	pa	1000		
Resolution	pa	1.00		
Calibration uncertainty	pa	2.35	<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	1.53	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	512		
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	0.08
Expanded uncertainty at a 95% Confidence Interval	0.15

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	1.27
Expanded uncertainty at a 95% Confidence Interval	2.49

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	28.42
Expanded uncertainty at a 95% Confidence Interval	55.71

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	2.63
Expanded uncertainty at a 95% Confidence Interval	5.16

END OF REPORT