RICARDO-AEA

Assessment of particulate emissions from energy-from-waste plant

National Atmospheric Emissions Inventory

Report for Defra

AQ0726

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Table of contents

1 Introduction ... 1

2 Installation information ... 1

3 Assessment ... 2

3.1 Sampling methodology ... 2

3.2 Deviations ... 3

3.3 Results ... 4

3.4 Particulate emission factors ... 7

4 Comparison with NAEI Emission Factors ... 9

5 Published PM size fractionation data ... 12

5.1 Emission factors ... 12

5.2 Particle size fractionation measurements ... 12

6 Recommendation ... 13

7 Acknowledgment ... 14

8 References ... 14

Appendices

Appendix 1: Stack emissions monitoring report: Riverside Resource Recovery Ltd

Appendix 2: Stack emissions monitoring report: Newlincs Development Ltd

Appendix 3: Stack emissions monitoring report: Lakeside Energy From Waste Ltd

Appendix 4: Stack emissions monitoring report: Veolia ES South Downs Ltd

Appendix 5: Stack emissions monitoring report: MES Environmental Ltd

1 Introduction

Emissions of particulates from energy from waste (EfW) plant, specifically mass burn incinerators, have attracted growing attention in recent years. Ricardo-AEA completed a measurement programme to provide a study of particulate emissions, including Particulate Matter < 10µm (PM_{10}), Particulate Matter < 2.5µm ($PM_{2.5}$) and total particulates (total PM). The measurement programme was completed by accredited emission monitoring contractors (ESG), who used European Standard emission measurement techniques at selected United Kingdom EfW plant.

The work was undertaken to support the UK National Atmospheric Emissions Inventory (NAEI).

2 Installation information

Sampling of particulate emissions was undertaken at a selection of municipal solid waste EfW plant operating across the United Kingdom. Table 1 and Table 2 provide details of the selected plant.

Table 1: Plant details

Site name	Operator	Site address
“Riverside”	Riverside Resource Recovery Ltd	Norman Road Belvedere Bexley Kent DA17 6JY
“Newlincs”	Newlincs Development Ltd	South Marsh Road Stallingborough Grimsby North East Lincolnshire DN41 BZ
“Lakeside”	Lakeside Energy From Waste Ltd	Lakeside Road Colnbrook Slough Berkshire SL3 0FE
“Newhaven”	Veolia ES South Downs Ltd	Energy Recovery Facility North Quay Road Newhaven East Sussex BN9 0HE
“Stoke-on-Trent”	MES Environmental Ltd	Stoke-on-Trent Energy from Waste Plant Campbell Road Sideway Stoke On Trent ST4 4DX

Table 2: EfW plant specifications

Parameter	Riverside	Newlincs	Lakeside	Newhaven	Stoke-on-Trent
Description of process	Incineration of waste				
Continuous or batch	Continuous				
Normal load, throughput or continuous rating	Approx. 30 tonnes per hour	7.2 - 8 tonnes per hour	88 tonnes per hour	Approx. 28 tonnes per hour	11 - 12.5 tonnes per hour
Fuel used during monitoring	Waste	Waste	Waste	Waste	Waste
Pollution abatement	Bag filtration Cyclone Lime injection Carbon injection Scrubber	Bag filtration Lime injection Powdered activated carbon Urea injection	Bag filtration Lime injection Powdered activated carbon Ammonia injection	Bag filtration Lime injection Powdered activated carbon Ammonia injection	Bag filtration Lime injection Powdered activated carbon Urea injection Semi-dry scrubbing
Number of streams	3	1	2	2	2

Note: the EfW plant incorporate auxiliary burners to support combustion and measurement periods may have included short periods where the auxiliary burners were in use.

3 Assessment

3.1 Sampling methodology

A consistent sampling methodology was applied at each EfW plant, comprising the following approach:

- Samples of PM_{10} and $PM_{2.5}$ at all sites were collected using a cascade impactor and sampling protocol meeting the requirements of the EN test Standard (BS EN ISO 23210, 2009). The cascade impactor employs the principle of inertial separation to classify particulates into multiple size ranges.
- Particles are driven toward a collecting surface, consisting of a conditioned and pre-weighed substrate. The size of the particles collected is controlled by the velocity of the sampled flue gas within the impactor.
- The collecting substrates are reconditioned and reweighed following sampling, to determine the mass collected.
- To determine the most representative sampling point in the sampling plane, a homogeneity assessment was undertaken, based on BS EN ISO 23210.

- The velocity measurement at the chosen point was used to determine an appropriate sampling nozzle to provide near isokinetic sample flow rate. The volume of duct gas sampled is measured, allowing the particulate concentration at each cut size to be determined.
- Multiple tests (between four and six) were carried out at a selected unit on each installation.
- Extended sampling periods were used to address, as far as possible, uncertainty in the mass of particulate material collected because the anticipated PM concentrations were low (<1 mg/m^3).
- The average velocity of the flue gases was determined at each plant prior to and after the PM_{10}/$PM_{2.5}$ measurements to allow determination of the flue gas flow rate.
- Total PM emission concentrations were determined at two plant.
- Flow measurement and measurement of total PM emission concentrations were determined using an EN Standard (BS EN 13284-1, 2002).

3.2 Monitoring deviations

Monitoring deviations from the Standard were necessary at all plant in order to provide the most effective assessment of particulate concentrations whilst allowing for plant-specific variations. The monitoring deviations are detailed in Table 3 below and described in further detail in the test reports which are provided in the Appendices.

Table 3: Deviations from standard sampling practices used in the assessment of PM emissions from the 5 EfW plants

Methodological deviation	Riverside	Newlincs	Lakeside	Newhaven	Stoke-on-Trent
Goose-neck nozzle Goose-neck nozzles were used as unable to use vertical entry nozzle as recommended under BS EN 23210.	✓	✓	✓	✓	✓
Sample flow variation The sample flow rate could not be maintained within 5% of the nominal flow throughout testing. As the results are at or very near the LOD this is anticipated to have limited impact on the outcome of the measurements.	✓	✓	✓	✓	✓
Pitot static pressure measurements Readings taken every 10 minutes during six hour runs instead of the recommended 5 minutes. This was a practical constraint arising from the extended sampling periods.			✓	✓	
Total PM nozzle size 5mm nozzle used as it was not possible to achieve isokinetic flow with the minimum (6mm) nozzle specified in EN13284-1. Volume of gas sampled during 6-hour sample run deemed to be acceptable.				✓	
Single point Total PM sampling To provide direct comparison with the particle size measurements.				✓	

Flow traverse Monitoring completed at a reduced number of velocity traverse points, due to CEM probes causing obstructions on the same sample plane.					✓

3.3 Results

Table 4 and Table 5 provides the results of each PM_{10} and $PM_{2.5}$ sampling run at all EfW plants, including the measured concentration and uncertainty. Where results were found to be at or below the limit of detection reported by the testhouse the figures have been highlighted in *italics*.

All concentrations and flowrates are normalised to a dry gas condition at STP (0°C, 101.3 kPa) and at 11% oxygen.

Table 4: Emission sampling results for PM_{10}

Run	Parameter	Units	Riverside	Newlincs	Lakeside	Newhaven	Stoke-on-Trent
PM_{10}							
Run 1	Concentration	mg/m^3	0.281	*0.019*	0.008	0.07	*0.014*
	Uncertainty		0.26	0.04	0.01	0.09	0.01
Run 2	Concentration	mg/m^3	0.016	0.022	0.042	*0.009*	0.012
	Uncertainty		0.01	0.04	0.03	0.01	0.01
Run 3	Concentration	mg/m^3	0.033	*0.018*	0.027	0.03	*0.059*
	Uncertainty		0.03	0.03	0.02	0.04	0.06
Run 4	Concentration	mg/m^3	*0.015*	0.02	0.034	0.021	0.088
	Uncertainty		0.01	0.04	0.03	0.03	0.1
Run 5	Concentration	mg/m^3	0.084	0.021			
	Uncertainty		0.08	0.04			
Run 6	Concentration	mg/m^3	0.081	0.023			
	Uncertainty		0.08	0.04			
Min	Concentration	mg/m^3	0.015	0.018	0.008	0.009	0.012
Max	Concentration	mg/m^3	0.281	0.023	0.042	0.07	0.088
Average	Concentration	mg/m^3	0.085	0.021	0.028	0.033	0.043

Table 5: Emission sampling results for $PM_{2.5}$

Run	Parameter	Units	Riverside	Newlincs	Lakeside	Newhaven	Stoke-on-Trent
$PM_{2.5}$							
Run 1	Concentration	mg/m^3	*0.008*	*0.009*	0.005	0.056	*0.005*
	Uncertainty		0.01	0.02	0.01	0.09	0.01
Run 2	Concentration	mg/m^3	*0.008*	0.013	0.006	*0.004*	0.005
	Uncertainty		0.01	0.02	0.01	0.01	0.01
Run 3	Concentration	mg/m^3	*0.007*	*0.009*	*0.003*	*0.008*	*0.01*
	Uncertainty		0.01	0.02	0.01	0.01	0.02
Run 4	Concentration	mg/m^3	*0.008*	0.01	0.006	0.009	0.048
	Uncertainty		0.01	0.02	0.01	0.01	0.08
Run 5	Concentration	mg/m^3	*0.008*	0.011			
	Uncertainty		0.01	0.02			
Run 6	Concentration	mg/m^3	0.029	0.01			
	Uncertainty		0.05	0.02			
Min	Concentration	mg/m^3	0.007	0.009	0.003	0.004	0.005
Max	Concentration	mg/m^3	0.029	0.013	0.006	0.056	0.048
Average	Concentration	mg/m^3	0.011	0.010	0.005	0.019	0.017

Table 6 provides the average emission concentration of all stack emission parameters for each plant. Individual test details are contained within the measurement reports (see Appendices). The minimum, maximum and average emission concentration values derived from the average concentrations from all 5 plant are provided in Table 7.

Table 6: Average emission sampling results summary

Parameter	Units	Riverside	Newlincs	Lakeside	Newhaven	Stoke-on-Trent
Total PM (average result of all runs)	mg/m^3	*Not measured*	*Not measured*	*Not measured*	0.7	0.47
Uncertainty	mg/m^3	-	-	-	0.26	0.07
PM_{10} (average result of all runs)	mg/m^3	0.085	0.021	0.028	0.033	0.043
Uncertainty	mg/m^3	0.08	0.04	0.02	0.04	0.05
$PM_{2.5}$ (average result of all runs)	mg/m^3	0.011	0.010	0.005	0.019	0.017
Uncertainty	mg/m^3	0.02	0.02	0.01	0.03	0.03
PM_{10} (% of total PM)	%	-	-	-	4.6	9.1
$PM_{2.5}$ (% of total PM)	%	-	-	-	2.7	3.6
$PM_{2.5}$ (% of PM_{10})	%	-	-	-	59	40
Oxygen	% v/v	7	12	5	7	12
Moisture	%	18.6	13.3	12.9	17	16
Stack gas temperature	°C	127	144	146	151	151
Stack gas velocity (actual)	m/s	14.3	22.4	17	18	20.6
Gas volumetric flow rate at reference conditions	m^3/hour	154,608	39,134	152,825	77,669	69,915

Table 7: Summary of particulate concentrations measured at all EfW plant

Pollutant (sites measured)	Range of average emission concentrations, all EfW plant (mg/m^3)		
	Min	**Max**	**Average**
Total PM (2)	0.47	0.70	0.59
PM_{10} (5)	0.021	0.085	0.042
$PM_{2.5}$ (5)	0.005	0.019	0.012

3.4 Particulate emission factors

3.4.1 Flue gas volume factors

Published flue gas volume factors for EfW plant, applicable to those sampled in this study, have been sourced in order to develop emission factors from the average measured particulate concentrations. The flue gas volume factors (Table 8) are summarised in cubic metres per gigajoule (GJ) of net energy consumed and cubic metres per tonne of waste burnt. Unless noted otherwise, an average net calorific value for waste of 10.4 MJ.kg (European IPPC Bureau 2006) has been applied.

Table 8: Reference flue gas volume factors

Source	Volume factor (energy input basis) (m^3/GJ net, dry vol. at 11% O_2 and STP*)	Volume factor (mass basis) (m^3/tonne, dry volume at 11% O_2 and STP)	Reported flue gas volume	Reported units
JRC report on NOx and dioxin emissions (Tzimas E and Peteves SD)	598	6,222	2.96	m^3/kg, dry volume at 0% O_2, STP
WI BREF (European IPPC Bureau, 2006)	500	5,200	5200	m^3/tonne, dry volume, 11% O_2, STP
World Bank MSW incineration guide (Rand T et al, World Bank, 2000)	525	5,460	0.25	m^3/MJ, dry volume at 0% O_2, STP
USEPA Method 19 (USEPA)	728	7,567	2.57×10^{-07}	m^3/J, dry volume at 0% O_2, NTP and gross energy input
Denmark CHP report (Nielsen, M et al , 2010)	523	5,438	249	m^3/GJ, dry volume, 0% O_2, STP
Denmark CHP report	529	5,500	5500	m^3/tonne, dry volume, 11% O_2, STP
UK waste model (Ricardo-AEA)	426	3,960	3.96	m^3/kg, dry volume, 11% O_2, STP (9.3 GJ/tonne)
KEMA/VGB Table 6.1 (Graham, D et al VGB Powertech, 2012)	592	7,161	0.282	m^3/MJ (net), dry volume at 0% O_2, STP (12.1 GJ/Tonne)
KEMA/VGB Table 6.6	580	-	0.276	m^3/MJ (net), dry volume at 0% O_2, STP
Min	426	3,960		
Max	728	7,567		
Median	529	5,480		
Average	556	5,814		

*Standard temperature and pressure (0°C, 101.3 kPa).

3.4.2 Calculated particulate emission factors

The average measured PM_{10} and $PM_{2.5}$ concentrations (

Table 7) have been applied to the range of flue gas volume factors (Table 8) to provide a range of emission factors for total particulates, PM_{10} and $PM_{2.5}$ (Table 9).

Table 9: Calculated emission factors for PM emissions from EfW plant for different flue gas volume factors

Pollutant	Units	Minimum	Max	Median
Total PM	**g/GJ**	0.249	0.426	0.309
PM_{10}		0.018	0.030	0.022
$PM_{2.5}$		0.005	0.009	0.007
Total PM	**g/tonne**	2.32	4.43	3.21
PM_{10}		0.17	0.32	0.23
$PM_{2.5}$		0.05	0.09	0.07

4 Comparison with NAEI Emission Factors

The emission factors (EFs) produced by this study were compared with the emission factors used in recent years to estimate particulate emissions in the NAEI (Table 10). The NAEI calculates both PM_{10} and $PM_{2.5}$ using the same factor, which is applied each year to the site-specific particulate emissions data. Emissions are calculated on the basis of kilotonnes of particulate per megatonne of waste consumed. This has been compared with the "Max" EF for grams per tonne of waste from this emissions monitoring study, shown in Table 9 (highlighted in yellow), that is – the average emission concentration from the study combined with the maximum gas volume factor. The maximum combined emission factor (from the maximum of the average emission concentrations from each plant and the maximum flue gas volume) is shown in parentheses in Table 10.

Table 10: Comparison of NAEI particulate EFs and "Max" EFs from emissions monitoring study

Year	NAEI EF - NFR 1 Public power from municipal waste incineration		EF from this study		Percentage change from NAEI EF	
	PM_{10} kt/Mt fuel consumed	$PM_{2.5}$ kt/Mt fuel consumed	PM_{10} kt/Mt fuel consumed	$PM_{2.5}$ kt/Mt fuel consumed	PM_{10}	$PM_{2.5}$
2004	0.012	0.012	0.00032 (0.00064)	0.00009 (0.00014)	-97%	-99%
2005	0.013	0.013			-97%	-99%
2006	0.009	0.009			-97%	-99%
2007	0.008	0.008			-96%	-99%
2008	0.008	0.008			-96%	-99%
2009	0.007	0.007			-96%	-99%
2010	0.008	0.008			-96%	-99%
2011	0.009	0.009			-97%	-99%
2012	0.008	0.008			-96%	-99%
2013	0.008	0.009			-96%	-99%

The EFs provided by the monitoring assessment represent a significant reduction from the EFs currently used in the NAEI. Between 2004 and 2013 these EFs would represent a decrease in emission from the EfW sector of between 96-97 % of PM_{10} and 99% of $PM_{2.5}$.

Particulate emissions are reported under "NFR code 1: Energy" in the NAEI. Table 11 and

Table 12 provide the total emissions of PM_{10} and $PM_{2.5}$ from all sources and “NFR code 1” sources. Contributions from the incineration of municipal solid waste (MSW) are given as a percentage of the total PM emissions listed under NFR 1, using both the current and proposed EFs.

Table 11 and

Table 12 indicate that although the change in EF for particulate emissions from the incineration of MSW in EfW can be considered significant; the impact on total UK PM emissions is minor.

Table 11: Comparison of PM_{10} emissions using the current and new EFs with emissions from all sources and NFR code 1 sources

Year	Total UK PM_{10} emissions	NFR 1 PM_{10} emissions	PM_{10} emissions from MSW incineration with current EF	PM_{10} emissions from MSW incineration with new EF	PM_{10} emissions from MSW incineration as a % of total NFR 1 PM_{10} emissions with current EF	PM_{10} emissions from MSW incineration as a % of total NFR 1 PM_{10} emissions with new EF
	kilotonnes					
2004	151	90	0.038	0.001	0.04%	0.001%
2005	147	89	0.040	0.001	0.05%	0.001%
2006	147	88	0.033	0.001	0.04%	0.001%
2007	143	85	0.030	0.001	0.04%	0.001%
2008	138	82	0.029	0.001	0.04%	0.001%
2009	127	77	0.033	0.001	0.04%	0.002%
2010	129	81	0.038	0.002	0.05%	0.002%
2011	123	75	0.046	0.002	0.06%	0.002%
2012	125	77	0.046	0.002	0.06%	0.002%
2013	123	76	0.047	0.002	0.06%	0.002%

Table 12: Comparison of $PM_{2.5}$ emissions using the current and new EFs with emissions from all sources and NFR code 1 sources

Year	Total UK $PM_{2.5}$ emissions	NFR 1 $PM_{2.5}$ emissions	$PM_{2.5}$ emissions from MSW incineration with current EF	$PM_{2.5}$ emissions from MSW incineration with new EF	$PM_{2.5}$ emissions from MSW incineration as a % of total NFR 1 $PM_{2.5}$ emissions with current EF	$PM_{2.5}$ emissions from MSW incineration as a % of total NFR 1 $PM_{2.5}$ emissions with new EF
	kilotonnes					
2004	98	76	0.038	0.0003	0.05%	0.0004%
2005	96	74	0.040	0.0003	0.05%	0.0004%
2006	95	74	0.033	0.0003	0.05%	0.0004%
2007	93	71	0.030	0.0003	0.04%	0.0005%
2008	90	70	0.029	0.0003	0.04%	0.0005%
2009	84	66	0.033	0.0004	0.05%	0.0006%
2010	87	70	0.038	0.0004	0.05%	0.0006%
2011	81	64	0.046	0.0004	0.07%	0.0007%
2012	82	65	0.046	0.0005	0.07%	0.0008%
2013	82	64	0.047	0.0005	0.07%	0.0008%

5 Published PM size fractionation data

5.1 Emission factors

Default emission factors and size fractionation data for municipal solid waste incineration for development of national emission inventories are published by the US Environmental Protection Agency (USEPA (AP42)) and European Environment Agency (EEA, 2013). Table 13 shows a summary of the size fractionation data from these sources and the results from this measurement programme.

Table 13 : Comparison of size fractionation with USEPA and EEA data

Pollutant	Range of average measured emission concentrations, all EfW plants				USEPA	EEA
	Min	Max	Average	Average	Note 1	Note 2
	mg/m³	mg/m³	mg/m³	%	%	%
Total PM	0.47	0.70	0.59	-	-	-
PM_{10}	0.021	0.085	0.042	7.1	79.0	74.9
$PM_{2.5}$	0.005	0.019	0.012	2.0	44.9	49.8

Notes :

1. USEPA size fractionation from USEPA Generalised particle size distributions for mixed fuel combustion (without abatement control) combined with fabric filter abatement technology control efficiencies.
2. EEA size fractionation from EEA Tier 2 factors for uncontrolled (no abatement) MSW incineration combined with control efficiencies for particle and gas abatement.

5.2 Particle size fractionation measurements

An emission survey of industrial activities in Germany, including combustion technologies and industrial processes, found that in more than 70% of the individual emission measurement results from industrial plants and domestic stoves the PM_{10} portion amounted to more than 90% and the $PM_{2.5}$ portion between 50% and 90% of the total particulate emission (Ehrlich, 2007). The measurement programme did not include measurements at EfW facilities but did cover a wide range of combustion plant from domestic wood stoves to large coal-fired power stations.

A study of facilities in Finland and Sweden (VTT, 2007) included measurements of total particulate and $PM_{2.5}$ at four EfW plant (one a pilot plant burning refuse derived fuel). Table 14 compares the results from this measurement programme with a summary of the results of the study from Finland and Sweden.

Table 14 : Comparison with $PM_{2.5}$ emission study from Finland and Sweden

Pollutant (sites measured)	Range of average measured emission concentrations, all EfW plants, mg/m³			Range of average measured emission concentrations, all EfW plants VTT study, mg/m³			
	Min	Max	Average	1	2	3	4
Total particulates	0.47	0.70	0.59	0.13	0.6	0.3	0.1
PM_{10}	0.021	0.085	0.042	-	-	-	-
$PM_{2.5}$	0.005	0.019	0.012 (2.0%)	<0.1 (<77%)	0.04, 0.08 (7, 13%)	0.04 (13%)	0.02-0.05 (20-50%)

6 Recommendation

The measurements indicate low PM_{10} and $PM_{2.5}$ emissions from a range of UK EfW plant. Several individual measurements were at or near the limits of detection of the measurement method. This is not unexpected as the total PM emission concentrations were expected to be low – periodic and continuous emission measurements undertaken for regulatory compliance indicated total PM emissions generally below 1 mg/m^3 for these facilities which all apply fabric filters for PM abatement.

However, notwithstanding issues in comparing measurement methods and the incomplete coverage of total PM measurements, the implied fraction of PM_{10} and $PM_{2.5}$ in the total PM is lower than indicated in emission inventory guidance and indicates that most PM emitted from EfW is larger than PM_{10} which is counterintuitive. A study of $PM_{2.5}$ emissions from incineration plant in Sweden and Finland found similar concentrations as the average determined at UK plant but the proportion of $PM_{2.5}$ in the PM was higher. A German study of PM fractionation for combustion and industrial processes (but not EfW plant) found higher fractions of $PM_{2.5}$ and PM_{10} than were determined at the UK EfW plant in this study.

This may reflect issues in the PM_{10} and $PM_{2.5}$ measurement technique at such low concentrations and, it is noted that a number of deviations from the Standard were reported including use of 'gooseneck' nozzles where material could have been deposited. During this study, it was not possible to validate the use of goose-neck nozzle as required under the Standard.

The sector is not a key category for PM_{10} and $PM_{2.5}$ emissions in the UK emission inventory and it is considered that a worst case emission factor could be adopted without impacting overall uncertainty of the NAEI. However, it is recommended that any future investigations should include modification of sampling facilities to allow deployment of sampling equipment with the straight nozzle configuration to allow full compliance with the BS EN ISO 23210 Standard. It is recommended that any future measurement programme adopting a gooseneck nozzle should include validation.

7 Acknowledgment

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Appendices

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Appendix 1 – Stack emissions monitoring report: Riverside Resource Recovery Ltd

STACK EMISSIONS MONITORING REPORT

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GL17 0DD
Tel: 01594 546 343

Your contact at ESG
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Business Manager - South
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Operator & Address:
Riverside Resource Recovery Ltd
Norman Road
Belvedere
Bexley
Kent
DA17 6JY
-
-

Permit
N/A - Investigative Monitoring

Release Point:
Stream 3

Sampling Date(s):
27th February to 3rd March 2014

ESG Job Number:	LCH00704
Report Date:	16th Feb 2015
Version:	1
Report By:	Paul Jones
MCERTS Number:	MM 02 044
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2, 3 & 4
Report Approved By:	Andy Tiffen
MCERTS Number:	MM 05 640
Business Title:	MCERTS Level 2 - Projects Manager
Technical Endorsements:	1, 2 & 4
Signature:	A.Tiffen.

UKAS TESTING 1015

mCERTS THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

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
Determination of representative sampling location

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

Riverside Resource Recovery Ltd operates a incineration of waste process at Belvedere

Environmental Scientifics Group Limited were commissioned by Ricardo AEA to carry out stack emissions monitoring to determine the release of PM_{10} & $PM_{2.5}$ from the following Plant under standard operating conditions.

The measurements were commissioned by Ricardo-AEA on behalf of the Department of Environment, Food and Rural Affairs (Defra) to provide information for the UK National Atmospheric Emissions Inventory (NAEI).

Plant

Stream 3

Operator

Riverside Resource Recovery Ltd
Norman Road
Belvedere
Bexley
Kent
DA17 6JY
-

Stack Emissions Monitoring Test House

Environmental Scientifics Group Limited - Mitcheldean Laboratory
Acacia Building
Vantage Point Business Village
Mitcheldean
GL17 0DD
UKAS and MCERTS Accreditation Number: 1015

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.
MCERTS accredited results will only be claimed where both the sampling and analytical stages are UKAS accredited.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Limit**	**MCERTS accredited result**
PM_{10} **(Average result of 6 runs)**	mg/m³	0.085	0.08	-	✓
PM_{10} Emission Rate **(Average result of 6 runs)**	g/hr	13.71	12.9	-	
$PM_{2.5}$ **(Average result of 6 runs)**	mg/m³	0.011	0.02	-	✓
$PM_{2.5}$ Emission Rate **(Average result of 6 runs)**	g/hr	1.81	3.17	-	
PM_{10} - Runs					
PM_{10} - Run 1	mg/m³	0.281	0.26	-	✓
PM_{10} Emission Rate - Run 1	g/hr	45.14	42.4	-	
PM_{10} - Run 2	mg/m³	0.016	0.01	-	✓
PM_{10} Emission Rate - Run 2	g/hr	2.53	2.4	-	
PM_{10} - Run 3	mg/m³	0.033	0.03	-	✓
PM_{10} Emission Rate - Run 3	g/hr	5.27	5.0	-	
PM_{10} - Run 4	mg/m³	***0.015***	0.01	-	✓
PM_{10} Emission Rate - Run 4	g/hr	2.53	2.4	-	
PM_{10} - Run 5	mg/m³	0.084	0.08	-	✓
PM_{10} Emission Rate - Run 5	g/hr	13.73	12.9	-	
PM_{10} - Run 6	mg/m³	0.081	0.08	-	✓
PM_{10} Emission Rate - Run 6	g/hr	13.09	12.3	-	
$PM_{2.5}$ - Runs					
$PM_{2.5}$ - Run 1	mg/m³	***0.008***	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 1	g/hr	45.14	79.0	-	
$PM_{2.5}$ - Run 2	mg/m³	***0.008***	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 2	g/hr	1.26	2.2	-	
$PM_{2.5}$ - Run 3	mg/m³	***0.007***	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 3	g/hr	1.10	1.92	-	
$PM_{2.5}$ - Run 4	mg/m³	***0.008***	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 4	g/hr	1.26	2.21	-	
$PM_{2.5}$ - Run 5	mg/m³	***0.008***	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 5	g/hr	1.27	2.23	-	
$PM_{2.5}$ - Run 6	mg/m³	0.029	0.05	-	✓
$PM_{2.5}$ Emission Rate - Run 6	g/hr	4.74	8.29	-	
Oxygen	% v/v	7	1.40	-	✓
Moisture	%	18.6	1.4	-	✓
Stack Gas Temperature	^oC	127	-	-	✓
Stack Gas Velocity	m/s	14.3	-	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	209054	-	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	140320	-	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	113683	-	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	154608	-	-	

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 test specific flow data. Mass emissions for non isokinetic tests and isokinetic tests are calculated using these values

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
PM_{10} Run 1	27 February 2014	14:59 - 17:59	180 minutes
PM_{10} Run 2	28 February 2014	09:40 - 12:40	180 minutes
PM_{10} Run 3	28 February 2014	13:03 - 16:03	180 minutes
PM_{10} Run 4	03 March 2014	10:23 - 13:23	180 minutes
PM_{10} Run 5	03 March 2014	14:19 - 17:19	180 minutes
PM_{10} Run 6	04 March 2014	09:48 - 12:48	180 minutes
$PM_{2.5}$ Run 1	27 February 2014	14:59 - 17:59	180 minutes
$PM_{2.5}$ Run 2	28 February 2014	09:40 - 12:40	180 minutes
$PM_{2.5}$ Run 3	28 February 2014	13:03 - 16:03	180 minutes
$PM_{2.5}$ Run 4	03 March 2014	10:23 - 13:23	180 minutes
$PM_{2.5}$ Run 5	03 March 2014	14:19 - 17:19	180 minutes
$PM_{2.5}$ Run 6	04 March 2014	09:48 - 12:48	180 minutes
Stack Gas Flow Rate & Temperature Run 1	27 February 2014	12:30	-
Stack Gas Flow Rate & Temperature Run 2	27 February 2014	18:04	-
Stack Gas Flow Rate & Temperature Run 3	28 February 2014	12:45	-
Stack Gas Flow Rate & Temperature Run 4	28 February 2014	16:15	-
Stack Gas Flow Rate & Temperature Run 5	03 March 2014	10:15	-
Stack Gas Flow Rate & Temperature Run 6	03 March 2014	14:00	-
Stack Gas Flow Rate & Temperature Run 7	03 March 2014	17:30	-
Stack Gas Flow Rate & Temperature Run 8	04 March 2014	09:30	-
Stack Gas Flow Rate & Temperature Run 9	04 March 2014	13:00	-

EXECUTIVE SUMMARY

PROCESS DETAILS	
Parameter	**Process Details**
Description of process	Incineration of waste
Continuous or batch	Continuous
Product Details	Energy from waste
Part of batch to be monitored (if applicable)	N/A
Normal load, throughput or continuous rating	approx. 30 tonnes/hr
Fuel used during monitoring	waste/diesel
Abatement	Cyclone, lime and carbon injection, scrubber and bag filter
Plume Appearance	Not visible from monitoring location

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by Environmental Scientifics Group Limited 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 +/- %**
PM_{10}	SRM - BS EN 23210	AE 136	1015	Yes	0.015 mg/m³	94 %
$PM_{2.5}$	SRM - BS EN 23210	AE 136	1015	Yes	0.007 mg/m³	175 %
O_2	SRM - BS EN 14789	AE 102	1015	Yes	0.01%	19.3%
H_2O	AM - M22/FTIR	AE 063	1015	Yes	0.01 %	7.5%
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	5 Pa	-

The measurement uncertainties for the PM_{10} and $PM_{2.5}$ measurements reflect that measured concentrations were near or below the Limit of Detection.

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
PM_{10}	Gravimetric	AE 106	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	1 year
$PM_{2.5}$	Gravimetric	AE 106	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	1 year

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	MCERTS Accredited Analysis	Laboratory	Data Archive Location	Archive Period
O_2	Paramagnetism	AE 102	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	5 years
H_2O	Fourier Transform - Infra Red	AE 063	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	5 years

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	118	Pa	>= 5 Pa	Yes	BS EN 13284-1
Lowest Gas Velocity	13.46	m/s	-	-	-
Highest Gas Velocity	14.99	m/s	-	-	-
Ratio of Gas Velocities	1.11	-	< 3 : 1	Yes	BS EN 13284-1
Mean Velocity	14.25	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^{o}	Yes	BS EN 13284-1
No local negative flow	Yes	-	-	Yes	BS EN 13284-1

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Circular	-
Depth	2.27	m
Width	-	m
Area	4.05	m^2
Port Depth	160	mm

SAMPLING LINES & POINTS			
	Isokinetic (CEN Methods)	**Isokinetic** (ISO Methods)	**Non-Iso & Gases**
Sample port size	4.5" flange	-	4.5" flange
Number of lines used	2	-	1
Number of points / line	10	-	1
Duct orientation	Vertical	-	Vertical
Filtration	In Stack	-	In Stack

SAMPLING PLATFORM	
General Platform Information	
Permanent / Temporary Platform / Ground level / Floor Level / Roof	Permanent (windshield)
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	Yes
Depth of Platform = >Stack depth / diameter + wall and port thickness + 1.5m	Yes

Sampling Platform Improvement Recommendations (if applicable)

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

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Goose-neck nozzle Validation

Due to the long port sleeve, it was physically impossible to inserted the cascade impactor using the straight entry nozzle setup recommended in BS EN 23210. Therefore the use of a goose-neck setup was used as this was the only feasible method for monitoring. The standard requires that the use of a goose-neck nozzle is validated, however on this occasion it has not been possible to demonstrate that losses in the nozzle meet the criteria in the standard because the measured concentrations were low and the weight of particulate recovered from the nozzle rinses and the filter media were at or near the weighing LoD. In the context of the low emission concentrations detemined during the measurements (all less than 0.1 mg/Nm3), losses in the sampling nozzle are unlikely to increase the concentrations significantly.

Sample flow variation

The sample flowrate could not be maintained within 5% of the nominal flow throughout the testing periods (which were over extended periods due to the anticipated low PM emission concentrations). Whilst this will have affected the actual cutpoints achieved by the impactor, the results are all at or very near the LOD for the tests and hence this is anticipated to have limited impact on the outcome of the measurements.

Determination of representative sampling location

An assessment of temperature homogeneity was performed in accordance with EN 23210 Annex-G on the first day of monitoring.

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
PM_{10}	SRM - BS EN 23210	AE 136	1015	Yes	6
$PM_{2.5}$	SRM - BS EN 23210	AE 136	1015	Yes	6
O_2	SRM - BS EN 14789	AE 102	1015	Yes	6
H_2O	AM - M22/FTIR	AE 063	1015	Yes	6
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	9

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	P1799	Horiba PG-250 Analyser	-	Laboratory Balance	-
Box Thermocouples	P1799	FT-IR	P2060	Tape Measure	P1935
Meter In Thermocouple	P1799	FT-IR Oven Box	-	Stopwatch	-
Meter Out Thermocouple	P1799	Bernath 3006 FID	-	Protractor	-
Control Box Timer	P1799	Signal 3030 FID	-	Barometer	P2090
Oven Box	-	Servomex	-	Digital Micromanometer	-
Probe	LSO--11-29	JCT Heated Head Filter	-	Digital Temperature Meter	-
Probe Thermocouple	P1945	Thermo FID	-	Stack Thermocouple	P1947
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	P2056	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	-	Chiller (JCT/MAK 10)	-	1m Heated Line (3)	-
Last Impinger Arm	P1967	Heated Line Controller (1)	8414	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	P1930
Callipers	P1805	Impactor 1	NR18706	10m Heated Line (2)	-
Small DGM	-	0	-	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	-
Inclinometer (Swirl Device)	P2094		-	20m Heated Line (2)	-

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

CALIBRATION / CHECK GASES

Gas (traceable to ISO 17025)	Cylinder I.D Number	Supplier	ppm	%	Analytical Tolerance +/- %
Oxygen	DA B2	BOC	-	10.06	2
Methane	DA B2	BOC	87.1	-	2
Carbon Dioxide	DA B2	BOC	-	12	2

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

STACK EMISSIONS MONITORING TEAM

Team Leader	Paul Jones MCERTS Level 2, Technical Endorsements 1, 2, 3 & 4 MM 02 044 MCERTS Expiry Date - Mar 2018 H&S Expiry Date - Sep 2015
Team Leader	Dominic Houghton MCERTS Level 2, Technical Endorsements 1, 2, 3 & 4 MM 04 529 MCERTS Expiry Date - Dec 2016 H&S Expiry Date - Sep 2014
Technician	Rad Poremba MCERTS Level 1 MM 10 1069 MCERTS Expiry Date - Jul 2015 H&S Expiry Date - Jul 2015

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PM_{10} SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	14:59 - 17:59 27 February 2014	0.281	0.015	-	45.14
Run 2	09:40 - 12:40 28 February 2014	0.016	0.015	-	2.53
Run 3	13:03 - 16:03 28 February 2014	0.033	0.014	-	5.27
Run 4	10:23 - 13:23 03 March 2014	0.015	0.022	-	2.53
Run 5	14:19 - 17:19 03 March 2014	0.084	0.018	-	13.73
Run 6	09:48 - 12:48 04 March 2014	0.081	0.015	-	13.09
Blank 1	-	0.015	-	-	-
Blank 2	-	0.015	-	-	-
Blank 3	-	0.015	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.
where values are below the LOD the LOD will be reported.

$PM_{2.5}$ SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	14:59 - 17:59 27 February 2014	0.008	0.008	-	1.24
Run 2	09:40 - 12:40 28 February 2014	0.008	0.008	-	1.26
Run 3	13:03 - 16:03 28 February 2014	0.007	0.007	-	1.10
Run 4	10:23 - 13:23 03 March 2014	0.008	0.011	-	1.26
Run 5	14:19 - 17:19 03 March 2014	0.008	0.009	-	1.27
Run 6	09:48 - 12:48 04 March 2014	0.029	0.008	-	4.74
Blank 1	-	0.007	-	-	-
Blank 2	-	0.007	-	-	-
Blank 3	-	0.007	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.
where values are below the LOD the LOD will be reported, where this occurs the quoted uncertainties will be relatively high.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

$PM_{2.5}$ (BF) SAMPLES WEIGHTS				
Test	$PM_{2.5}$ Filter Number	Filter Start Weight g	Filter End Weight g	$PM_{2.5}$ Mass Gained on Filter g
Run 1	QC964	32.91794	32.91788	-0.00006
Run 2	QC995	32.90496	32.90428	-0.00068
Run 3	QC992	32.96615	32.96598	-0.00017
Run 4	QC985	32.81522	32.81481	-0.00041
Run 5	QC977	31.89809	31.89751	-0.00058
Run 6	QC961	32.45560	32.45581	0.00021
Blank 1	QC966	31.64069	31.64038	-0.00031
Blank 2	QC984	32.06282	32.06271	-0.00011
Blank 3	QC976	32.43702	32.43687	-0.00015

PM_{10} (CP2) SAMPLES WEIGHTS				
Test	PM_{10} Filter Number g	Filter Start Weight g	Filter End Weight g	PM_{10} Mass Gained on Filter g
Run 1	QC958	15.73756	15.73933	0.00177
Run 2	QC989	15.89540	15.89538	-0.00002
Run 3	QC992	15.18101	15.18120	0.00019
Run 4	QC974	15.94752	15.94710	-0.00042
Run 5	QC991	15.15272	15.15321	0.00049
Run 6	QC957	15.36466	15.36503	0.00037
Blank 1	QC968	15.26944	15.26936	-0.00008
Blank 2	QC990	15.56496	15.56491	-0.00005
Blank 3	QC975	14.63281	14.63223	-0.00058

$PM_{2.5}$ & PM_{10} (BF & CP2) SAMPLES WEIGHTS COMBINED							
Test	$PM_{2.5}$ Filter Number	PM_{10} Filter Number	$PM_{2.5}$ Mass Gained on Filter g	PM_{10} Mass Gained on Filter g	Actual $PM_{2.5}$ & PM_{10} Combined Total Mass Gained g	$PM_{2.5}$ & PM_{10} Combined Weighing LOD g	*Reported $PM_{2.5}$ & PM_{10} Combined Total Mass Gained g
Run 1	QC964	QC958	-0.00006	0.00177	0.00171	0.00010	0.00182
Run 2	QC995	QC989	-0.00068	-0.00002	-0.00070	0.00010	0.00010
Run 3	QC992	QC992	-0.00017	0.00019	0.00002	0.00010	0.00024
Run 4	QC985	QC974	-0.00041	-0.00042	-0.00083	0.00010	0.00010
Run 5	QC977	QC991	-0.00058	0.00049	-0.00009	0.00010	0.00054
Run 6	QC961	QC957	0.00021	0.00037	0.00058	0.00010	0.00058
Blank 1	QC966	QC968	-0.00031	-0.00008	-0.00039	0.00010	0.00010
Blank 2	QC984	QC990	-0.00011	-0.00005	-0.00016	0.00010	0.00010
Blank 3	QC976	QC975	-0.00015	-0.00058	-0.00073	0.00010	0.00010

* Where weighing values are below the LOD possibly due to loss of filter material, the LOD will be reported.

NOTE - Where the filter weight gain is less than the weighing uncertainty, the weighing uncertainty is used for further calculations. The weighing uncertainty is 0.00005g.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	744.8
Stack static pressure, P_{static}	mm H_2O	-1.9
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	744.6
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	$H_2$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		5.12
Gas meter correction factor, Y_d		1.06
Mean dry gas meter temperature, T_m		32.71
Mean pressure drop across orifice, ΔH	mmH_2O	81.28
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		4.770
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	5.8874
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		7.40
% oxygen reference condition		11
O_2 Reference Factor — $O2\ Ref = \frac{21.0 - act\%O2}{21.0 - ref\%O2}$		1.36
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	6.487
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1898
	%	18.98
Moisture by FTIR	%	18.98
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.83
Mean of velocity heads, ΔP_{avg}	mm H_2O	13.64
Mean square root of velocity heads, $\sqrt{\Delta P}$		3.7
Mean stack gas temperature, T_s	°C	126
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	14.94

Molecular weight of dry gas, M_d		
CO_2		9.54
O_2		7.40
Total		16.94
N_2 (100 -Total)		83.06
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.82
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.58
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	4.05
$Q_a = (60)(A_s)(V_s)$	m³/min	3627.2
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	30.00
Actual Flow Rate @ DGM	l/min	31.6
Isokinetic Rate		105.21
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00177
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.30914
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.38157
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.28057
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		45.14
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0085
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0105
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0077
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		1.24

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 2 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	742.5	CO_2		9.49
Stack static pressure, P_{static}	mm H_2O	-1.9	O_2		7.61
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	742.4	Total		17.10
			N_2 (100 -Total)		82.90
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.82
Moisture trap weight increase,Vlc	g	H_20 by FTIR	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.70
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		5.13	Area of stack, A_s	m^2	4.05
Gas meter correction factor, Y_d		1.06	$Q_a = (60)(A_s)(V_s)$	m³/min	3671.1
Mean dry gas meter temperature, T_m		31.64	**Percent isokinetic, %I**		
Mean pressure drop across orifice, ΔH	mmH_2O	88.92	Required Flow Rate @ DGM	l/min	31.00
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		4.787	Actual Flow Rate @ DGM	l/min	31.8
Volume of gas metered wet, V_{mstw}			Isokinetic Rate		102.72
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	5.8338	Acceptable 90% - 130%		Yes
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Particulate Concentration, C_{PM10}**		
			Mass of particulate collected on PM_{10} filter, M_f		0.00005
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0171
% oxygen measured in gas stream, act%O_2		7.61			
% oxygen reference condition		11	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0209
O_2 Reference Factor	O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$	1.34			
			$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0156
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	6.412			
Moisture content, B_{wo}			**Particulate Emission Rates, E**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1794	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		2.53
	%	17.94	**Particulate Concentration, $C_{PM2.5}$**		
Moisture by FTIR	%	17.94	Mass of particulate collected on filter, M_f		0.00005
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0086
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.83	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0104
Mean of velocity heads, ΔP_{avg}	mm H_2O	13.99			
Mean square root of velocity heads, $\sqrt{\Delta P}$		3.74	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0078
Mean stack gas temperature, T_s	°C	126			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	15.12	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		1.26

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 3 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	742.5
Stack static pressure, P_{static}	mm H_2O	-1.9
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	742.4
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 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		5.84
Gas meter correction factor, Y_d		1.06
Mean dry gas meter temperature, T_m		36.15
Mean pressure drop across orifice, ΔH	mmH_2O	116.75
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.381
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.5835
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		7.49
% oxygen reference condition		11
O_2 Reference Factor — O2 Ref = (21.0 - act%O2) / (21.0 - ref%O2)		1.35
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	7.269
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1826
	%	18.26
Moisture by FTIR	%	18.26
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.83
Mean of velocity heads, ΔP_{avg}	mm H_2O	13.45
Mean square root of velocity heads, $\sqrt{\Delta P}$		3.67
Mean stack gas temperature, T_s	°C	126
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	14.83

Molecular weight of dry gas, M_d		
CO_2		9.54
O_2		7.49
Total		17.04
N_2 (100 -Total)		82.96
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.83
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.67
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	4.05
$Q_a = (60)(A_s)(V_s)$	m³/min	3602.4
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	31.10
Actual Flow Rate @ DGM	l/min	32.4
Isokinetic Rate		104.33
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00019
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0365
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0446
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0330
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		5.27
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0076
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0093
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0069
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		1.10

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 4 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	727.5	CO_2		9.69
Stack static pressure, P_{static}	mm H_2O	-1.9	O_2		6.91
$P_s = P_b + (P_{static}) / 13.6$	mm Hg	727.4	Total		16.60
			N_2 (100 -Total)		83.40
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.83
Moisture trap weight increase,Vlc	g	H_20 by FTIR	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.59
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		5.02	Area of stack, A_s	m^2	4.05
Gas meter correction factor, Y_d		1.06	$Q_a = (60)(A_s)(V_s)$	m³/min	3669.7
Mean dry gas meter temperature, T_m		30.88	**Percent isokinetic, %I**		
Mean pressure drop across orifice, ΔH	mmH_2O	84.39	Required Flow Rate @ DGM	l/min	29.40
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		4.597	Actual Flow Rate @ DGM	l/min	27.9
Volume of gas metered wet, V_{mstw}			Isokinetic Rate		94.86
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	5.6702	Acceptable 90% - 130%		Yes
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Particulate Concentration, C_{PM10}**		
			Mass of particulate collected on PM_{10} filter, M_f		0.00005
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
			$C_{wet} = M_n / V_{mstw}$	mg/m³	0.0176
% oxygen measured in gas stream, act%O_2		6.91			
% oxygen reference condition		11	$C_{dry} = M_n / V_{mstd}$	mg/m³	0.0218
O_2 Reference Factor: O2 Ref = (21.0 - act%O2) / (21.0 - ref%O2)		1.41			
			$C_{dry@X\%O2} = M_n / V_{mstd@X\%oxygen}$	mg/m³	0.0154
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	6.475			
Moisture content, B_{wo}			**Particulate Emission Rates, E**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1893	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		2.53
	%	18.93	**Particulate Concentration, $C_{PM2.5}$**		
Moisture by FTIR	%	18.93	Mass of particulate collected on filter, M_f		0.00005
Velocity of stack gas, V_s			$C_{wet} = M_n / V_{mstw}$	mg/m³	0.0088
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.83	$C_{dry} = M_n / V_{mstd}$	mg/m³	0.0109
Mean of velocity heads, ΔP_{avg}	mm H_2O	13.55			
Mean square root of velocity heads, $\sqrt{\Delta P}$		3.68	$C_{dry@X\%O2} = M_n / V_{mstd@X\%oxygen}$	mg/m³	0.0077
Mean stack gas temperature, T_s	°C	128			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	15.11	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		1.26

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 5 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	742.5
Stack static pressure, P_{static}	mm H_2O	-1.9
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	742.4
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	$H_2$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		4.87
Gas meter correction factor, Y_d		1.06
Mean dry gas meter temperature, T_m		30.86
Mean pressure drop across orifice, ΔH	mmH_2O	79.00
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		4.567
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	5.6563
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		6.91
% oxygen reference condition		11
O_2 Reference Factor: $O2\ Ref = \frac{21.0 - act\%O2}{21.0 - ref\%O2}$		1.41
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	6.435
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1925
	%	19.25
Moisture by FTIR	%	19.25
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.83
Mean of velocity heads, ΔP_{avg}	mm H_2O	13.36
Mean square root of velocity heads, $\sqrt{\Delta P}$		3.66
Mean stack gas temperature, T_s	°C	129
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	14.87

Molecular weight of dry gas, M_d		
CO_2		9.66
O_2		6.91
Total		16.57
N_2 (100 -Total)		83.43
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.82
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.55
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	4.05
$Q_a = (60)(A_s)(V_s)$	m³/min	3610.7
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	29.40
Actual Flow Rate @ DGM	l/min	27.1
Isokinetic Rate		92.04
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00049
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0955
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.1182
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0839
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		13.73
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0088
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0109
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0078
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		1.27

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 6 — PM_{10} & $PM_{2.5}$

Parameter	Unit	Value
Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	742.5
Stack static pressure, P_{static}	mm H_2O	-1.9
$P_s = P_b + (P_{static}) / 13.6$	mm Hg	742.4
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 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		5.47
Gas meter correction factor, Y_d		1.06
Mean dry gas meter temperature, T_m		29.38
Mean pressure drop across orifice, ΔH	mmH_2O	101.27
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.161
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.3145
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		7.20
% oxygen reference condition		11
O_2 Reference Factor: O2 Ref = (21.0 - act%O2) / (21.0 - ref%O2)		1.38
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$	m^3	7.123
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1827
	%	18.27
Moisture by FTIR	%	18.27
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.83
Mean of velocity heads, ΔP_{avg}	mm H_2O	13.17
Mean square root of velocity heads, √ΔP		3.63
Mean stack gas temperature, T_s	°C	129
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	14.73

Parameter	Unit	Value
Molecular weight of dry gas, M_d		
CO_2		9.54
O_2		7.20
Total		16.73
N_2 (100 -Total)		83.27
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.81
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.66
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	4.05
$Q_a = (60)(A_s)(V_s)$	m³/min	3577.8
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	29.50
Actual Flow Rate @ DGM	l/min	30.4
Isokinetic Rate		102.92
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00037
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00021
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0919
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.1124
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0814
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		13.09
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00021
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0333
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0407
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0295
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		4.74

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PM_{10} & $PM_{2.5}$ 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	31.56	0.10	0.12	-457	0.63	Yes
Run 2	31.84	0.04	0.1	-508	0.64	Yes
Run 3	32.45	0.2	0.25	-508	0.65	Yes
Run 4	27.89	0.05	0.12	-406	0.56	Yes
Run 5	27.06	0.09	0.14	-432	0.54	Yes
Run 6	30.36	0.1	0.1	-457	0.61	Yes

ISOKINETICITY		
Run	Flow Variation %	Acceptable Variation
Run 1	105.2	Yes
Run 2	102.7	Yes
Run 3	104.3	Yes
Run 4	94.9	Yes
Run 5	92.0	Yes
Run 6	102.9	Yes

Acceptable Flow rate 90 -130%

FILTERS					
Run	Filter Material	Filter Size mm	Max Filtration Temperature °C	Pre-conditioning Filter Temperature °C	Post conditioning Filtration Temperature °C
Run 1	QF	50	127	180	160
Run 2	QF	50	126	180	160
Run 3	QF	50	127	180	160
Run 4	QF	50	130	180	160
Run 5	QF	50	147	180	160
Run 6	QF	50	144	180	160

QF = Quartz Fibre

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Conformity with relevant aspects of BS EN ISO 23210:2009

GENERAL METHODOLOGY

The equipment employed is a Paul Gothe, Johnas cascade impactor (see pg 13 for serial number) system meeting the requirements of BS EN ISO 23210. The standard cites a two-stage impactor system.

The method for sampling requires the extraction of a representative sample of duct gas isokinetically, into a specially designed in-stack sampling head. The Cascade Impactor is a multi-stage, multi-jet impactor which aerodynamically classifies particulates into multiple size ranges. The cascade impactor uses the principle of inertial separation to size segregate particulate samples from the gas stream. The impactor has two stages for particle size determination. Each stage gives a cut-point based on aerodynamic diameter of the particle.

During sampling, the particles are driven (jetted) toward a collecting surface where they may cling. By changing the velocity (orifice size of the jet), the size of the particles collected is controlled. The size of the jets within each stage is constant, but for each succeeding stage the jets get smaller. Impaction occurs when the particle's inertia overcomes the aerodynamic drag. Otherwise, the particle remains in the air stream and proceeds to the next stage. To keep the cut-point for each stage constant, the impactor is operated at a constant flow rate.

At each stage, the particle impacts on to a conditioned and pre-weighed substrate. Following sampling, the substrates are reconditioned and reweighed to determine the mass collected.

Based on the sampling conditions (sampling rate and gas temperature) the cut size (D50 – diameter of particles having a 50% probability of penetration) associated with each impactor stage may be determined.

An homogeneity assessment based on BS EN ISO 23210, Annex G, is undertaken to determine the most representative sampling point in the sampling plane (temperature, velocity and oxygen are suitable surrogates for particulate matter). The velocity measurement at the chosen point is used to determine an appropriate sampling nozzle/flow rate in order to ensure that isokinetic conditions are maintained throughout sampling to within the 90-130% range allowed in the standard (8.1) and which is consistent with the sampling equipment.

Concurrently, the volume of duct gas sampled is measured. This then enables the particulate concentration at each cut size to be determined.

The outlet gas from the sampling head is passed via a sampling probe through an impinger train with the purpose of removing water prior to entry to the sampling control box. It is not intended that the sampling train be used for additional sampling of condensible determinands and as such the train is unheated.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Conformity with relevant aspects of BS EN ISO 23210:2009

Sampling Plane Validation Criteria				
EA Technical Guidance Note (Monitoring) M1	Result	Units	Requirement	Compliant
Lowest Differential Pressure	118	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	13.46	m/s	-	-
Highest Gas Velocity	14.99	m/s	-	-
Ratio of Gas Velocities	1.11	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^o	Yes
No local negative flow	Yes	-	-	Yes

Conformance with BS EN ISO 23210:2009			
Reference	Requirement	Result	Compliant
Section 6.3	Suitable Impcator Used	See statement of conformity for Impactor	Yes
Section 8.1	Sampling position acceptable (as per 13284-1)	As per table "Sampling Plane Validation"	Yes
Section 8.1	Nozzle arrangement	See statement of conformity for Impactor	Yes
Section 8.1	Representative sampling point	See Homogeneity assessment below	Yes
Section 8.1	Constant Sample gas flow, iso-kinetic rate 90% to 130%		
	Run 1 - Required flow 30 (LPM)		-
	Run 1 - Minimum permissable flow 27 (LPM)	27.62	Yes
	Run 1 - Maximum permissable flow 39 (LPM)	36.58	Yes
	Run 2 - Required flow 31 (LPM)		-
	Run 2 - Minimum permissable flow 27.9 (LPM)	29.13	Yes
	Run 2 - Maximum permissable flow 40.3 (LPM)	38.17	Yes
	Run 3 - Required flow 31.1 (LPM)		-
	Run 3 - Minimum permissable flow 27.99 (LPM)	28.60	Yes
	Run 3 - Maximum permissable flow 40.43 (LPM)	36.00	Yes
	Run 4 - Required flow 29.4 (LPM)		-
	Run 4 - Minimum permissable flow 26.46 (LPM)	26.62	Yes
	Run 4 - Maximum permissable flow 38.22 (LPM)	30.84	Yes
	Run 5 - Required flow 29.4 (LPM)		-
	Run 5 - Minimum permissable flow 26.46 (LPM)	26.60	Yes
	Run 5 - Maximum permissable flow 38.22 (LPM)	29.20	Yes
	Run 6 - Required flow 29.5 (LPM)		-
	Run 6 - Minimum permissable flow 26.55 (LPM)	27.60	Yes
	Run 6 - Maximum permissable flow 38.35 (LPM)	33.20	Yes
Section 8.1	Overall blank taken once per day	Yes	Yes
Section 8.2	Impactor cleaned between each measurement	Yes	Yes
Section 8.2	Arrangement of impactor plates	See statement of conformity for Impactor	Yes
Section 8.3.2	Data taken for velocity, composition, temp & pressure	See "Preliminary stack survey" section	Yes
Section 8.3.3	Sampling rate determination in accordance with Annex A	Yes	Yes
Section 8.3.3	Sample flow rate kept +/- 5% of nominal flow rate		
	Run 1 - Max sample flow deviation from nominal (%)	9.7	No
	Run 2 - Max sample flow deviation from nominal (%)	10.0	No
	Run 3 - Max sample flow deviation from nominal (%)	14.3	No
	Run 4 - Max sample flow deviation from nominal (%)	6.2	No
	Run 5 - Max sample flow deviation from nominal (%)	34.2	No
	Run 6 - Max sample flow deviation from nominal (%)	19.0	No
Section 8.3.4	Nozzle selectedto allow iso-kinetic rate 90% to 130%	Yes, as above	Yes
Section 8.3.5	Leak check less than 2%		
	Run 1	0.32	Yes
	Run 2	0.13	Yes
	Run 3	0.62	Yes
	Run 4	0.18	Yes
	Run 5	0.33	Yes
	Run 6	0.33	Yes
Section 8.3.6	Impactor at flue gas temperature before sampling	Yes	Yes
Section 8.3.6	Angle of nozzle less than 10 Degress to flow	Yes	Yes
Section 8.3.6	Flowrate has checked and recorded every 5 mins	Yes	Yes
Section 8.3.6	Dynamic pressure recorded every 5 mins	Yes	Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Homogeneity assessment

Assessment 1

Point number (i)	Distance along sample line (mm)	Probe Marking (mm)	O2 % grid	O2 % fixed	r_i
1	59	129	8	8	1.002
2	187.8	257.8	9	9	1.001
3	336.8	406.8	9	10	0.993
4	520.1	590.1	10	10	0.990
5	786.3	856.3	10	10	0.982
6	1513.7	1583.7	9	9	1.000
7	1779.9	1849.9	9	9	1.030
8	1963.2	2033.2	9	8	1.045
9	2112.2	2182.2	9	9	1.022
10	2241	2311	9	9	1.003
Second Line					
1	59	129	10	10	0.990
2	187.8	257.8	10	10	1.002
3	336.8	406.8	9	9	1.000
4	520.1	590.1	8	8	1.000
5	786.3	856.3	9	8	1.045
6	1513.7	1583.7	9	9	0.999
7	1779.9	1849.9	9	9	1.003
8	1963.2	2033.2	10	10	1.000
9	2112.2	2182.2	10	10	1.004
10	2241	2311	9	9	0.998

No. of points	20
S_{grid}	0.59
S_{ref}	0.65
$\bar{r}$	1.005
Is $S_{grid} <= S_{ref}$?	Yes

F Factor	0.812
$F_{N-1; N-1; 0.95}$	2.17
Is F Factor < $F_{N-1;N-1;0.95}$?	N/A

S_{pos}	N/A
$t_{N-1;0.95}$	2.093
U_{pos}	N/A
Permissible Uncertainty	6
Is $U_{pos} < 0.5 * U_{perm}$?	N/A

Sample can be taken from any location

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DAILY OXYGEN SUMMARY

Run	Sampling Times	Concentration %	LOD %
1	14:59 - 17:59 27 February 2014	7.40	0.01
2	09:40 - 12:40 28 February 2014	7.61	0.01
3	13:03 - 16:03 28 February 2014	7.49	0.01
4	10:23 - 13:23 03 March 2014	6.91	0.01
5	14:19 - 17:19 03 March 2014	6.91	0.01
6	09:48 - 12:48 04 March 2014	7.20	0.01

PRE SAMPLING CALIBRATION DATA

Date	Time of Analyser Check	Range (%)	Zero Reading at analyser	Span Reading at analyser	Zero Check at analyser	Zero Check down line	Span Check down line	Leak Rate %
27 February 2014	11:51 - 12:03	20.9	0.00	10.06	0.00	-0.27	10.19	1.28
03 March 2014	09:14 - 09:24	20.9	0.00	10.06	0.00	0.10	9.78	-2.86

POST SAMPLING CALIBRATION DATA

Date	Time of Analyser Check	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
28 February 2014	15:59 - 16:10	-0.19	10.14	0.38	-1.29
04 March 2014	12:42 - 12:58	0	9.59	-0.48	-0.89

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GAS SUMMARY

Test	Sampling Times	Concentration %	Analysis Areas	Interference (%) *	LOD %
Moisture Run 1	14:59 - 17:59 27 February 2014	19.0	3200 - 3401	0.7	0.01
Moisture Run 2	09:40 - 12:40 28 February 2014	17.9	3200 - 3401	0.97	0.01
Moisture Run 3	13:03 - 16:03 28 February 2014	18.3	3200 - 3401	0.97	0.01
Moisture Run 4	10:23 - 13:23 03 March 2014	18.9	3200 - 3401	0.97	0.01
Moisture Run 5	14:19 - 17:19 03 March 2014	19.3	3200 - 3401	1.68	0.01
Moisture Run 6	09:48 - 12:48 04 March 2014	18.3	3200 - 3401	1.68	0.01
Carbon Dioxide Run 1	14:59 - 17:59 27 February 2014	9.5	2000 - 2223	1.54	0.04
Carbon Dioxide Run 2	09:40 - 12:40 28 February 2014	9.5	2000 - 2223	0.97	0.04
Carbon Dioxide Run 3	13:03 - 16:03 28 February 2014	9.5	2000 - 2223	0.97	0.04
Carbon Dioxide Run 4	10:23 - 13:23 03 March 2014	9.7	2000 - 2223	0.97	0.04
Carbon Dioxide Run 5	14:19 - 17:19 03 March 2014	9.7	2000 - 2223	0.27	0.04
Carbon Dioxide Run 6	09:48 - 12:48 04 March 2014	9.5	2000 - 2223	0.27	0.04

*M22 Specifies interference must be <5%.

FTIR CALIBRATION CHECKS

Pre - Sampling Checks - System			Date of Checks	27 February 2014		Time of Checks	12:49	
Post Sampling Checks - System			Date of Checks	28 February 2014		Time of Checks	16:00	
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
H_2O	0.02	0.01	-0.02	87.1	86.7	-0.45	87.1	0.45
CO_2(%)	0.00	0.00	0.00	12.0	12.1	0.69	12.1	-0.22

Pre - Sampling Checks - System			Date of Checks	03 March 2014		Time of Checks	08:52	
Post Sampling Checks - System			Date of Checks	04 March 2014		Time of Checks	12:50	
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
H_2O	0.09	0.10	0.02	87.1	85.9	-1.35	85.2	-0.88
CO_2(%)	0.00	0.00	0.00	12.0	12.1	1.20	12.0	-1.45

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.

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	2.27	m
Stack Width, W	-	m
Stack Area, A	4.05	m^2
Average stack gas temperature	127	^oC
Stack static pressure	-0.26	kPa
Barometric Pressure	99.13	kPa
Pitot tube calibration coefficient, K_{pt}	0.83	-

Stack Gas Composition & Molecular Weights

Component	Molar Mass M	Density kg/m^3 p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m^3 pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m^3 pi
CO_2	44	1.96	9.50	0.10	0.19	7.73	0.08	0.15
O_2	32	1.43	7.25	0.07	0.10	5.90	0.06	0.08
N_2	28	1.25	83.25	0.83	1.04	67.76	0.68	0.85
H_2O	18	0.80	-	-	-	18.61	0.19	0.15

Where: p = M / 22.41 p*i* = r x p

Calculation of Stack Gas Densities

Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3300	kg/m^3
Wet Density (STP), P_{STW}	1.2319	kg/m^3
Dry Density (Actual), P_{Actual}	0.8864	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.821	kg/m^3

Where:

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

P_{STW} = (P_{STD} + p*i* of H_2O) / (1 + (p*i* of H_2O / 0.8036))

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

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	27 February 2014
Time of Survey	12:30
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	0.11	14.0	137	124	14.56	-	<15
2	0.34	13.4	131	124	14.24	-	<15
3	0.57	13.8	135	125	14.47	-	<15
4	0.79	13.0	127	125	14.05	-	<15
5	1.02	12.8	125	125	13.94	-	<15
6	1.25	12.4	122	125	13.72	-	<15
7	1.48	13.8	135	125	14.47	-	<15
8	1.70	14.2	139	125	14.68	-	<15
9	1.93	14.8	145	125	14.99	-	<15
10	2.16	12.0	118	123	13.46	-	<15
Mean	-	13.4	132	125	14.26	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	0.11	13.2	129	125	14.15	-	<15
2	0.34	14.0	137	125	14.58	-	<15
3	0.57	14.0	137	125	14.58	-	<15
4	0.79	13.8	135	125	14.47	-	<15
5	1.02	13.6	133	125	14.37	-	<15
6	1.25	13.6	133	124	14.35	-	<15
7	1.48	14.0	137	124	14.56	-	<15
8	1.70	13.8	135	124	14.45	-	<15
9	1.93	14.2	139	123	14.64	-	<15
10	2.16	13.0	127	123	14.01	-	<15
Mean	-	13.7	134	124	14.42	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 2

Date of Survey	27 February 2014
Time of Survey	18:04
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl º
1	0.11	13.3	130	125	14.21	-	<15
2	0.34	13.6	133	125	14.37	-	<15
3	0.57	13.8	135	125	14.47	-	<15
4	0.79	13.0	127	125	14.05	-	<15
5	1.02	13.0	127	125	14.05	-	<15
6	1.25	13.0	127	125	14.05	-	<15
7	1.48	13.8	135	125	14.47	-	<15
8	1.70	13.6	133	125	14.37	-	<15
9	1.93	14.0	137	125	14.58	-	<15
10	2.16	13.3	130	123	14.17	-	<15
Mean	-	13.4	132	125	14.28	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl º
1	0.11	13.5	132	126	14.33	-	<15
2	0.34	14.0	137	126	14.60	-	<15
3	0.57	14.0	137	125	14.58	-	<15
4	0.79	14.0	137	125	14.58	-	<15
5	1.02	13.6	133	125	14.37	-	<15
6	1.25	13.8	135	124	14.45	-	<15
7	1.48	14.0	137	124	14.56	-	<15
8	1.70	13.8	135	124	14.45	-	<15
9	1.93	13.6	133	125	14.37	-	<15
10	2.16	13.0	127	125	14.05	-	<15
Mean	-	13.7	135	125	14.43	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 3

Date of Survey	28 February 2014
Time of Survey	12:45
Velocity Measurement Device:	S-Type Pitot

Sampling Line A							
Traverse Point	Distance into duct (m)	ΔP pt mmH$_2$O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.0	127	126	14.06	-	<15
2	0.34	13.2	129	126	14.17	-	<15
3	0.57	13.6	133	126	14.39	-	<15
4	0.79	13.4	131	126	14.28	-	<15
5	1.02	13.6	133	126	14.39	-	<15
6	1.25	13.6	133	126	14.39	-	<15
7	1.48	13.4	131	126	14.28	-	<15
8	1.70	13.2	129	126	14.17	-	<15
9	1.93	13.0	127	126	14.06	-	<15
10	2.16	13.2	129	126	14.17	-	<15
Mean	-	13.32	131	126	14.24	-	

Sampling Line B							
Traverse Point	Distance into duct (m)	ΔP pt mmH$_2$O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.0	127	125	14.05	-	<15
2	0.34	13.2	129	126	14.17	-	<15
3	0.57	13.5	132	126	14.33	-	<15
4	0.79	13.5	132	126	14.33	-	<15
5	1.02	13.2	129	126	14.17	-	<15
6	1.25	13.2	129	126	14.17	-	<15
7	1.48	13.3	130	126	14.23	-	<15
8	1.70	13.5	132	126	14.33	-	<15
9	1.93	13.6	133	126	14.39	-	<15
10	2.16	13.5	132	126	14.33	-	<15
Mean	-	13.4	131	126	14.25	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 4

Date of Survey	28 February 2014
Time of Survey	16:15
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.3	130	125	14.21	-	<15
2	0.34	13.6	133	125	14.37	-	<15
3	0.57	13.5	132	125	14.31	-	<15
4	0.79	13.6	133	125	14.37	-	<15
5	1.02	13.4	131	125	14.26	-	<15
6	1.25	13.3	130	125	14.21	-	<15
7	1.48	13.2	129	125	14.15	-	<15
8	1.70	13.3	130	125	14.21	-	<15
9	1.93	13.4	131	125	14.26	-	<15
10	2.16	13.5	132	125	14.31	-	<15
Mean	-	13.4	131	125	14.27	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.2	129	125	14.15	-	<15
2	0.34	13.4	131	125	14.26	-	<15
3	0.57	13.6	133	125	14.37	-	<15
4	0.79	13.5	132	125	14.31	-	<15
5	1.02	13.4	131	125	14.26	-	<15
6	1.25	13.5	132	125	14.31	-	<15
7	1.48	13.5	132	125	14.31	-	<15
8	1.70	13.4	131	125	14.26	-	<15
9	1.93	13.3	130	125	14.21	-	<15
10	2.16	13.2	129	125	14.15	-	<15
Mean	-	13.4	131	125	14.26	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 5

Date of Survey	03 March 2014
Time of Survey	10:15
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.6	133	128	14.42	-	<15
2	0.34	13.4	131	128	14.32	-	<15
3	0.57	13.6	133	128	14.42	-	<15
4	0.79	13.2	129	128	14.21	-	<15
5	1.02	13.4	131	128	14.32	-	<15
6	1.25	13.2	129	128	14.21	-	<15
7	1.48	13.4	131	128	14.32	-	<15
8	1.70	13.4	131	128	14.32	-	<15
9	1.93	13.6	133	128	14.42	-	<15
10	2.16	13.0	127	128	14.10	-	<15
Mean	-	13.38	131	128	14.30	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.2	129	128	14.21	-	<15
2	0.34	13.6	133	128	14.42	-	<15
3	0.57	13.8	135	128	14.53	-	<15
4	0.79	13.6	133	128	14.42	-	<15
5	1.02	13.6	133	128	14.42	-	<15
6	1.25	13.6	133	128	14.42	-	<15
7	1.48	13.4	131	128	14.32	-	<15
8	1.70	13.6	133	128	14.42	-	<15
9	1.93	13.2	129	128	14.21	-	<15
10	2.16	13.0	127	128	14.10	-	<15
Mean	-	13.5	132	128	14.35	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 6

Date of Survey	03 March 2014
Time of Survey	14:00
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.2	129	128	14.21	-	<15
2	0.34	13.5	132	128	14.37	-	<15
3	0.57	13.6	133	128	14.42	-	<15
4	0.79	13.5	132	128	14.37	-	<15
5	1.02	13.4	131	128	14.32	-	<15
6	1.25	13.3	130	128	14.26	-	<15
7	1.48	13.5	132	128	14.37	-	<15
8	1.70	13.5	132	128	14.37	-	<15
9	1.93	13.6	133	128	14.42	-	<15
10	2.16	13.2	129	128	14.21	-	<15
Mean	-	13.4	132	128	14.33	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.4	131	128	14.32	-	<15
2	0.34	13.6	133	128	14.42	-	<15
3	0.57	13.5	132	128	14.37	-	<15
4	0.79	13.6	133	128	14.42	-	<15
5	1.02	13.6	133	128	14.42	-	<15
6	1.25	13.5	132	128	14.37	-	<15
7	1.48	13.6	133	128	14.42	-	<15
8	1.70	13.6	133	128	14.42	-	<15
9	1.93	13.3	130	128	14.26	-	<15
10	2.16	13.0	127	128	14.10	-	<15
Mean	-	13.5	132	128	14.35	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 7

Date of Survey	03 March 2014
Time of Survey	17:30
Velocity Measurement Device:	S-Type Pitot

Sampling Line A							
Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.2	129	128	14.21	-	<15
2	0.34	13.4	131	128	14.32	-	<15
3	0.57	13.6	133	128	14.42	-	<15
4	0.79	13.5	132	128	14.37	-	<15
5	1.02	13.7	134	128	14.47	-	<15
6	1.25	13.8	135	128	14.53	-	<15
7	1.48	13.5	132	128	14.37	-	<15
8	1.70	13.3	130	128	14.26	-	<15
9	1.93	13.3	130	128	14.26	-	<15
10	2.16	13.0	127	128	14.10	-	<15
Mean	-	13.43	132	128	14.33	-	

Sampling Line B							
Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.5	132	128	14.37	-	<15
2	0.34	13.3	130	128	14.26	-	<15
3	0.57	13.7	134	128	14.47	-	<15
4	0.79	13.9	136	128	14.58	-	<15
5	1.02	13.6	133	128	14.42	-	<15
6	1.25	13.4	131	128	14.32	-	<15
7	1.48	13.5	132	128	14.37	-	<15
8	1.70	13.4	131	128	14.32	-	<15
9	1.93	13.3	130	128	14.26	-	<15
10	2.16	13.2	129	128	14.21	-	<15
Mean	-	13.5	132	128	14.36	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 8

Date of Survey	04 March 2014
Time of Survey	09:30
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	13.0	127	128	14.10	-	<15
2	0.34	13.3	130	128	14.26	-	<15
3	0.57	13.0	127	128	14.10	-	<15
4	0.79	12.9	126	128	14.05	-	<15
5	1.02	13.2	129	128	14.21	-	<15
6	1.25	13.3	130	128	14.26	-	<15
7	1.48	13.2	129	128	14.21	-	<15
8	1.70	13.1	128	128	14.15	-	<15
9	1.93	13.0	127	128	14.10	-	<15
10	2.16	12.8	125	128	13.99	-	<15
Mean	-	13.1	128	128	14.14	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.11	12.8	125	128	13.99	-	<15
2	0.34	12.6	123	128	13.88	-	<15
3	0.57	12.8	125	128	13.99	-	<15
4	0.79	13.0	127	128	14.10	-	<15
5	1.02	13.3	130	128	14.26	-	<15
6	1.25	13.0	127	128	14.10	-	<15
7	1.48	13.0	127	128	14.10	-	<15
8	1.70	13.0	127	128	14.10	-	<15
9	1.93	12.8	125	128	13.99	-	<15
10	2.16	12.8	125	128	13.99	-	<15
Mean	-	12.9	127	128	14.05	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 9

Date of Survey	04 March 2014
Time of Survey	13:00
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl º
1	0.11	12.7	124	128	13.94	-	<15
2	0.34	12.8	125	128	13.99	-	<15
3	0.57	12.9	126	128	14.05	-	<15
4	0.79	13.1	128	128	14.15	-	<15
5	1.02	13.3	130	128	14.26	-	<15
6	1.25	13.2	129	128	14.21	-	<15
7	1.48	13.3	130	128	14.26	-	<15
8	1.70	13.1	128	128	14.15	-	<15
9	1.93	13.0	127	128	14.10	-	<15
10	2.16	13.0	127	128	14.10	-	<15
Mean	-	13.0	128	128	14.12	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl º
1	0.11	12.6	123	128	13.88	-	<15
2	0.34	12.5	123	128	13.83	-	<15
3	0.57	12.8	125	128	13.99	-	<15
4	0.79	13.0	127	128	14.10	-	<15
5	1.02	13.0	127	128	14.10	-	<15
6	1.25	13.0	127	128	14.10	-	<15
7	1.48	13.4	131	128	14.32	-	<15
8	1.70	13.2	129	128	14.21	-	<15
9	1.93	13.1	128	128	14.15	-	<15
10	2.16	13.0	127	128	14.10	-	<15
Mean	-	13.0	127	128	14.08	-	

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	118	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	13.46	m/s	-	-
Highest Gas Velocity	14.99	m/s	-	-
Ratio of Gas Velocities	1.11	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^o	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V

Velocity at Traverse Point, $V = K_{pt} \times (1-\varepsilon) * \sqrt{(2 * \Delta P_{pt} / P_{ActualW})}$

Where:

K_{pt} = Pitot tube calibration coefficient

$(1-\varepsilon)$ = Compressibility correction factor, assumed at a constant 0.998

Average Stack Gas Velocity, Va	**14.25**	m/s

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))

Day 1	27 February 2014

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	125	0	^{o}C
Total Pressure	99.0	101.3	kPa
Oxygen	7.4	11	%
Moisture	18.98	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	14.35		m/s
Stack Area (A)	4.05		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	209054		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	140320		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	113683		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	154608		m^3/hr

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

Day 2	28 February 2014

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	127	0	^oC
Total Pressure	98.9	101.3	kPa
Oxygen	7.3	11	%
Moisture	18.38	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	14.29		m/s
Stack Area (A)	4.05		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	208281		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	138861		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	113343		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	154853		m^3/hr

Day 3	03 March 2014

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	128	0	^oC
Total Pressure	98.7	101.3	kPa
Oxygen	7.1	11	%
Moisture	18.76	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	14.17		m/s
Stack Area (A)	4.05		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	206414		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	136975		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	111277		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	155187		m^3/hr

Nomenclature:

Ts = Absolute Temperature, Standard Conditions, 273 K

Ps = Absolute Pressure, Standard Conditions, 101.3 kPa

Ta = Absolute Temperature, Actual Conditions, K

Pa = Absolute Pressure, Actual Conditions, kPa

Ma = Water vapour, Actual Conditions, % Vol

Ms = Water vapour, Reference Conditions, % Vol

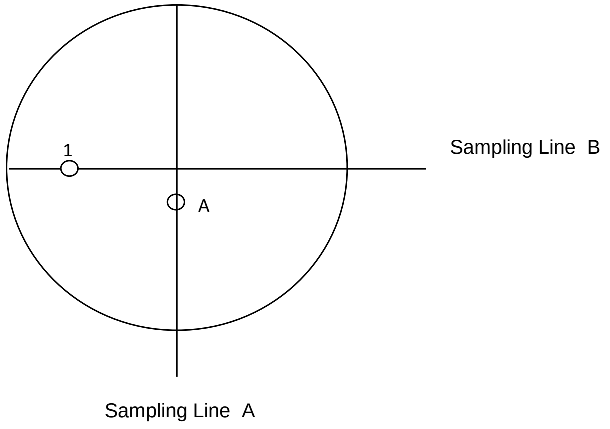
O_2a = Oxygen, Actual Conditions, % Vol

O_2s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK DIAGRAM

	Value	Units
Stack Depth	2.27	m
Stack Width	-	m
Area	4.05	m^2



Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	30	0.68	m

Isokinetic Sampling CEN Methods			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl º
1	85.0	1.93	<15

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

SAMPLING LOCATION

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - PM 10

Run	Sampled m³	Sampled Gas K	Sampled Gas kPa	Sampled Gas % by volume	Oxygen % by volume	Limit of % by mass	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	0.10	-
as a %	0.02	0.50	0.50	1.00	1.35	N/A	0.38
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.10	-
as a %	0.02	0.50	0.51	1.00	1.31	N/A	0.31
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 3	0.001	2	0.5	1	0.1	0.1000	-
as a %	0.01	0.50	0.51	1.00	1.33	N/A	0.77
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 4	0.001	2	0.5	1	0.1	0.10	-
as a %	0.02	0.50	0.52	1.00	1.45	N/A	0.43
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 5	0.001	2	0.5	1	0.1	0.10	-
as a %	0.02	0.50	0.51	1.00	1.45	N/A	0.52
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 6	0.001	2	0.5	1	0.1	0.10	-
as a %	0.07	0.50	0.51	1.00	1.39	N/A	0.33
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	Mass of particulate mg	O2 Correction -	Leak mg/m³	Combined uncertainty
Run 1	0.0644	0.1542	0.382	1.000	-
MU as mg/m³	0.0034	0.0154	0.0021	0.00062	**5.55**
MU as %	0.0531	5.5	0.735	0.220	-
Run 2	0.0036	0.1560	0.021	1.000	-
MU as mg/m³	0.0002	0.0156	0.0001	0.00003	**100.00**
MU as %	0.0030	100.0	0.747	0.181	-
Run 3	0.0068	0.1376	0.045	1.000	-
MU as mg/m³	0.0004	0.0138	0.0002	0.00015	**41.676**
MU as %	0.0062	41.7	0.740	0.445	-
Run 4	0.0037	0.15	0.022	1.00	-
MU as mg/m³	0.0002	0.02	0.0001	0.00004	**100.00**
MU as %	0.0029	100.0	0.710	0.25	-
Run 5	0.0196	0.16	0.118	1.00	-
MU as mg/m³	0.0010	0.02	0.0006	0.00025	**18.53**
MU as %	0.0159	18.5	0.710	0.30	-
Run 6	0.0322	0.05	0.041	1.00	-
MU as mg/m³	0.0004	0.01	0.0002	0.00006	**17.26**
MU as %	0.0056	17.2	0.725	0.19	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**mg/m³**	**11.36**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**mg/m³**	**200.02**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**mg/m³**	**83.39**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**mg/m³**	**200.02**	**%**
R5 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**mg/m³**	**37.15**	**%**
R6 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.01**	**mg/m³**	**34.60**	**%**

(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 - PM 2.5

Run	Sampled m^3	Sampled Gas K	Sampled Gas kPa	Sampled Gas % by volume	Oxygen % by volume	Limit of % by mass	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	0.05	-
as a %	0.02	0.50	0.50	1.00	1.35	N/A	0.38
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.02	0.50	0.51	1.00	1.31	N/A	0.31
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 3	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.01	0.50	0.51	1.00	1.33	N/A	0.77
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 4	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.02	0.50	0.52	1.00	1.45	0.00	0.43
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 5	0.001	2	0.5	1	0.1	0.05	-
as a %	0.02	0.50	0.51	1.00	1.45	N/A	0.52
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 6	0.001	2	0.5	1	0.1	0.05	-
as a %	0.07	0.50	0.51	1.00	1.39	N/A	0.33
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m^3	Mass of particulate mg	O2 Correction -	Leak mg/m^3	Combined uncertainty
Run 1	0.00	0.1542	0.0105	1.000	-
MU as mg/m^3	0.0001	0.0077	0.0001	0.00002	**100.00**
MU as %	0.0015	100.0000	0.7353	0.22	-
Run 2	0.0018	0.1560	0.0104	1.000	-
MU as mg/m^3	0.0001	0.0078	0.0001	0.00001	**100.00**
MU as %	0.0015	100.0000	0.7467	0.18	-
Run 3	0.0016	0.1560	0.0105	1.000	-
MU as mg/m^3	0.0001	0.0078	0.0001	0.00003	**100.00**
MU as %	0.0015	100.0000	0.7403	0.44	-
Run 4	0.0018	0.1544	0.0109	1.0000	-
MU as mg/m^3	0.0001	0.0077	0.0001	0.00002	**100.00**
MU as %	0.0015	100.0000	0.7099	0.25	-
Run 5	0.002	0.155	0.0109	1.000	-
MU as mg/m^3	0.000	0.008	0.0001	0.00002	**100.00**
MU as %	0.001	100.000	0.7097	0.30	-
Run 6	0.03	0.14	0.0407	1.00	**-**
MU as mg/m^3	0.00	0.01	0.0002	0.00006	**23.82**
MU as %	0.0	23.8	0.7245	0.19	**-**

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.015**	**mg/m^3**	**200.02**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.016**	**mg/m^3**	**200.02**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.016**	**mg/m^3**	**200.02**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.015**	**mg/m^3**	**200.02**	**%**
R5 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.016**	**mg/m^3**	**200.02**	**%**
R6 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.014**	**mg/m^3**	**47.71**	**%**

(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 - CARBON DIOXIDE BY FTIR

Actual Measured Concentration	9.53	% vol
Measured Concentration at Reference Conditions	9.53	% vol
Emission Limit Value	-	% vol
Instrument Range	20	% vol
Check Gas Concentration	12.00	% vol

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)	0.000	<5%	Yes
Span drift (calculated from start and end readings).	-0.219	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	0.990	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.100	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	-1.300	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	1.600	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	1.544	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.080	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	% vol
Uncertainty of linearity (lack of fit) U_{fit}	-0.220
Uncertainty of zero drift $U_{0,dr}$	0.000
Uncertainty of span drift $U_{s,dr}$	-0.025
Uncertainty of volume or pressure flow dependence U_{spress}	0.115
Uncertainty in Ambient Temperature U_{temp}	0.151
Uncertainty in Voltage U_{volt}	0.186
Uncertainty of interferents U_i	0.179
Uncertainty of Repeatability U_r	0.016
Uncertainty of Certified Reference Material U_{cal}	0.069

Measurement Uncertainty	% vol
Combined uncertainty	0.40
Expanded uncertainty at a 95% Confidence Interval	0.79

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	8.32
Expressed as a % of the Measured Concentration at Reference Conditions	8.32
Expressed as a % of the Emission Limit Value	-

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE BY FTIR

Actual Measured Concentration	18.77	% vol
Measured Concentration at Reference Conditions	18.77	% vol
Emission Limit Value	30	% vol
Instrument Range	40	% vol
Check Gas Concentration (Methane was used as a Surrogate)	62.21	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)	-0.025	<5%	Yes
Span drift (calculated from start and end readings).	0.447	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	0.990	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.100	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	-1.000	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	0.710	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	0.683	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.170	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	% vol
Uncertainty of linearity (lack of fit) U_{fit}	-0.443
Uncertainty of zero drift $U_{0,dr}$	-0.006
Uncertainty of span drift $U_{s,dr}$	0.104
Uncertainty of volume or pressure flow dependence U_{spress}	0.231
Uncertainty in Ambient Temperature U_{temp}	0.234
Uncertainty in Voltage U_{volt}	0.166
Uncertainty of interferents U_i	0.159
Uncertainty of Repeatability U_r	0.069
Uncertainty of Certified Reference Material U_{cal}	0.359

Measurement Uncertainty	% vol
Combined uncertainty	0.71
Expanded uncertainty at a 95% Confidence Interval	1.42

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	7.55
Expressed as a % of the Measured Concentration at Reference Conditions	7.55
Expressed as a % of the Emission Limit Value	4.72

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 1 - 27 February 2014

Reference	11	%vol
Measured concentration	7.40	%vol
Calibration gas	10.06	%vol
Full Scale	20.9	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	120	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	302	minutes	-	-
Number of readings in measurement	302	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.38	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-1.29	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.11704	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	1.28	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	-0.328
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.097
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.014
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	0.055
Uncertainty of calibration gas	ucalib	0.085

Measurement uncertainty (Concentration Measured)	7.40	%vol
Combined uncertainty	0.37	%vol
% of value	4.94	%

Expanded uncertainty expressed with a level of confidence of 95%	**9.88**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**0.73**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 2 - 27 February 2014

Reference	11	%vol
Measured concentration	7.57	%vol
Calibration gas	10.06	%vol
Full Scale	20.9	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	120	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	391	minutes	-	-
Number of readings in measurement	391	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.38	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-1.29	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.11704	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	1.28	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	-0.341
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.097
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.068
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	0.056
Uncertainty of calibration gas	ucalib	0.087

Measurement uncertainty (Concentration Measured)	7.57	%vol
Combined uncertainty	0.38	%vol
% of value	5.07	%

Expanded uncertainty expressed with a level of confidence of 95%	**10.13**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**0.77**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 3 - 03 March 2014

Reference	11	%vol
Measured concentration	6.95	%vol
Calibration gas	10.06	%vol
Full Scale	20.9	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	120	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	468	minutes	-	-
Number of readings in measurement	468	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	-0.48	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.89	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.11704	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	-2.86	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	-0.633
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.097
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.068
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	-0.115
Uncertainty of calibration gas	ucalib	0.080

Measurement uncertainty (Concentration Measured)	6.95	%vol
Combined uncertainty	0.66	%vol
% of value	9.55	%

Expanded uncertainty expressed with a level of confidence of 95%	**19.11**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**1.33**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 4 - 03 March 2014

Reference	11	%vol
Measured concentration	7.18	%vol
Calibration gas	10.06	%vol
Full Scale	20.9	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	120	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	188	minutes	-	-
Number of readings in measurement	188	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	-0.99	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-1.89	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.11704	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	-2.86	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	-1.352
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.097
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.068
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	-0.119
Uncertainty of calibration gas	ucalib	0.083

Measurement uncertainty (Concentration Measured)	7.18	%vol
Combined uncertainty	1.37	%vol
% of value	19.04	%

Expanded uncertainty expressed with a level of confidence of 95%		**38.09**	**% of value**
Standard deviation of repeatability at span level	urs	#DIV/0!	

APPENDIX 4 - Summaries, Calculations, Raw Data and Charts

NOTE - The following data is provided for information only and falls outside ESG's scope of accreditation

COMBINED UNCOLLECTED SUMMARY

Test	Sampling Times	>PM_{10} Concentration		Probe Rinse Concentration		Combined Unweighed Concentration	
		Measured mg/m³	LOD mg/m³	Measured mg/m³	LOD mg/m³	Measured mg/m³	LOD mg/m³
Run 1	14:59 - 17:59 27 February 2014	-	-	0.617	0.200	0.617	0.208
Run 2	09:40 - 12:40 28 February 2014	-	-	0.452	0.203	0.452	0.211
Run 3	13:03 - 16:03 28 February 2014	-	-	0.179	0.179	0.186	0.186
Run 4	10:23 - 13:23 03 March 2014	-	-	0.201	0.201	0.208	0.208
Run 5	14:19 - 17:19 03 March 2014	-	-	0.202	0.202	0.210	0.210
Run 6	09:48 - 12:48 04 March 2014	-	-	0.323	0.183	0.323	0.190

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

Where the result is less than the LOD, the LOD is reported.

SAMPLES

Test	>PM_{10} Filter Number	Filter Start Weight g	Filter End Weight g	Mass Gained on Filter g	Probe Rinse Number g	Probe Rinse Start Weight g	Probe Rinse End Weight g	Mass Gained in Rinse g	Combined Total Mass Gained g
Run 1	-	-	-	-	8268	185.6722	185.6762	0.00400	0.00400
Run 2	-	-	-	-	8270	202.94590	202.94880	0.00290	0.00290
Run 3	-	-	-	-	8311	178.35600	178.35720	0.00120	0.00120
Run 4	-	-	-	-	8312	197.51310	197.51410	0.00100	0.00100
Run 5	-	-	-	-	8313	184.45100	184.45200	0.00100	0.00100
Run 6	-	-	-	-	8314	192.35870	192.36100	0.00230	0.00230
Blank 1	-	-	-	-	8267	193.54890	193.54910	0.00020	0.00020
Blank 2	-	-	-	-	8269	165.16350	165.16410	0.00060	0.00060
Blank 3	-	-	-	-	8309	184.39820	184.39840	0.00020	0.00020
Blank 4	-	-	-	-	8310	186.26920	186.26940	0.00020	0.00020

PAUL GOTHE BOCHUM

Manufacturer of Emissions Control Technology
SEIT 1924

DIN ISO 9001

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VAT-No.: DE 813078723
Trade Register Bochum: HRB-6891

To our customers

Your ref	Your letter	Our ref	Date 14.03.2007

Calibration of the Johnas Impactor according to **ISO 23210**
6.2 Separation curves and Section 6.3 Verification of the separation curves

The Johnas Impactor from Paul Gothe GmbH was developed before the ISO Guideline was evaluated and after the Germans and the Netherlands Authorities have enough experiences with our impactor. After that the European Delegation creates the ISO Guideline 23210. The section 6.3 is important and was influence by the Germans. They have the experiences and write the rules for the calibration section accordingly it was made for the Johnas-Impactor.
The development from the Johnas impactor starts with a doctoral thesis from Mrs. John at the Gerhard-Mercator-University. She makes the intensive testing and Mr. Geueke from the North Rhine Westphalia State Environment Agency makes additional verifications at the ESA (Emission Simulation Facility) at the Hessian Agency for the Environment and Geology (HLUG).

Most of the literatures and papers are in German, but all well-known:

1. Probenahme und chemische Analytik von korngrößenfraktionierten Immissions- und Emissionsaerosolen. Von der Fakultät für Naturwissenschaften der Gerhard-Mercator-Universität – Gesamthochschule Duisburg zur Erlangung des akademischen Grades eines Dr. rer. nat. genehmigte Dissertation von ASTRID CHRISTIANE JOHN aus Lichtenfels.
2. Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit Luftreinhaltung Forschungsbericht 298 44 280, Korngrößenverteilung (PM10 und PM2,5) von Staubemissionen relevanter stationärer Quellen (Teil II zu 297 44 853), von Dipl.-Ing. A. Dreiseidler, Ing. D. Straub, Prof. Dr.-Ing. G. Baumbach, Universität Stuttgart, Institut für Verfahrenstechnik und Dampfkesselwesen (IVD), Abteilung Reinhaltung der Luft (RdL), Institutsleiter: Prof. Dr.-Ing. K.R.G. Hein, IM AUFTRAG DES UMWELTBUNDESAMTES Juni 2001.
3. VDI 2066, part 10
4. Gefahrstoffe-Reinhaltung der Luft 59 (1999), Nr.11/12, S. 449-453

All this papers shows, that the design of the Johnas Impactor is a proved version for the determination of the PM 2.5 and PM 10. The shape of the separation curves is similar to those specified in ISO 7708:1995 and the separation efficiency at 10 µm and 2,5 µm is 50 % according to section 6.3 of the ISO 23210.

What you need more? There is no authority which has more competence as the listed authorities.

If you still in doubt, you maybe get in contact with Mr. Geueke (phone: ++49-201-7995-1263).

Paul Gothe GmbH

PAUL GOTHE BOCHUM

Manufacturer of Emissions Control Technology
SEIT 1924

DIN ISO 9001

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To our customers

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Trade Register Bochum: HRB-6891

Your ref	Your letter	Our ref	Date 14.03.2007

Declaration of conformity

Herewith the company Paul Gothe GmbH in Bochum declare that the manufactured Cascade Impactor Johnas follows the guidelines from the North Rhine Westphalia State Environment Agency according the convention from 24 June 1999 and the PM 4 stage follows the convention of the Federal Environment Agency from 09. March 2005.

Our Cascade Impactor Johnas was developed in cooperation with the North Rhine Westphalia State Environment and the Gerhard-Mercator University Duisburg. This impactor was validated and after that 2004 adopted in the German Standard VDI 2066, part 10 and 2005 in ISO Standard 23210. All sizes of our manufactured impactors are according to these guidelines, individually checked according our strict quality management and named with a specific serial number. Only an impactor with this serial number is according to the Guideline VDI 2066, part 10 and ISO Standard 23210 and can use for the determination of PM 10 and PM 2.5.

Paul Gothe GmbH

Dr. Torsten Grodten

-manager-

Impactor Johnas according to the VDI 2066 and ISO 23210 and the convention from

Umwelt Bundes Amt
Für Mensch und Umwelt

Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen
NRW.

END OF REPORT

Appendix 2 – Stack emissions monitoring report: Newlincs Development Ltd

STACK EMISSIONS MONITORING REPORT

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

Your contact at ESG
Mark Woodruff Business Manager - North Tel: 0161 443 0982 Email: mark.woodruff@esg.co.uk

Operator & Address:
Newlincs Development Limited South Marsh Road Stallingborough Grimsby North East Lincolnshire DN41 8BZ

Permit
N/A - Investigative Monitoring

Release Point:
A1 - Incinerator Stack

Sampling Date(s):
5th - 7th March 2014

ESG Job Number:	LNO 11737
Report Date:	18th Feb 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
Report Approved By:	Andy Tiffen
MCERTS Number:	MM 05 640
Business Title:	MCERTS Level 2 - Projects Manager
Technical Endorsements:	1, 2 & 4
Signature:	

UKAS TESTING 1015

CONTENTS

EXECUTIVE SUMMARY

Stack Emissions Monitoring Objectives
- Plant
- Operator
- Stack Emissions Monitoring Test House

Emissions Summary
Monitoring Times
Process Details
Monitoring Methods
Analytical Methods
- Sampling Methods with Subsequent Analysis
- On-Site Testing
Sampling Location
- Sampling Plane Validation Criteria
- Duct Characteristics
- Sampling Lines & Sample Points
- Sampling Platform
- Sampling Location / Platform Improvement Recommendations
Sampling and Analytical Method Deviations
Determination of representative sampling location

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

Newlincs Development Limited operates a waste incineration process at Stallingborough

Environmental Scientifics Group Limited were commissioned by Ricardo AEA to carry out stack emissions monitoring to determine the release of PM_{10} & $PM_{2.5}$ from the following Plant under standard operating conditions.

The measurements were commissioned by Ricardo-AEA on behalf of the Department of Environment, Food and Rural Affairs (Defra) to provide information for the UK National Atmospheric Emissions Inventory (NAEI).

Plant

A1 - Incinerator Stack

Operator

Newlincs Development Limited
South Marsh Road
Stallingborough
Grimsby
North East Lincolnshire
DN41 8BZ

Stack Emissions Monitoring Test House

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

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.
MCERTS accredited results will only be claimed where both the sampling and analytical stages are UKAS accredited.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Limit**	**MCERTS accredited result**
PM_{10} **(Average result of 6 runs)**	mg/m³	0.021	0.04	-	✓
PM_{10} Emission Rate **(Average result of 6 runs)**	g/hr	0.86	1.6	-	
$PM_{2.5}$ **(Average result of 6 runs)**	mg/m³	0.010	0.02	-	✓
$PM_{2.5}$ Emission Rate **(Average result of 6 runs)**	g/hr	0.43	0.82	-	
PM_{10} - Runs					
PM_{10} - Run 1	mg/m³	***0.019***	0.04	-	✓
PM_{10} Emission Rate - Run 1	g/hr	0.82	1.6	-	
PM_{10} - Run 2	mg/m³	0.022	0.04	-	✓
PM_{10} Emission Rate - Run 2	g/hr	0.96	1.8	-	
PM_{10} - Run 3	mg/m³	***0.018***	0.03	-	✓
PM_{10} Emission Rate - Run 3	g/hr	0.78	1.5	-	
PM_{10} - Run 4	mg/m³	0.020	0.04	-	✓
PM_{10} Emission Rate - Run 4	g/hr	0.87	1.6	-	
PM_{10} - Run 5	mg/m³	0.021	0.04	-	✓
PM_{10} Emission Rate - Run 5	g/hr	0.78	1.5	-	
PM_{10} - Run 6	mg/m³	0.023	0.04	-	✓
PM_{10} Emission Rate - Run 6	g/hr	0.97	1.8	-	
$PM_{2.5}$ - Runs					
$PM_{2.5}$ - Run 1	mg/m³	***0.009***	0.02	-	✓
$PM_{2.5}$ Emission Rate - Run 1	g/hr	0.82	1.6	-	
$PM_{2.5}$ - Run 2	mg/m³	0.013	0.02	-	✓
$PM_{2.5}$ Emission Rate - Run 2	g/hr	0.56	1.1	-	
$PM_{2.5}$ - Run 3	mg/m³	***0.009***	0.02	-	✓
$PM_{2.5}$ Emission Rate - Run 3	g/hr	0.39	0.75	-	
$PM_{2.5}$ - Run 4	mg/m³	0.010	0.02	-	✓
$PM_{2.5}$ Emission Rate - Run 4	g/hr	0.43	0.83	-	
$PM_{2.5}$ - Run 5	mg/m³	0.011	0.02	-	✓
$PM_{2.5}$ Emission Rate - Run 5	g/hr	0.39	0.74	-	
$PM_{2.5}$ - Run 6	mg/m³	0.010	0.02	-	✓
$PM_{2.5}$ Emission Rate - Run 6	g/hr	0.41	0.78	-	
Oxygen	% v/v	12	0.46	-	✓
Moisture	%	13.3	1.4	-	✓
Stack Gas Temperature	°C	144	-	-	✓
Stack Gas Velocity	m/s	22.4	-	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	76122	-	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	49758	-	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	42683	-	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	39134	-	-	

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 test specific flow data. Mass emissions for non isokinetic tests and isokinetic tests are calculated using these values

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
PM_{10} Run 1	05 March 2014	15:06 - 18:06	180 minutes
PM_{10} Run 2	06 March 2014	09:03 - 12:03	180 minutes
PM_{10} Run 3	06 March 2014	12:35 - 15:35	180 minutes
PM_{10} Run 4	06 March 2014	16:09 - 19:09	180 minutes
PM_{10} Run 5	07 March 2014	08:49 - 11:49	180 minutes
PM_{10} Run 6	07 March 2014	12:55 - 15:55	180 minutes
$PM_{2.5}$ Run 1	05 March 2014	15:06 - 18:06	180 minutes
$PM_{2.5}$ Run 2	06 March 2014	09:03 - 12:03	180 minutes
$PM_{2.5}$ Run 3	06 March 2014	12:35 - 15:35	180 minutes
$PM_{2.5}$ Run 4	06 March 2014	16:09 - 19:09	180 minutes
$PM_{2.5}$ Run 5	07 March 2014	08:49 - 11:49	180 minutes
$PM_{2.5}$ Run 6	07 March 2014	12:55 - 15:55	180 minutes
Stack Gas Flow Rate & Temperature Run 1	05 March 2014	11:00	-
Stack Gas Flow Rate & Temperature Run 2	05 March 2014	18:46	-
Stack Gas Flow Rate & Temperature Run 3	06 March 2014	08:20	-
Stack Gas Flow Rate & Temperature Run 4	06 March 2014	12:08	-
Stack Gas Flow Rate & Temperature Run 5	06 March 2014	15:35	-
Stack Gas Flow Rate & Temperature Run 6	06 March 2014	19:35	-
Stack Gas Flow Rate & Temperature Run 7	07 March 2014	08:25	-
Stack Gas Flow Rate & Temperature Run 8	07 March 2014	11:55	-
Stack Gas Flow Rate & Temperature Run 9	07 March 2014	12:40	-
Stack Gas Flow Rate & Temperature Run 10	07 March 2014	16:00	-

EXECUTIVE SUMMARY

PROCESS DETAILS	
Parameter	**Process Details**
Description of process	Waste Incineration
Continuous or batch	Continuous
Product Details	Municipal Waste
Part of batch to be monitored (if applicable)	Stable conditions
Normal load, throughput or continuous rating	7.2 - 8 Tonnes/hour
Fuel used during monitoring	Waste
Abatement	Bag Filter with Lime, PAC and Urea injection
Plume Appearance	Not visible from the sample location during time of testing.

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by Environmental Scientifics Group Limited 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 +/- %
PM_{10}	SRM - BS EN 23210	AE 136	1015	Yes	0.019 mg/m³	189 %
$PM_{2.5}$	SRM - BS EN 23210	AE 136	1015	Yes	0.009 mg/m³	191 %
O_2	SRM - BS EN 14789	AE 102	1015	Yes	0.01%	3.8%
H_2O	AM - M22/FTIR	AE 063	1015	Yes	0.1 %	10.8%
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	5 Pa	-

The measurement uncertainties for the PM_{10} and $PM_{2.5}$ measurements reflect that measured concentrations were near or below the Limit of Detection.

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
PM_{10}	Gravimetric	AE 106	1015	Yes	ESG Stockport	ESG Stockport	1 year
$PM_{2.5}$	Gravimetric	AE 106	1015	Yes	ESG Stockport	ESG Stockport	1 year

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	MCERTS Accredited Analysis	Laboratory	Data Archive Location	Archive Period
O_2	Paramagnetism	AE 102	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	255	Pa	>= 5 Pa	Yes	BS EN 13284-1
Lowest Gas Velocity	20.27	m/s	-	-	-
Highest Gas Velocity	24.63	m/s	-	-	-
Ratio of Gas Velocities	1.21	-	< 3 : 1	Yes	BS EN 13284-1
Mean Velocity	22.44	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^{o}	Yes	BS EN 13284-1
No local negative flow	Yes	-	-	Yes	BS EN 13284-1

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Circular	-
Depth	1.10	m
Width	-	m
Area	0.95	m^2
Port Depth	490	mm

SAMPLING LINES & POINTS			
	Isokinetic (CEN Methods)	**Isokinetic** (ISO Methods)	**Non-Iso & Gases**
Sample port size	5 inch BSP	-	5 inch BSP
Number of lines used	1	-	1
Number of points / line	1	-	1
Duct orientation	Vertical	-	Vertical
Filtration	In Stack	-	In Stack

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

M1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	Yes
Platform has 2 levels of handrails (approximately 0.5 m & 1.0 m high)	Yes
Platform has vertical base boards (approximately 0.25 m high)	Yes
Platform has removable chains / self closing gates at the top of ladders	N/A
Handrail / obstructions do not hamper insertion of sampling equipment	Yes
Depth of Platform = >Stack depth / diameter + wall and port thickness + 1.5m	Yes

Sampling Platform Improvement Recommendations (if applicable)

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

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Goose-neck nozzle Validation

Due to the long port sleeve, it was physically impossible to inserted the cascade impactor using the straight entry nozzle setup recommended in BS EN 23210. Therefore the use of a goose-neck setup was used as this was the only feasible method for monitoring. The standard requires that the use of a goose-neck nozzle is validated, however on this occasion it has not been possible to demonstrate that losses in the nozzle meet the criteria in the standard because the measured concentrations were low and the weight of particulate recovered from the nozzle rinses and the filter media were at or near the weighing LoD. In the context of the low emission concentrations detemined during the measurements (all less than 0.1 mg/Nm3), losses in the sampling nozzle are unlikely to increase the concentrations significantly.

Sample flow variation

The sample flowrate could not be maintained within 5% of the nominal flow throughout the testing periods (which were over extended periods due to the anticipated low PM emission concentrations). Whilst this will have affected the actual cutpoints achieved by the impactor, the results are all at or very near the LOD for the tests and hence this is anticipated to have limited impact on the outcome of the measurements.

Determination of representative sampling location

An assessment of temperature homogeneity was performed in accordance with EN 23210 Annex-G on the first day of monitoring 5th March 2014. There was a feedstock change on the morning of the third day 7th March 2014 from municipal waste to Community Recyling Centre waste. A further homogeneity test was performed on 7th March and the representative sampling point was determined to be at the same location as on 5th March.

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**
PM_{10}	SRM - BS EN 23210	AE 136	1015	Yes	6
$PM_{2.5}$	SRM - BS EN 23210	AE 136	1015	Yes	6
O_2	SRM - BS EN 14789	AE 102	1015	Yes	6
H_2O	AM - M22/FTIR	AE 063	1015	Yes	6
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	10

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 13-11	Horiba PG-250 Analyser	-	Laboratory Balance	LNO 00-12/00-13
Box Thermocouples	LNO 03-11	FT-IR	LNO 0750	Tape Measure	LNO 24-DJH
Meter In Thermocouple	LNO 03-11	FT-IR Oven Box	LNO 1207	Stopwatch	LNO 17-DJH
Meter Out Thermocouple	LNO 03-11	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17-11	Signal 3030 FID	-	Barometer	LNO 08-DJH
Oven Box	-	Servomex	LNO 21-22	Digital Micromanometer	LNO 01-DJH
Probe	LNO 11-41	JCT Heated Head Filter	-	Digital Temperature Meter	LNO 03-DJH
Probe Thermocouple	LNO 10-41	Thermo FID	-	Stack Thermocouple	-
Probe	LNO 11-44	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	LNO 10-44	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LNO 06-DJH	Anemometer	-	1m Heated Line (1)	LNO 18-05
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	-	Chiller (JCT/MAK 10)	LNO 21-40	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	-	Impactor 1	NR 18706	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	LNO 03-84
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 +/- %
Oxygen	HPC770	BOC	-	10.01	2
Methane	HPC763	BOC	101	-	2
Carbon Dioxide	HPC 751	BOC	-	8.8	2

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

STACK EMISSIONS MONITORING TEAM

Team Leader	Dominic Houghton MCERTS Level 2 Te1 Expiry Date - Dec 2016 Te2 Expiry Date - Dec 2016 Te3 Expiry Date - Mar 2018 Te4 Expiry Date - Dec 2016 MM 04 529 MCERTS Expiry Date - Dec 2016 H&S Expiry Date - Sep 2014
Technician	Ryan Murphy MCERTS Level 1 MM 07 826 MCERTS Expiry Date - Mar 2018 H&S Expiry Date - Apr 2017
Technician	Mark Derbyshire MCERTS Level 1 MM 07 824 MCERTS Expiry Date - Dec 2017 H&S Expiry Date - Apr 2017

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PM_{10} SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	15:06 - 18:06 05 March 2014	0.019	0.019	-	0.82
Run 2	09:03 - 12:03 06 March 2014	0.022	0.019	-	0.96
Run 3	12:35 - 15:35 06 March 2014	0.018	0.018	-	0.78
Run 4	16:09 - 19:09 06 March 2014	0.020	0.019	-	0.87
Run 5	08:49 - 11:49 07 March 2014	0.021	0.015	-	0.78
Run 6	12:55 - 15:55 07 March 2014	0.023	0.019	-	0.97
Blank 1	-	0.025	-	-	-
Blank 2	-	0.019	-	-	-
Blank 3	-	0.019	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.
where values are below the LOD the LOD will be reported.

$PM_{2.5}$ SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	15:06 - 18:06 05 March 2014	0.009	0.009	-	0.41
Run 2	09:03 - 12:03 06 March 2014	0.013	0.009	-	0.56
Run 3	12:35 - 15:35 06 March 2014	0.009	0.009	-	0.39
Run 4	16:09 - 19:09 06 March 2014	0.010	0.009	-	0.43
Run 5	08:49 - 11:49 07 March 2014	0.011	0.008	-	0.39
Run 6	12:55 - 15:55 07 March 2014	0.010	0.009	-	0.41
Blank 1	-	0.019	-	-	-
Blank 2	-	0.010	-	-	-
Blank 3	-	0.010	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.
where values are below the LOD the LOD will be reported, where this occurs the quoted uncertainties will be relatively high.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

$PM_{2.5}$ (BF) SAMPLES WEIGHTS				
Test	$PM_{2.5}$ Filter Number	Filter Start Weight g	Filter End Weight g	$PM_{2.5}$ Mass Gained on Filter g
Run 1	QC980	32.65638	32.65629	-0.00009
Run 2	QC981	31.79779	31.79786	0.00007
Run 3	QC993	31.83096	31.83075	-0.00021
Run 4	QC998	32.04127	32.04118	-0.00009
Run 5	QC999	32.70270	32.70245	-0.00025
Run 6	QC1000	32.91012	32.90998	-0.00014
Blank 1	QC982	32.68564	32.68574	0.00010
Blank 2	QC947	32.73502	32.73488	-0.00014
Blank 3	QC962	32.63680	32.63641	-0.00039

PM_{10} (CP2) SAMPLES WEIGHTS				
Test	PM_{10} Filter Number g	Filter Start Weight g	Filter End Weight g	PM_{10} Mass Gained on Filter g
Run 1	QC978	14.98713	14.98711	-0.00002
Run 2	QC979	15.69719	15.69716	-0.00003
Run 3	QC993	15.66026	15.66020	-0.00006
Run 4	QC994	16.11741	16.11722	-0.00019
Run 5	QC1001	15.56659	15.56647	-0.00012
Run 6	QC1002	15.27270	15.27277	0.00007
Blank 1	QC987	15.49893	15.49896	0.00003
Blank 2	QC908	15.95230	15.95219	-0.00011
Blank 3	QC945	16.05912	16.05901	-0.00011

$PM_{2.5}$ & PM_{10} (BF & CP2) SAMPLES WEIGHTS COMBINED							
Test	$PM_{2.5}$ Filter Number	PM_{10} Filter Number	$PM_{2.5}$ Mass Gained on Filter g	PM_{10} Mass Gained on Filter g	Actual $PM_{2.5}$ & PM_{10} Combined Total Mass Gained g	$PM_{2.5}$ & PM_{10} Combined Weighing LOD g	*Reported $PM_{2.5}$ & PM_{10} Combined Total Mass Gained g
Run 1	QC980	QC978	-0.00009	-0.00002	-0.00011	0.00010	0.00010
Run 2	QC981	QC979	0.00007	-0.00003	0.00004	0.00010	0.00012
Run 3	QC993	QC993	-0.00021	-0.00006	-0.00027	0.00010	0.00010
Run 4	QC998	QC994	-0.00009	-0.00019	-0.00028	0.00010	0.00010
Run 5	QC999	QC1001	-0.00025	-0.00012	-0.00037	0.00010	0.00010
Run 6	QC1000	QC1002	-0.00014	0.00007	-0.00007	0.00010	0.00012
Blank 1	QC982	QC987	0.00010	0.00003	0.00013	0.00010	0.00013
Blank 2	QC947	QC908	-0.00014	-0.00011	-0.00025	0.00010	0.00010
Blank 3	QC962	QC945	-0.00039	-0.00011	-0.00050	0.00010	0.00010

* Where weighing values are below the LOD possibly due to loss of filter material, the LOD will be reported.
NOTE - Where the filter weight gain is less than the weighing uncertainty, the weighing uncertainty is used for further calculations. The weighing uncertainty is 0.00005g.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	765.0
Stack static pressure, P_{static}	mm H_2O	-1.7
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	764.9
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 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		5.91
Gas meter correction factor, Y_d		1.05
Mean dry gas meter temperature, T_m		23.80
Mean pressure drop across orifice, ΔH	mmH_2O	129.19
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.842
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.8102
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		11.83
% oxygen reference condition		11
O_2 Reference Factor: O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		0.92
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	5.357
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1422
	%	14.22
Moisture by FTIR	%	14.22
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, ΔP_{avg}	mm H_2O	36.70
Mean square root of velocity heads, $\sqrt{\Delta P}$		6.1
Mean stack gas temperature, T_s	°C	145
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	24.88

Molecular weight of dry gas, M_d		
CO_2		7.35
O_2		11.83
Total		19.18
N_2 (100 -Total)		80.82
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.65
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.99
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.95
$Q_a = (60)(A_s)(V_s)$	m³/min	1418.6
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	32.80
Actual Flow Rate @ DGM	l/min	35.3
Isokinetic Rate		107.69
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00005
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.01468
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.01712
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.01867
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.82
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0073
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0086
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0093
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.41

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 2 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	765.0	CO_2		7.52
Stack static pressure, P_{static}	mm H_2O	-1.7	O_2		11.76
$P_s = P_b + (P_{static}) / 13.6$	mm Hg	764.9	Total		19.28
			N_2 (100 -Total)		80.72
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.67
Moisture trap weight increase,Vlc	g	H_20 by FTIR	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.94
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		5.96	Area of stack, A_s	m^2	0.95
Gas meter correction factor, Y_d		1.05	$Q_a = (60)(A_s)(V_s)$	m³/min	1399.1
Mean dry gas meter temperature, T_m		24.01	**Percent isokinetic, %I**		
Mean pressure drop across orifice, ΔH	mmH_2O	129.46	Required Flow Rate @ DGM	l/min	32.90
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.879	Actual Flow Rate @ DGM	l/min	36.0
Volume of gas metered wet, V_{mstw}			Isokinetic Rate		109.43
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.9038	Acceptable 90% - 130%		Yes
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Particulate Concentration, C_{PM10}**		
			Mass of particulate collected on PM_{10} filter, M_f		0.00005
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00007
			$C_{wet} = M_n / V_{mstw}$	mg/m³	0.0174
% oxygen measured in gas stream, act%O_2		11.76			
% oxygen reference condition		11	$C_{dry} = M_n / V_{mstd}$	mg/m³	0.0204
O_2 Reference Factor: O2 Ref = (21.0 - act%O2) / (21.0 - ref%O2)		0.92			
			$C_{dry@X\%O2} = M_n / V_{mstd@X\%oxygen}$	mg/m³	0.0221
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	5.432			
Moisture content, B_{wo}			**Particulate Emission Rates, E**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1484	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.96
	%	14.84	**Particulate Concentration, $C_{PM2.5}$**		
Moisture by FTIR	%	14.84	Mass of particulate collected on filter, M_f		0.00007
Velocity of stack gas, V_s			$C_{wet} = M_n / V_{mstw}$	mg/m³	0.0101
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.84	$C_{dry} = M_n / V_{mstd}$	mg/m³	0.0119
Mean of velocity heads, ΔP_{avg}	mm H_2O	35.70			
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.98	$C_{dry@X\%O2} = M_n / V_{mstd@X\%oxygen}$	mg/m³	0.0129
Mean stack gas temperature, T_s	°C	145			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	24.53	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.56

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 3 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	757.5	CO_2		7.53
Stack static pressure, P_{static}	mm H_2O	-1.7	O_2		11.66
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	757.4	Total		19.19
			N_2 (100 -Total)		80.81
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.67
Moisture trap weight increase,Vlc	g	H_20 by FTIR	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		28.00
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		6.02	Area of stack, A_s	m^2	0.95
Gas meter correction factor, Y_d		1.05	$Q_a = (60)(A_s)(V_s)$	m³/min	1355.6
Mean dry gas meter temperature, T_m		28.12	**Percent isokinetic, %I**		
Mean pressure drop across orifice, ΔH	mmH_2O	121.49	Required Flow Rate @ DGM	l/min	31.60
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.800	Actual Flow Rate @ DGM	l/min	33.4
Volume of gas metered wet, V_{mstw}			Isokinetic Rate		105.82
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.7702	Acceptable 90% - 130%		Yes
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Particulate Concentration, C_{PM10}**		
			Mass of particulate collected on PM_{10} filter, M_f		0.00005
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
% oxygen measured in gas stream, act%O_2		11.66	$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0148
% oxygen reference condition		11	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0172
O_2 Reference Factor O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		0.93	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0185
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	5.417			
Moisture content, B_{wo}			**Particulate Emission Rates, E**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1433	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.78
	%	14.33	**Particulate Concentration, $C_{PM2.5}$**		
Moisture by FTIR	%	14.33	Mass of particulate collected on filter, M_f		0.00005
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0074
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.84	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0086
Mean of velocity heads, ΔP_{avg}	mm H_2O	33.19			
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.76	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0092
Mean stack gas temperature, T_s	°C	145			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	23.77	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.39

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 4 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	757.5
Stack static pressure, P_{static}	mm H_2O	-1.7
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	757.4
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 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		5.55
Gas meter correction factor, Y_d		1.05
Mean dry gas meter temperature, T_m		25.54
Mean pressure drop across orifice, ΔH	mmH$_2$O	111.62
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.388
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.2874
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		11.65
% oxygen reference condition		11
O_2 Reference Factor — O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		0.94
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	5.038
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1430
	%	14.30
Moisture by FTIR	%	14.30
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, ΔP_{avg}	mm H_2O	35.24
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.94
Mean stack gas temperature, T_s	°C	145
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	24.50

Molecular weight of dry gas, M_d		
CO_2		7.44
O_2		11.65
Total		19.09
N_2 (100 -Total)		80.91
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.66
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.99
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.95
$Q_a = (60)(A_s)(V_s)$	m³/min	1397.2
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	31.70
Actual Flow Rate @ DGM	l/min	30.8
Isokinetic Rate		97.25
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00005
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0159
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0186
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0198
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.87
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0080
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0093
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0099
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.43

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 5 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	765.0	CO_2		7.01
Stack static pressure, P_{static}	mm H_2O	-1.7	O_2		13.02
$P_s = P_b + (P_{static}) / 13.6$	mm Hg	764.9	Total		20.03
			N_2 (100 -Total)		79.97
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.64
Moisture trap weight increase,Vlc	g	H_20 by FTIR	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		28.65
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		6.05	Area of stack, A_s	m^2	0.95
Gas meter correction factor, Y_d		1.05	$Q_a = (60)(A_s)(V_s)$	m³/min	1277.3
Mean dry gas meter temperature, T_m		26.04	**Percent isokinetic, %I**		
Mean pressure drop across orifice, ΔH	mmH_2O	122.68	Required Flow Rate @ DGM	l/min	33.30
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.932	Actual Flow Rate @ DGM	l/min	33.6
Volume of gas metered wet, V_{mstw}			Isokinetic Rate		100.98
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.4826	Acceptable 90% - 130%		Yes
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Particulate Concentration, C_{PM10}**		
			Mass of particulate collected on PM_{10} filter, M_f		0.00005
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
			$C_{wet} = M_n / V_{mstw}$	mg/m³	0.0154
% oxygen measured in gas stream, act%O_2		13.02			
% oxygen reference condition		11	$C_{dry} = M_n / V_{mstd}$	mg/m³	0.0169
O_2 Reference Factor: O2 Ref = (21.0 - act%O2) / (21.0 - ref%O2)		0.80			
			$C_{dry@X\%O2} = M_n / V_{mstd@X\%oxygen}$	mg/m³	0.0211
$V_{mstd@X\%oxygen} = (V_{mstd}) (O_{2\ Ref})$	m^3	4.733			
Moisture content, B_{wo}			**Particulate Emission Rates, E**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.0850	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.78
	%	8.50	**Particulate Concentration, $C_{PM2.5}$**		
Moisture by FTIR	%	8.50	Mass of particulate collected on filter, M_f		0.00005
Velocity of stack gas, V_s			$C_{wet} = M_n / V_{mstw}$	mg/m³	0.0077
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.84	$C_{dry} = M_n / V_{mstd}$	mg/m³	0.0084
Mean of velocity heads, ΔP_{avg}	mm H_2O	30.57			
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.53	$C_{dry@X\%O2} = M_n / V_{mstd@X\%oxygen}$	mg/m³	0.0106
Mean stack gas temperature, T_s	°C	144			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	22.40	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.39

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 6 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	750.0
Stack static pressure, P_{static}	mm H_2O	-2.1
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	749.9
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	$H_2$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		5.72
Gas meter correction factor, Y_d		1.05
Mean dry gas meter temperature, T_m		22.45
Mean pressure drop across orifice, ΔH	mmH_2O	120.95
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.561
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.4359
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		11.80
% oxygen reference condition		11
O_2 Reference Factor: O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		0.92
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	5.116
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1360
	%	13.60
Moisture by FTIR	%	13.60
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, ΔP_{avg}	mm H_2O	32.76
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.72
Mean stack gas temperature, T_s	°C	145
$V_s = (K_p)(C_p)(\sqrt{\Delta P})\frac{(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	23.71

Molecular weight of dry gas, M_d		
CO_2		7.27
O_2		11.80
Total		19.07
N_2 (100 -Total)		80.93
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.64
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		28.05
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.95
$Q_a = (60)(A_s)(V_s)$	m³/min	1352.0
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	32.70
Actual Flow Rate @ DGM	l/min	31.8
Isokinetic Rate		97.15
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00007
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0186
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0216
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0235
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.97
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0078
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0090
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0098
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.41

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PM_{10} & $PM_{2.5}$ 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	35.32	0.10	0.14	-305	0.71	Yes
Run 2	36.00	0.16	0.24	-457	0.72	Yes
Run 3	33.44	0.12	0.22	-508	0.67	Yes
Run 4	30.83	0.14	0.13	-508	0.62	Yes
Run 5	33.63	0.12	0.18	-508	0.67	Yes
Run 6	31.77	0.18	0.18	-559	0.64	Yes

ISOKINETICITY		
Run	Flow Variation %	Acceptable Variation
Run 1	107.7	Yes
Run 2	109.4	Yes
Run 3	105.8	Yes
Run 4	97.2	Yes
Run 5	101.0	Yes
Run 6	97.1	Yes

Acceptable Flow rate 90 -130%

FILTERS					
Run	Filter Material	Filter Size mm	Max Filtration Temperature °C	Pre-conditioning Filter Temperature °C	Post conditioning Filtration Temperature °C
Run 1	QF	50	149	180	160
Run 2	QF	50	147	180	160
Run 3	QF	50	147	180	160
Run 4	QF	50	146	180	160
Run 5	QF	50	147	180	160
Run 6	QF	50	148	180	160

QF = Quartz Fibre

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Conformity with relevant aspects of BS EN ISO 23210:2009

GENERAL METHODOLOGY

The equipment employed is a Paul Gothe, Johnas cascade impactor (see pg 13 for serial number) system meeting the requirements of BS EN ISO 23210. The standard cites a two-stage impactor system.

The method for sampling requires the extraction of a representative sample of duct gas isokinetically, into a specially designed in-stack sampling head. The Cascade Impactor is a multi-stage, multi-jet impactor which aerodynamically classifies particulates into multiple size ranges. The cascade impactor uses the principle of inertial separation to size segregate particulate samples from the gas stream. The impactor has two stages for particle size determination. Each stage gives a cut-point based on aerodynamic diameter of the particle.

During sampling, the particles are driven (jetted) toward a collecting surface where they may cling. By changing the velocity (orifice size of the jet), the size of the particles collected is controlled. The size of the jets within each stage is constant, but for each succeeding stage the jets get smaller. Impaction occurs when the particle's inertia overcomes the aerodynamic drag. Otherwise, the particle remains in the air stream and proceeds to the next stage. To keep the cut-point for each stage constant, the impactor is operated at a constant flow rate.

At each stage, the particle impacts on to a conditioned and pre-weighed substrate. Following sampling, the substrates are reconditioned and reweighed to determine the mass collected.

Based on the sampling conditions (sampling rate and gas temperature) the cut size (D50 – diameter of particles having a 50% probability of penetration) associated with each impactor stage may be determined.

An homogeneity assessment based on BS EN ISO 23210, Annex G, is undertaken to determine the most representative sampling point in the sampling plane (temperature, velocity and oxygen are suitable surrogates for particulate matter). The velocity measurement at the chosen point is used to determine an appropriate sampling nozzle/flow rate in order to ensure that isokinetic conditions are maintained throughout sampling to within the 90-130% range allowed in the standard (8.1) and which is consistent with the sampling equipment.

Concurrently, the volume of duct gas sampled is measured. This then enables the particulate concentration at each cut size to be determined.

The outlet gas from the sampling head is passed via a sampling probe through an impinger train with the purpose of removing water prior to entry to the sampling control box. It is not intended that the sampling train be used for additional sampling of condensible determinands and as such the train is unheated.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Conformity with relevant aspects of BS EN ISO 23210:2009

Sampling Plane Validation Criteria				
EA Technical Guidance Note (Monitoring) M1	Result	Units	Requirement	Compliant
Lowest Differential Pressure	255	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	20.27	m/s	-	-
Highest Gas Velocity	24.63	m/s	-	-
Ratio of Gas Velocities	1.21	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^{o}	Yes
No local negative flow	Yes	-	-	Yes

Conformance with BS EN ISO 23210:2009			
Reference	Requirement	Result	Compliant
Section 6.3	Suitable Impcator Used	See statement of conformity for Impactor	Yes
Section 8.1	Sampling position acceptable (as per 13284-1)	As per table "Sampling Plane Validation"	Yes
Section 8.1	Nozzle arrangement	See statement of conformity for Impactor	Yes
Section 8.1	Representative sampling point	See Homogeneity assessment below	Yes
Section 8.1	Constant Sample gas flow, iso-kinetic rate 90% to 130%		
	Run 1 - Required flow 32.8 (LPM)		-
	Run 1 - Minimum permissable flow 29.52 (LPM)	29.79	Yes
	Run 1 - Maximum permissable flow 42.64 (LPM)	41.49	Yes
	Run 2 - Required flow 32.9 (LPM)		-
	Run 2 - Minimum permissable flow 29.61 (LPM)	30.16	Yes
	Run 2 - Maximum permissable flow 42.77 (LPM)	40.49	Yes
	Run 3 - Required flow 31.6 (LPM)		-
	Run 3 - Minimum permissable flow 28.44 (LPM)	31.40	Yes
	Run 3 - Maximum permissable flow 41.08 (LPM)	35.36	Yes
	Run 4 - Required flow 31.7 (LPM)		-
	Run 4 - Minimum permissable flow 28.53 (LPM)	28.60	Yes
	Run 4 - Maximum permissable flow 41.21 (LPM)	33.80	Yes
	Run 5 - Required flow 33.3 (LPM)		-
	Run 5 - Minimum permissable flow 29.97 (LPM)	30.20	Yes
	Run 5 - Maximum permissable flow 43.29 (LPM)	37.60	Yes
	Run 6 - Required flow 32.7 (LPM)		-
	Run 6 - Minimum permissable flow 29.43 (LPM)	29.80	Yes
	Run 6 - Maximum permissable flow 42.51 (LPM)	33.00	Yes
Section 8.1	Overall blank taken once per day	Yes	Yes
Section 8.2	Impactor cleaned between each measurement	Yes	Yes
Section 8.2	Arrangement of impactor plates	See statement of conformity for Impactor	Yes
Section 8.3.2	Data taken for velocity, composition, temp & pressure	See "Preliminary stack survey" section	Yes
Section 8.3.3	Sampling rate determination in accordance with Annex A	Yes	Yes
Section 8.3.3	Sample flow rate kept +/- 5% of nominal flow rate		
	Run 1 - Max sample flow deviation from nominal (%)	7.1	No
	Run 2 - Max sample flow deviation from nominal (%)	7.5	No
	Run 3 - Max sample flow deviation from nominal (%)	6.5	No
	Run 4 - Max sample flow deviation from nominal (%)	7.0	No
	Run 5 - Max sample flow deviation from nominal (%)	11.7	No
	Run 6 - Max sample flow deviation from nominal (%)	9.1	No
Section 8.3.4	Nozzle selectedto allow iso-kinetic rate 90% to 130%	Yes, as above	Yes
Section 8.3.5	Leak check less than 2%		
	Run 1	0.28	Yes
	Run 2	0.44	Yes
	Run 3	0.36	Yes
	Run 4	0.45	Yes
	Run 5	0.36	Yes
	Run 6	0.57	Yes
Section 8.3.6	Impactor at flue gas temperature before sampling	Yes	Yes
Section 8.3.6	Angle of nozzle less than 10 Degress to flow	Yes	Yes
Section 8.3.6	Flowrate has checked and recorded every 5 mins	Yes	Yes
Section 8.3.6	Dynamic pressure recorded every 5 mins	Yes	Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Homogeneity assessment

Assessment 1, Municipal waste

Point number (i)	Distance along sample line (mm)	Probe Marking (mm)	Temp Deg C grid	Temp Deg C fixed	r_i
1	28.2	518.2	143	145	0.986
2	89.8	579.8	142	145	0.979
3	161.1	651.1	143	146	0.979
4	248.8	738.8	144	144	1.000
5	376.1	866.1	144	145	0.993
6	723.9	1213.9	144	145	0.993
7	851.2	1341.2	144	146	0.986
8	938.9	1428.9	144	146	0.986
9	1010.2	1500.2	145	146	0.993
10	1071.8	1561.8	146	146	1.000
Second Line					
1	28.2	518.2	145	146	0.993
2	89.8	579.8	144	145	0.993
3	161.1	651.1	145	145	1.000
4	248.8	738.8	145	145	1.000
5	376.1	866.1	145	145	1.000
6	723.9	1213.9	145	145	1.000
7	851.2	1341.2	145	145	1.000
8	938.9	1428.9	145	146	0.993
9	1010.2	1500.2	145	145	1.000
10	1071.8	1561.8	145	145	1.000

No. of points	20
S_{grid}	0.94
S_{ref}	0.571
F	0.99
Is $S_{grid} <= S_{ref}$?	No

F Factor	2.71
$F_{N-1; N-1; 0.95}$	2.17
Is F Factor < $F_{N-1;N-1;0.95}$?	No

S_{pos}	0.747
$t_{N-1;0.95}$	2.093
U_{pos}	1.563
Permissible Uncertainty	10
Is $U_{pos} < 0.5 * U_{perm}$?	Yes

Sample can be taken from a representative location

The best location for SRM probe is Line A, 1010.2 mm along sample line

Assessment 2, CRC waste

Point number (i)	Distance along sample line (mm)	Probe Marking (mm)	Temp Deg C grid	Temp Deg C fixed	r_i
1	28.2	518.2	144	144	1.000
2	89.8	579.8	144	144	1.000
3	161.1	651.1	145	144	1.007
4	248.8	738.8	144	144	1.000
5	376.1	866.1	143	144	0.993
6	723.9	1213.9	143	144	0.993
7	851.2	1341.2	143	143	1.000
8	938.9	1428.9	143	143	1.000
9	1010.2	1500.2	143	143	1.000
10	1071.8	1561.8	143	143	1.000
Second Line					
1	28.2	518.2	143	143	1.000
2	89.8	579.8	143	143	1.000
3	161.1	651.1	144	143	1.007
4	248.8	738.8	144	143	1.007
5	376.1	866.1	144	144	1.000
6	723.9	1213.9	145	144	1.007
7	851.2	1341.2	144	144	1.000
8	938.9	1428.9	144	144	1.000
9	1010.2	1500.2	144	144	1.000
10	1071.8	1561.8	144	144	1.000

No. of points	20
S_{grid}	0.66
S_{ref}	0.503
F	1.00
Is S_{grid} <= S_{ref} ?	No

F Factor	1.708
$F_{N-1; N-1; 0.95}$	2.17
Is F Factor < $F_{N-1;N-1;0.95}$?	Yes

S_{pos}	0.423
$t_{N-1;0.95}$	2.093
U_{pos}	0.885
Permissible Uncertainty	10
Is U_{pos} < 0.5 * U_{perm} ?	N/A

Sample can be taken from any location

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DAILY OXYGEN SUMMARY

Run	Sampling Times	Concentration %	LOD %
1	15:06 - 18:06 05 March 2014	11.83	0.01
2	09:03 - 12:03 06 March 2014	11.76	0.01
3	12:35 - 15:35 06 March 2014	11.66	0.01
4	16:09 - 19:09 06 March 2014	11.65	0.01
5	08:49 - 11:49 07 March 2014	13.02	0.01
6	12:55 - 15:55 07 March 2014	11.80	0.01

PRE SAMPLING CALIBRATION DATA

Date	Time of Analyser Check	Range (%)	Zero Reading at analyser	Span Reading at analyser	Zero Check at analyser	Zero Check down line	Span Check down line	Leak Rate %
05 March 2014	10:00 - 10:30	25	0.00	10.01	0.00	0.03	10.02	0.10
06 March 2014	08:30 - 08:50	25	0.00	10.01	0.00	-0.02	10.03	0.20
07 March 2014	08:05 - 08:30	25	0.00	10.01	0.00	0.00	10.03	0.20

POST SAMPLING CALIBRATION DATA

Date	Time of Analyser Check	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
06 March 2014	08:00 - 08:30	0.05	10.06	0.08	0.20
06 March 2014	19:15 - 19:30	0.06	10.1	0.32	-0.10
07 March 2014	16:05 - 16:15	-0.12	9.9	-0.48	-0.10

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GAS SUMMARY

Test	Sampling Times	Concentration %	Analysis Areas	Interference (%) *	LOD %
Moisture Run 1	15:06 - 18:06 05 March 2014	14.2	3200 - 3401	1.7	0.10
Moisture Run 2	09:03 - 12:03 06 March 2014	14.8	3200 - 3401	0.97	0.10
Moisture Run 3	12:35 - 15:35 06 March 2014	14.3	3200 - 3401	0.97	0.10
Moisture Run 4	16:09 - 19:09 06 March 2014	14.3	3200 - 3401	0.97	0.10
Moisture Run 5	08:49 - 11:49 07 March 2014	8.5	3200 - 3401	1.68	0.00
Moisture Run 6	12:55 - 15:55 07 March 2014	13.6	3200 - 3401	1.68	0.00
Carbon Dioxide Run 1	15:06 - 18:06 05 March 2014	7.3	2000 - 2223	0.27	0.01
Carbon Dioxide Run 2	09:03 - 12:03 06 March 2014	7.5	2000 - 2223	0.97	0.01
Carbon Dioxide Run 3	12:35 - 15:35 06 March 2014	7.1	2000 - 2223	0.97	0.01
Carbon Dioxide Run 4	16:09 - 19:09 06 March 2014	7.1	2000 - 2223	0.97	0.01
Carbon Dioxide Run 6	12:55 - 15:55 07 March 2014	7.1	2000 - 2223	0.27	0.01

*M22 Specifies interference must be <5%.

FTIR CALIBRATION CHECKS

Pre - Sampling Checks - System			Date of Checks	05 March 2014		Time of Checks	12:57	
Post Sampling Checks - System			Date of Checks	06 March 2014		Time of Checks	08:49	
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
H_2O	0.21	0.49	0.92	101.0	101.7	0.66	99.7	-1.97
CO_2(%)	0.00	0.00	0.01	8.8	8.6	-2.27	8.7	0.58

Pre - Sampling Checks - System			Date of Checks	06 March 2014		Time of Checks	08:35	
Post Sampling Checks - System			Date of Checks	06 March 2014		Time of Checks	19:14	
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
H_2O	0.21	0.01	-0.14	101.0	99.7	-1.32	99.0	-0.67
CO_2(%)	0.00	0.00	0.01	8.8	8.7	-1.70	8.7	0.19

Pre - Sampling Checks - System			Date of Checks	07 March 2014		Time of Checks	08:17	
Post Sampling Checks - System			Date of Checks	07 March 2014		Time of Checks	16:07	
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
H_2O	0.21	0.00	-0.14	101.0	99.4	-1.58	99.0	-0.40
CO_2(%)	0.00	0.00	0.01	8.8	8.5	-3.41	8.6	1.57

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.

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	1.10	m
Stack Width, W	-	m
Stack Area, A	0.95	m^2
Average stack gas temperature	144	^oC
Stack static pressure	-0.25	kPa
Barometric Pressure	101.5	kPa
Pitot tube calibration coefficient, K_{pt}	0.84	-

Stack Gas Composition & Molecular Weights

Component	Molar Mass M	Density kg/m^3 p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m^3 pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m^3 pi
CO_2	44	1.96	8.57	0.09	0.17	7.43	0.07	0.15
O_2	32	1.43	11.95	0.12	0.17	10.36	0.10	0.15
N_2	28	1.25	79.48	0.79	0.99	68.91	0.69	0.86
H_2O	18	0.80	-	-	-	13.30	0.13	0.11

Where: p = M / 22.41 p*i* = r x p

Calculation of Stack Gas Densities

Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3317	kg/m^3
Wet Density (STP), P_{STW}	1.2614	kg/m^3
Dry Density (Actual), P_{Actual}	0.8705	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.825	kg/m^3

Where:

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

P_{STW} = (P_{STD} + p*i* of H_2O) / (1 + (p*i* 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 March 2014
Time of Survey	11:00
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	30.0	294	143	21.80	-	<15
2	0.17	32.0	314	142	22.49	-	<15
3	0.28	32.0	314	143	22.52	-	<15
4	0.39	28.0	274	144	21.09	-	<15
5	0.50	30.0	294	143	21.80	-	<15
6	0.61	30.0	294	144	21.83	-	<15
7	0.72	34.0	333	144	23.24	-	<15
8	0.83	34.0	333	144	23.24	-	<15
9	0.94	32.0	314	146	22.60	-	<15
10	1.05	28.0	274	146	21.14	-	<15
Mean	-	31.0	304	144	22.17	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	30.0	294	145	21.86	-	<15
2	0.17	32.0	314	144	22.54	-	<15
3	0.28	32.0	314	145	22.57	-	<15
4	0.39	30.0	294	145	21.86	-	<15
5	0.50	28.0	274	145	21.11	-	<15
6	0.61	28.0	274	145	21.11	-	<15
7	0.72	30.0	294	145	21.86	-	<15
8	0.83	30.0	294	145	21.86	-	<15
9	0.94	30.0	294	145	21.86	-	<15
10	1.05	32.0	314	145	22.57	-	<15
Mean	-	30.2	296	145	21.92	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 2

Date of Survey	05 March 2014
Time of Survey	18:46
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl º
1	0.06	32.0	314	144	22.54	-	<15
2	0.17	32.0	314	145	22.57	-	<15
3	0.28	36.0	353	145	23.94	-	<15
4	0.39	32.0	314	145	22.57	-	<15
5	0.50	30.0	294	145	21.86	-	<15
6	0.61	28.0	274	144	21.09	-	<15
7	0.72	32.0	314	144	22.54	-	<15
8	0.83	30.0	294	144	21.83	-	<15
9	0.94	30.0	294	144	21.83	-	<15
10	1.05	30.0	294	144	21.83	-	<15
Mean	-	31.2	306	144	22.26	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl º
1	0.06	32.0	314	144	22.54	-	<15
2	0.17	34.0	333	145	23.27	-	<15
3	0.28	34.0	333	145	23.27	-	<15
4	0.39	32.0	314	145	22.57	-	<15
5	0.50	32.0	314	145	22.57	-	<15
6	0.61	30.0	294	145	21.86	-	<15
7	0.72	30.0	294	145	21.86	-	<15
8	0.83	34.0	333	145	23.27	-	<15
9	0.94	32.0	314	145	22.57	-	<15
10	1.05	32.0	314	145	22.57	-	<15
Mean	-	32.2	316	145	22.63	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 3

Date of Survey	06 March 2014
Time of Survey	08:20
Velocity Measurement Device:	S-Type Pitot

Sampling Line A							
Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	32.0	314	137	22.35	-	<15
2	0.17	28.0	274	142	21.04	-	<15
3	0.28	32.0	314	143	22.52	-	<15
4	0.39	34.0	333	144	23.24	-	<15
5	0.50	32.0	314	143	22.52	-	<15
6	0.61	30.0	294	144	21.83	-	<15
7	0.72	28.0	274	144	21.09	-	<15
8	0.83	34.0	333	144	23.24	-	<15
9	0.94	36.0	353	146	23.97	-	<15
10	1.05	32.0	314	146	22.60	-	<15
Mean	-	31.8	312	143.3	22.44	-	

Sampling Line B							
Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	30.0	294	145	21.86	-	<15
2	0.17	32.0	314	144	22.54	-	<15
3	0.28	34.0	333	145	23.27	-	<15
4	0.39	36.0	353	145	23.94	-	<15
5	0.50	30.0	294	145	21.86	-	<15
6	0.61	28.0	274	145	21.11	-	<15
7	0.72	30.0	294	145	21.86	-	<15
8	0.83	34.0	333	145	23.27	-	<15
9	0.94	36.0	353	145	23.94	-	<15
10	1.05	32.0	314	145	22.57	-	<15
Mean	-	32.2	316	145	22.62	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 4

Date of Survey	06 March 2014
Time of Survey	12:08
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	34.0	333	145	23.27	-	<15
2	0.17	34.0	333	145	23.27	-	<15
3	0.28	36.0	353	145	23.94	-	<15
4	0.39	36.0	353	145	23.94	-	<15
5	0.50	32.0	314	144	22.54	-	<15
6	0.61	30.0	294	144	21.83	-	<15
7	0.72	30.0	294	146	21.88	-	<15
8	0.83	36.0	353	146	23.97	-	<15
9	0.94	34.0	333	145	23.27	-	<15
10	1.05	32.0	314	145	22.57	-	<15
Mean	-	33.4	327	145	23.05	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	32.0	314	146	22.60	-	<15
2	0.17	34.0	333	146	23.29	-	<15
3	0.28	36.0	353	145	23.94	-	<15
4	0.39	34.0	333	145	23.27	-	<15
5	0.50	38.0	372	145	24.60	-	<15
6	0.61	34.0	333	145	23.27	-	<15
7	0.72	36.0	353	144	23.91	-	<15
8	0.83	38.0	372	146	24.63	-	<15
9	0.94	36.0	353	145	23.94	-	<15
10	1.05	36.0	353	145	23.94	-	<15
Mean	-	35.4	347	145	23.74	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 5

Date of Survey	06 March 2014
Time of Survey	15:35
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	0.06	34.0	333	145	23.27	-	<15
2	0.17	32.0	314	145	22.57	-	<15
3	0.28	32.0	314	145	22.57	-	<15
4	0.39	30.0	294	146	21.88	-	<15
5	0.50	30.0	294	146	21.88	-	<15
6	0.61	28.0	274	146	21.14	-	<15
7	0.72	32.0	314	145	22.57	-	<15
8	0.83	36.0	353	146	23.97	-	<15
9	0.94	36.0	353	146	23.97	-	<15
10	1.05	34.0	333	146	23.29	-	<15
Mean	-	32.4	318	145.6	22.71	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	0.06	34.0	333	145	23.27	-	<15
2	0.17	34.0	333	145	23.27	-	<15
3	0.28	32.0	314	145	22.57	-	<15
4	0.39	34.0	333	146	23.29	-	<15
5	0.50	32.0	314	146	22.60	-	<15
6	0.61	30.0	294	146	21.88	-	<15
7	0.72	32.0	314	146	22.60	-	<15
8	0.83	36.0	353	146	23.97	-	<15
9	0.94	38.0	372	146	24.63	-	<15
10	1.05	36.0	353	146	23.97	-	<15
Mean	-	33.8	331	146	23.20	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 6

Date of Survey	06 March 2014
Time of Survey	19:35
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH$_2$O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	32.0	314	145	22.57	-	<15
2	0.17	34.0	333	145	23.27	-	<15
3	0.28	38.0	372	145	24.60	-	<15
4	0.39	36.0	353	146	23.97	-	<15
5	0.50	32.0	314	146	22.60	-	<15
6	0.61	30.0	294	146	21.88	-	<15
7	0.72	28.0	274	146	21.14	-	<15
8	0.83	30.0	294	146	21.88	-	<15
9	0.94	34.0	333	146	23.29	-	<15
10	1.05	36.0	353	146	23.97	-	<15
Mean	-	33.0	323	146	22.92	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH$_2$O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	32.0	314	145	22.57	-	<15
2	0.17	34.0	333	145	23.27	-	<15
3	0.28	38.0	372	146	24.63	-	<15
4	0.39	36.0	353	146	23.97	-	<15
5	0.50	32.0	314	145	22.57	-	<15
6	0.61	30.0	294	146	21.88	-	<15
7	0.72	28.0	274	146	21.14	-	<15
8	0.83	30.0	294	146	21.88	-	<15
9	0.94	34.0	333	146	23.29	-	<15
10	1.05	36.0	353	146	23.97	-	<15
Mean	-	33.0	323	146	22.92	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 7

Date of Survey	07 March 2014
Time of Survey	08:25
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	0.06	32.0	314	144	22.54	-	<15
2	0.17	32.0	314	144	22.54	-	<15
3	0.28	30.0	294	145	21.86	-	<15
4	0.39	30.0	294	144	21.83	-	<15
5	0.50	28.0	274	143	21.06	-	<15
6	0.61	28.0	274	143	21.06	-	<15
7	0.72	28.0	274	143	21.06	-	<15
8	0.83	28.0	274	143	21.06	-	<15
9	0.94	32.0	314	143	22.52	-	<15
10	1.05	34.0	333	143	23.21	-	<15
Mean	-	30.2	296	143.5	21.88	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	0.06	30.0	294	143	21.80	-	<15
2	0.17	28.0	274	143	21.06	-	<15
3	0.28	28.0	274	144	21.09	-	<15
4	0.39	28.0	274	144	21.09	-	<15
5	0.50	28.0	274	144	21.09	-	<15
6	0.61	26.0	255	145	20.35	-	<15
7	0.72	34.0	333	144	23.24	-	<15
8	0.83	32.0	314	144	22.54	-	<15
9	0.94	32.0	314	144	22.54	-	<15
10	1.05	32.0	314	144	22.54	-	<15
Mean	-	29.8	292	144	21.74	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 8

Date of Survey	07 March 2014
Time of Survey	11:55
Velocity Measurement Device:	S-Type Pitot

Sampling Line A							
Traverse Point	Distance into duct (m)	ΔP pt mmH$_2$O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	30.0	294	144	21.83	-	<15
2	0.17	32.0	314	143	22.52	-	<15
3	0.28	32.0	314	143	22.52	-	<15
4	0.39	30.0	294	143	21.80	-	<15
5	0.50	28.0	274	142	21.04	-	<15
6	0.61	26.0	255	142	20.27	-	<15
7	0.72	28.0	274	142	21.04	-	<15
8	0.83	30.0	294	142	21.78	-	<15
9	0.94	32.0	314	142	22.49	-	<15
10	1.05	32.0	314	142	22.49	-	<15
Mean	-	30.0	294	143	21.78	-	

Sampling Line B							
Traverse Point	Distance into duct (m)	ΔP pt mmH$_2$O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	32.0	314	143	22.52	-	<15
2	0.17	32.0	314	143	22.52	-	<15
3	0.28	32.0	314	143	22.52	-	<15
4	0.39	28.0	274	143	21.06	-	<15
5	0.50	30.0	294	142	21.78	-	<15
6	0.61	28.0	274	142	21.04	-	<15
7	0.72	26.0	255	142	20.27	-	<15
8	0.83	28.0	274	142	21.04	-	<15
9	0.94	28.0	274	142	21.04	-	<15
10	1.05	26.0	255	142	20.27	-	<15
Mean	-	29.0	284	142	21.41	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 9

Date of Survey	07 March 2014
Time of Survey	12:40
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	32.0	314	145	22.57	-	<15
2	0.17	34.0	333	145	23.27	-	<15
3	0.28	32.0	314	145	22.57	-	<15
4	0.39	34.0	333	146	23.29	-	<15
5	0.50	36.0	353	146	23.97	-	<15
6	0.61	32.0	314	146	22.60	-	<15
7	0.72	32.0	314	146	22.60	-	<15
8	0.83	36.0	353	146	23.97	-	<15
9	0.94	38.0	372	146	24.63	-	<15
10	1.05	32.0	314	146	22.60	-	<15
Mean	-	33.8	331	146	23.21	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	34.0	333	146	23.29	-	<15
2	0.17	36.0	353	146	23.97	-	<15
3	0.28	34.0	333	146	23.29	-	<15
4	0.39	32.0	314	146	22.60	-	<15
5	0.50	30.0	294	146	21.88	-	<15
6	0.61	32.0	314	145	22.57	-	<15
7	0.72	34.0	333	145	23.27	-	<15
8	0.83	34.0	333	146	23.29	-	<15
9	0.94	36.0	353	146	23.97	-	<15
10	1.05	34.0	333	146	23.29	-	<15
Mean	-	33.6	329	146	23.14	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 10

Date of Survey	07 March 2014
Time of Survey	16:00
Velocity Measurement Device:	S-Type Pitot

Sampling Line A							
Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	32.0	314	145	22.57	-	<15
2	0.17	34.0	333	145	23.27	-	<15
3	0.28	34.0	333	145	23.27	-	<15
4	0.39	34.0	333	146	23.29	-	<15
5	0.50	36.0	353	146	23.97	-	<15
6	0.61	32.0	314	146	22.60	-	<15
7	0.72	30.0	294	145	21.86	-	<15
8	0.83	34.0	333	145	23.27	-	<15
9	0.94	36.0	353	145	23.94	-	<15
10	1.05	34.0	333	145	23.27	-	<15
Mean	-	33.6	329	145	23.13	-	

Sampling Line B							
Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.06	34.0	333	145	23.27	-	<15
2	0.17	34.0	333	145	23.27	-	<15
3	0.28	32.0	314	144	22.54	-	<15
4	0.39	32.0	314	144	22.54	-	<15
5	0.50	36.0	353	144	23.91	-	<15
6	0.61	36.0	353	144	23.91	-	<15
7	0.72	34.0	333	144	23.24	-	<15
8	0.83	34.0	333	144	23.24	-	<15
9	0.94	34.0	333	144	23.24	-	<15
10	1.05	32.0	314	144	22.54	-	<15
Mean	-	33.8	331	144	23.17	-	

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	255	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	20.27	m/s	-	-
Highest Gas Velocity	24.63	m/s	-	-
Ratio of Gas Velocities	1.21	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	^{o}	$< 15^o$	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V

Velocity at Traverse Point, $V = K_{pt} \times (1-\varepsilon) * \sqrt{(2 * \Delta P_{pt} / P_{ActualW})}$

Where:

K_{pt} = Pitot tube calibration coefficient

$(1-\varepsilon)$ = Compressibility correction factor, assumed at a constant 0.998

Average Stack Gas Velocity, Va	**22.44**	m/s

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))

Day 1	05 March 2014

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	145	0	^oC
Total Pressure	101.3	101.3	kPa
Oxygen	11.8	11	%
Moisture	14.22	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	22.25		m/s
Stack Area (A)	0.95		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	76122		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	49758		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	42683		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	39134		m^3/hr

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

Day 2	06 March 2014		
Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	145	0	°C
Total Pressure	101.3	101.3	kPa
Oxygen	11.7	11	%
Moisture	14.50	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	22.95		m/s
Stack Area (A)	0.95		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	78525		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	51254		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	43821		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	40783		m^3/hr

Day 3	07 March 2014		
Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	144	0	°C
Total Pressure	101.2	101.3	kPa
Oxygen	12.4	11	%
Moisture	11.08	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	22.03		m/s
Stack Area (A)	0.95		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	75392		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	49356		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	43888		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	37699		m^3/hr

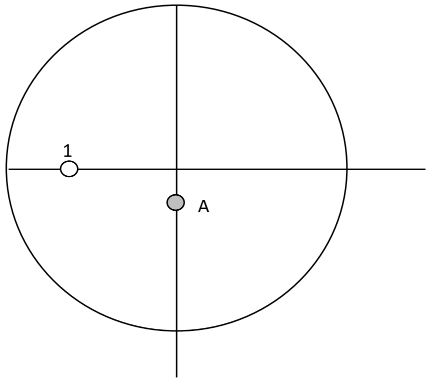
Nomenclature:

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	1.10	m
Stack Width	-	m
Area	0.95	m^2



Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	40	0.44	m

Isokinetic Sampling CEN Methods			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	85.0	0.94	<15

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

SAMPLING LOCATION

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - PM 10

Run	Sampled m³	Sampled Gas K	Sampled Gas kPa	Sampled Gas % by volume	Oxygen % by volume	Limit of % by mass	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	0.10	-
as a %	0.02	0.48	0.49	1.00	0.85	N/A	0.40
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.10	-
as a %	0.02	0.48	0.49	1.00	0.85	N/A	0.67
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 3	0.001	2	0.5	1	0.1	0.1000	-
as a %	0.02	0.48	0.50	1.00	0.86	N/A	0.66
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 4	0.001	2	0.5	1	0.1	0.10	-
as a %	0.02	0.48	0.50	1.00	0.86	N/A	0.42
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 5	0.001	2	0.5	1	0.1	0.10	-
as a %	0.02	0.48	0.49	1.00	0.77	N/A	0.54
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 6	0.001	2	0.5	1	0.1	0.10	-
as a %	0.11	0.48	0.49	1.00	0.85	N/A	0.57
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	Mass of particulate mg	O2 Correction -	Leak mg/m³	Combined uncertainty
Run 1	0.0053	0.1867	0.017	1.000	-
MU as mg/m^3	0.0002	0.0187	0.0002	0.00004	**100.01**
MU as %	0.0042	100.0	1.091	0.229	-
Run 2	0.0062	0.1841	0.020	1.000	-
MU as mg/m^3	0.0003	0.0184	0.0002	0.00009	**83.34**
MU as %	0.0050	83.3	1.082	0.385	-
Run 3	0.0052	0.1846	0.017	1.000	-
MU as mg/m^3	0.0002	0.0185	0.0002	0.00007	**100.006**
MU as %	0.0042	100.0	1.071	0.380	-
Run 4	0.0061	0.20	0.019	1.00	-
MU as mg/m^3	0.0002	0.02	0.0002	0.00005	**100.01**
MU as %	0.0045	100.0	1.070	0.24	-
Run 5	0.0068	0.21	0.017	1.00	-
MU as mg/m^3	0.0003	0.02	0.0003	0.00007	**100.01**
MU as %	0.0048	100.0	1.253	0.31	-
Run 6	0.0162	0.08	0.009	1.00	-
MU as mg/m^3	0.0001	0.01	0.0001	0.00003	**83.34**
MU as %	0.0022	83.3	1.087	0.33	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.04**	**mg/m³**	**200.03**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.04**	**mg/m³**	**166.70**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.04**	**mg/m³**	**200.03**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.04**	**mg/m³**	**200.03**	**%**
R5 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.04**	**mg/m³**	**200.03**	**%**
R6 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.02**	**mg/m³**	**166.70**	**%**

(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 - PM 2.5

Run	Sampled m³	Sampled Gas K	Sampled Gas kPa	Sampled Gas % by volume	Oxygen % by volume	Limit of % by mass	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	0.05	-
as a %	0.02	0.48	0.49	1.00	0.85	N/A	0.40
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.02	0.48	0.49	1.00	0.85	N/A	0.67
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 3	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.02	0.48	0.50	1.00	0.86	N/A	0.66
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 4	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.02	0.48	0.50	1.00	0.86	0.00	0.42
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 5	0.001	2	0.5	1	0.1	0.05	-
as a %	0.02	0.48	0.49	1.00	0.77	N/A	0.54
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 6	0.001	2	0.5	1	0.1	0.05	-
as a %	0.11	0.48	0.49	1.00	0.85	N/A	0.57
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	Mass of particulate mg	O2 Correction -	Leak mg/m³	Combined uncertainty
Run 1	0.00	0.1867	0.0086	1.000	-
MU as mg/m³	0.0001	0.0093	0.0001	0.00002	**100.01**
MU as %	0.0021	100.0000	1.0905	0.23	-
Run 2	0.0036	0.1841	0.0119	1.000	-
MU as mg/m³	0.0002	0.0092	0.0001	0.00005	**71.44**
MU as %	0.0029	71.4286	1.0823	0.38	-
Run 3	0.0037	0.2577	0.0120	1.000	-
MU as mg/m³	0.0002	0.0129	0.0001	0.00005	**100.01**
MU as %	0.0029	100.0000	1.0707	0.38	-
Run 4	0.0030	0.1985	0.0093	1.0000	-
MU as mg/m³	0.0001	0.0099	0.0001	0.00002	**100.01**
MU as %	0.0022	100.0000	1.0695	0.24	-
Run 5	0.003	0.211	0.0084	1.000	-
MU as mg/m³	0.000	0.011	0.0001	0.00003	**100.01**
MU as %	0.002	100.000	1.2531	0.31	-
Run 6	0.02	0.20	0.0090	1.00	**-**
MU as mg/m³	0.00	0.01	0.0001	0.00003	**100.01**
MU as %	0.0	100.0	1.0870	0.33	**-**

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.019**	**mg/m³**	**200.03**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.018**	**mg/m³**	**142.90**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.026**	**mg/m³**	**200.03**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.020**	**mg/m³**	**200.03**	**%**
R5 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.021**	**mg/m³**	**200.03**	**%**
R6 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.020**	**mg/m³**	**200.03**	**%**

(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 - CARBON DIOXIDE BY FTIR

Actual Measured Concentration	7.35	% vol
Measured Concentration at Reference Conditions	7.35	% vol
Emission Limit Value	-	% vol
Instrument Range	10	% vol
Check Gas Concentration	8.80	% vol

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)	0.010	<5%	Yes
Span drift (calculated from start and end readings).	0.581	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	0.990	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.100	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	-1.300	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	1.600	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	0.275	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.080	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	% vol
Uncertainty of linearity (lack of fit) U_{fit}	-0.110
Uncertainty of zero drift $U_{0,dr}$	0.001
Uncertainty of span drift $U_{s,dr}$	0.034
Uncertainty of volume or pressure flow dependence U_{spress}	0.057
Uncertainty in Ambient Temperature U_{temp}	0.075
Uncertainty in Voltage U_{volt}	0.092
Uncertainty of interferents U_i	0.016
Uncertainty of Repeatability U_r	0.008
Uncertainty of Certified Reference Material U_{cal}	0.051

Measurement Uncertainty	% vol
Combined uncertainty	0.18
Expanded uncertainty at a 95% Confidence Interval	0.37

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	4.98
Expressed as a % of the Measured Concentration at Reference Conditions	4.98
Expressed as a % of the Emission Limit Value	-

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE BY FTIR

Actual Measured Concentration	14.22	% vol
Measured Concentration at Reference Conditions	14.22	% vol
Emission Limit Value	30	% vol
Instrument Range	30	% vol
Check Gas Concentration (Methane was used as a Surrogate)	72.14	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)	0.923	<5%	Yes
Span drift (calculated from start and end readings).	-1.967	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	0.990	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.100	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	-1.000	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	0.710	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	1.676	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.170	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	% vol
Uncertainty of linearity (lack of fit) U_{fit}	-0.329
Uncertainty of zero drift $U_{0,dr}$	0.160
Uncertainty of span drift $U_{s,dr}$	-0.341
Uncertainty of volume or pressure flow dependence U_{spress}	0.171
Uncertainty in Ambient Temperature U_{temp}	0.174
Uncertainty in Voltage U_{volt}	0.123
Uncertainty of interferents U_i	0.290
Uncertainty of Repeatability U_r	0.051
Uncertainty of Certified Reference Material U_{cal}	0.417

Measurement Uncertainty	% vol
Combined uncertainty	0.76
Expanded uncertainty at a 95% Confidence Interval	1.53

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	10.76
Expressed as a % of the Measured Concentration at Reference Conditions	10.76
Expressed as a % of the Emission Limit Value	5.10

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 1 - 05 March 2014

Reference	11	%vol
Measured concentration	11.83	%vol
Calibration gas	10.01	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	30	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	180	minutes	-	-
Number of readings in measurement	180	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.08	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	0.20	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.10	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	0.183
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.020
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	0.007
Uncertainty of calibration gas	ucalib	0.137

Measurement uncertainty (Concentration Measured)	11.83	%vol
Combined uncertainty	0.27	%vol
% of value	2.27	%

Expanded uncertainty expressed with a level of confidence of 95%	**4.54**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**0.54**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 2 - 06 March 2014

Reference	11	%vol
Measured concentration	11.69	%vol
Calibration gas	10.01	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	30	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	606	minutes	-	-
Number of readings in measurement	606	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.32	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.10	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.20	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	0.117
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.081
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	0.013
Uncertainty of calibration gas	ucalib	0.135

Measurement uncertainty (Concentration Measured)	11.69	%vol
Combined uncertainty	0.24	%vol
% of value	2.07	%

Expanded uncertainty expressed with a level of confidence of 95%	**4.14**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**0.48**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 3 - 07 March 2014

Reference	11	%vol
Measured concentration	12.41	%vol
Calibration gas	10.01	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	30	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	426	minutes	-	-
Number of readings in measurement	426	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	-0.48	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.10	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.20	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	-0.349
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.081
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	0.014
Uncertainty of calibration gas	ucalib	0.143

Measurement uncertainty (Concentration Measured)	12.41	%vol
Combined uncertainty	0.41	%vol
% of value	3.31	%

Expanded uncertainty expressed with a level of confidence of 95%	**6.62**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**0.82**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 4 - Summaries, Calculations, Raw Data and Charts

NOTE - The following data is provided for information only and falls outside ESG's scope of accreditation

COMBINED UNCOLLECTED SUMMARY

Test	Sampling Times	$>PM_{10}$ Concentration		Probe Rinse Concentration		Combined Unweighed Concentration	
		Measured mg/m³	LOD mg/m³	Measured mg/m³	LOD mg/m³	Measured mg/m³	LOD mg/m³
Run 1	15:06 - 18:06 05 March 2014	0.009	0.009	0.243	0.243	0.252	0.252
Run 2	09:03 - 12:03 06 March 2014	0.009	0.009	0.239	0.239	0.249	0.249
Run 3	12:35 - 15:35 06 March 2014	0.009	0.009	0.240	0.240	0.249	0.249
Run 4	16:09 - 19:09 06 March 2014	0.010	0.010	0.258	0.258	0.268	0.268
Run 5	08:49 - 11:49 07 March 2014	0.011	0.011	0.275	0.275	0.285	0.285
Run 6	12:55 - 15:55 07 March 2014	0.010	0.010	0.254	0.254	0.264	0.264

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

Where the result is less than the LOD, the LOD is reported.

SAMPLES

Test	$>PM_{10}$ Filter Number	Filter Start Weight g	Filter End Weight g	Mass Gained on Filter g	Probe Rinse Number	Probe Rinse Start Weight g	Probe Rinse End Weight g	Mass Gained in Rinse g	Combined Total Mass Gained g
Run 1	QC978/QC980	47.6435	47.6434	-0.00011	QC978/QC980	184.4871	184.4874	0.00030	0.00019
Run 2	QC979/QC981	47.4950	47.4950	0.00004	QC979/QC981	188.86250	188.86250	0.00000	0.00004
Run 3	QC993/QC997	47.4912	47.4910	-0.00027	QC993/QC997	160.08390	160.08330	-0.00060	-0.00087
Run 4	QC994/QC998	48.1587	48.1584	-0.00028	QC994/QC998	179.02650	179.02780	0.00130	0.00102
Run 5	QC1001/QC999	48.2693	48.2689	-0.00037	QC1001/QC999	144.96360	144.96450	0.00090	0.00053
Run 6	QC1002/QC100	48.1828	48.1828	-0.00007	QC1002/QC100	185.67260	185.67300	0.00040	0.00033
Blank 1	QC987/QC982	48.1846	48.1847	0.00013	QC908/QC947	195.95230	195.95230	0.00000	0.00013
Blank 2	QC908/QC947	48.6873	48.6871	-0.00025	QC908/QC947	183.51920	183.51910	-0.00010	-0.00035
Blank 3	QC945/QC962	48.6959	48.6954	-0.00050	QC945/QC962	190.84600	190.84590	-0.00010	-0.00060

PAUL GOTHE BOCHUM

Manufacturer of Emissions Control Technology
SEIT 1924

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VAT-No.: DE 813078723
Trade Register Bochum: HRB-6891

To our customers

Your ref	Your letter	Our ref	Date 14.03.2007

Calibration of the Johnas Impactor according to **ISO 23210**
6.2 Separation curves and Section 6.3 Verification of the separation curves

The Johnas Impactor from Paul Gothe GmbH was developed before the ISO Guideline was evaluated and after the Germans and the Netherlands Authorities have enough experiences with our impactor. After that the European Delegation creates the ISO Guideline 23210. The section 6.3 is important and was influence by the Germans. They have the experiences and write the rules for the calibration section accordingly it was made for the Johnas-Impactor.
The development from the Johnas impactor starts with a doctoral thesis from Mrs. John at the Gerhard-Mercator-University. She makes the intensive testing and Mr. Geueke from the North Rhine Westphalia State Environment Agency makes additional verifications at the ESA (Emission Simulation Facility) at the Hessian Agency for the Environment and Geology (HLUG).

Most of the literatures and papers are in German, but all well-known:

1. Probenahme und chemische Analytik von korngrößenfraktionierten Immissions- und Emissionsaerosolen. Von der Fakultät für Naturwissenschaften der Gerhard-Mercator-Universität – Gesamthochschule Duisburg zur Erlangung des akademischen Grades eines Dr. rer. nat. genehmigte Dissertation von ASTRID CHRISTIANE JOHN aus Lichtenfels.
2. Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit Luftreinhaltung Forschungsbericht 298 44 280, Korngrößenverteilung (PM10 und PM2,5) von Staubemissionen relevanter stationärer Quellen (Teil II zu 297 44 853), von Dipl.-Ing. A. Dreiseidler, Ing. D. Straub, Prof. Dr.-Ing. G. Baumbach, Universität Stuttgart, Institut für Verfahrenstechnik und Dampfkesselwesen (IVD), Abteilung Reinhaltung der Luft (RdL), Institutsleiter: Prof. Dr.-Ing. K.R.G. Hein, IM AUFTRAG DES UMWELTBUNDESAMTES Juni 2001.
3. VDI 2066, part 10
4. Gefahrstoffe-Reinhaltung der Luft 59 (1999), Nr.11/12, S. 449-453

All this papers shows, that the design of the Johnas Impactor is a proved version for the determination of the PM 2.5 and PM 10. The shape of the separation curves is similar to those specified in ISO 7708:1995 and the separation efficiency at 10 µm and 2,5 µm is 50 % according to section 6.3 of the ISO 23210.

What you need more? There is no authority which has more competence as the listed authorities.

If you still in doubt, you maybe get in contact with Mr. Geueke (phone: ++49-201-7995-1263).

Paul Gothe GmbH

Westdeutsche Landesbank for Sparkasse Bochum
IBAN DE 24 430500 01 000 120 9840 Swift: WELADED1BOC

Companion: Paul Gothe-Stiftung
Management: Dr. T. Grodten and Th. Hinrichs

PAUL GOTHE BOCHUM

Manufacturer of Emissions Control Technology
SEIT 1924

DIN ISO 9001

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Trade Register Bochum: HRB-6891

To our customers

Your ref	Your letter	Our ref	Date 14.03.2007

Declaration of conformity

Herewith the company Paul Gothe GmbH in Bochum declare that the manufactured Cascade Impactor Johnas follows the guidelines from the North Rhine Westphalia State Environment Agency according the convention from 24 June 1999 and the PM 4 stage follows the convention of the Federal Environment Agency from 09. March 2005.

Our Cascade Impactor Johnas was developed in cooperation with the North Rhine Westphalia State Environment and the Gerhard-Mercator University Duisburg. This impactor was validated and after that 2004 adopted in the German Standard VDI 2066, part 10 and 2005 in ISO Standard 23210. All sizes of our manufactured impactors are according to these guidelines, individually checked according our strict quality management and named with a specific serial number. Only an impactor with this serial number is according to the Guideline VDI 2066, part 10 and ISO Standard 23210 and can use for the determination of PM 10 and PM 2.5.

Paul Gothe GmbH

Dr. Torsten Grodten

-manager-

Impactor Johnas according to the VDI 2066 and ISO 23210 and the convention from

Umwelt Bundes Amt
Für Mensch und Umwelt

Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen NRW.

END OF REPORT

Appendix 3 – Stack emissions monitoring report: Lakeside Energy From Waste Ltd

STACK EMISSIONS MONITORING REPORT

Environmental Scientifics Group

Acacia Building
Vantage Point Business Village
Mitcheldean
GL17 0DD
Tel: 01594 546 343

Your contact at ESG
Laurence Sharrock
Business Manager - South
Tel: 01594 546 343
Email: laurence.sharrock@esg.co.uk

Operator & Address:
Lakeside Energy From Waste Limited
Lakeside Road
Colnbrook
Slough
Berkshire
SL3 0FE
-
-

Permit
N/A - Investigative Monitoring

Release Point:
A1

Sampling Date(s):
19th to 21st March 2014

ESG Job Number:	LCH00710
Report Date:	16th Feb 2015
Version:	1
Report By:	Chris Houston
MCERTS Number:	MM 11 1135
MCERTS Level:	MCERTS Level 1 - Technician
Technical Endorsements:	
Report Approved By:	Andy Tiffen
MCERTS Number:	MM 05 640
Business Title:	MCERTS Level 2 - Projects Manager
Technical Endorsements:	1, 2 & 4
Signature:	A.T[signature]

UKAS TESTING 1015

CONTENTS

EXECUTIVE SUMMARY

Stack Emissions Monitoring Objectives
- Plant
- Operator
- Stack Emissions Monitoring Test House

Emissions Summary
Monitoring Times
Process Details
Monitoring Methods
Analytical Methods
- Sampling Methods with Subsequent Analysis
- On-Site Testing
Sampling Location
- Sampling Plane Validation Criteria
- Duct Characteristics
- Sampling Lines & Sample Points
- Sampling Platform
- Sampling Location / Platform Improvement Recommendations
Sampling and Analytical Method Deviations
Determination of representative sampling location

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

Lakeside Energy From Waste Limited operates a municipal and commercial waste incineration process at Colnbrook

Environmental Scientifics Group Limited were commissioned by Ricardo AEA to carry out stack emissions monitoring to determine the release of PM_{10} & $PM_{2.5}$ from the following Plant under standard operating conditions.

The measurements were commissioned by Ricardo-AEA on behalf of the Department of Environment, Food and Rural Affairs (Defra) to provide information for the UK National Atmospheric Emissions Inventory (NAEI).

Plant

A1

Operator

Lakeside Energy From Waste Limited
Lakeside Road
Colnbrook
Slough
Berkshire
SL3 0FE
-

Stack Emissions Monitoring Test House

Environmental Scientifics Group Limited - Mitcheldean Laboratory
Acacia Building
Vantage Point Business Village
Mitcheldean
GL17 0DD
UKAS and MCERTS Accreditation Number: 1015

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.
MCERTS accredited results will only be claimed where both the sampling and analytical stages are UKAS accredited.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Limit**	**MCERTS accredited result**
PM_{10} **(Average result of 4 runs)**	mg/m³	0.028	0.02	-	✓
PM_{10} Emission Rate **(Average result of 4 runs)**	g/hr	4.20	3.4	-	
$PM_{2.5}$ **(Average result of 4 runs)**	mg/m³	0.005	0.01	-	✓
$PM_{2.5}$ Emission Rate **(Average result of 4 runs)**	g/hr	0.77	1.39	-	
PM_{10} - Runs					
PM_{10} - Run 1	mg/m³	0.008	0.01	-	✓
PM_{10} Emission Rate - Run 1	g/hr	1.24	1.0	-	
PM_{10} - Run 2	mg/m³	0.042	0.03	-	✓
PM_{10} Emission Rate - Run 2	g/hr	6.50	5.3	-	
PM_{10} - Run 3	mg/m³	0.027	0.02	-	✓
PM_{10} Emission Rate - Run 3	g/hr	4.01	3.3	-	
PM_{10} - Run 4	mg/m³	0.034	0.03	-	✓
PM_{10} Emission Rate - Run 4	g/hr	5.07	4.2	-	
$PM_{2.5}$ - Runs					
$PM_{2.5}$ - Run 1	mg/m³	0.005	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 1	g/hr	1.24	2.2	-	
$PM_{2.5}$ - Run 2	mg/m³	0.006	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 2	g/hr	0.98	1.8	-	
$PM_{2.5}$ - Run 3	mg/m³	***0.003***	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 3	g/hr	0.46	0.83	-	
$PM_{2.5}$ - Run 4	mg/m³	0.006	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 4	g/hr	0.87	1.58	-	
Carbon Dioxide	% v/v	0.00	0.0	-	✓
Oxygen	% v/v	5	1.01	-	✓
Moisture	%	12.9	0.8	-	✓
Stack Gas Temperature	°C	146	-	-	✓
Stack Gas Velocity	m/s	17.0	-	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	211837	-	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	134761	-	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	107561	-	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	152825	-	-	

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 test specific flow data. Mass emissions for non isokinetic tests and isokinetic tests are calculated using these values

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
PM_{10} Run 1	19 March 2014	09:16 - 15:16	360 minutes
PM_{10} Run 2	19 March 2014	16:09 - 19:09	180 minutes
PM_{10} Run 3	20 March 2014	07:42 - 13:42	360 minutes
PM_{10} Run 4	20 March 2014	14:32 - 17:32	175 minutes
$PM_{2.5}$ Run 1	19 March 2014	09:16 - 15:16	360 minutes
$PM_{2.5}$ Run 2	19 March 2014	16:09 - 19:09	180 minutes
$PM_{2.5}$ Run 3	20 March 2014	07:42 - 13:42	360 minutes
$PM_{2.5}$ Run 4	20 March 2014	14:32 - 17:32	175 minutes
Stack Gas Flow Rate & Temperature Run 1	19 March 2014	07:45	-
Stack Gas Flow Rate & Temperature Run 2	19 March 2014	19:45	-
Stack Gas Flow Rate & Temperature Run 3	20 March 2014	07:30	-
Stack Gas Flow Rate & Temperature Run 4	20 March 2014	14:15	-
Stack Gas Flow Rate & Temperature Run 5	20 March 2014	17:50	-

EXECUTIVE SUMMARY

PROCESS DETAILS	
Parameter	**Process Details**
Description of process	Municipal and commercial waste incineration
Continuous or batch	Continuous
Product Details	Energy from waste
Part of batch to be monitored (if applicable)	N/A
Normal load, throughput or continuous rating	88 tonnes/hr
Fuel used during monitoring	Waste supplemented by gas oil
Abatement	Lime, activated carbon & ammonia injection with bag filters
Plume Appearance	Not visible from monitoring location

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by Environmental Scientifics Group Limited 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 +/- %**
PM_{10}	SRM - BS EN 23210	AE 136	1015	Yes	0.006 mg/m³	82 %
$PM_{2.5}$	SRM - BS EN 23210	AE 136	1015	Yes	0.003 mg/m³	181 %
CO_2	AM - M22/FTIR	AE 063	1015	Yes	0 %	9.39%
O_2	SRM - BS EN 14789	AE 102	1015	Yes	0.01%	20.9%
H_2O	AM - M22/FTIR	AE 063	1015	Yes	0.09 %	6.4%
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	5 Pa	-

The measurement uncertainties for the PM_{10} and $PM_{2.5}$ measurements reflect that measured concentrations were near or below the Limit of Detection.

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
PM_{10}	Gravimetric	AE 106	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	1 year
$PM_{2.5}$	Gravimetric	AE 106	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	1 year

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	MCERTS Accredited Analysis	Laboratory	Data Archive Location	Archive Period
CO_2	Fourier Transform - Infra Red	AE 063	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	5 years
O_2	Paramagnetism	AE 102	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	5 years
H_2O	Fourier Transform - Infra Red	AE 063	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	5 years

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	181	Pa	>= 5 Pa	Yes	BS EN 13284-1
Lowest Gas Velocity	16.69	m/s	-	-	-
Highest Gas Velocity	17.76	m/s	-	-	-
Ratio of Gas Velocities	1.06	-	< 3 : 1	Yes	BS EN 13284-1
Mean Velocity	17.02	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^{o}	Yes	BS EN 13284-1
No local negative flow	Yes	-	-	Yes	BS EN 13284-1

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Circular	-
Depth	2.08	m
Width	-	m
Area	3.40	m^2
Port Depth	90	mm

SAMPLING LINES & POINTS			
	Isokinetic (CEN Methods)	**Isokinetic** (ISO Methods)	**Non-Iso & Gases**
Sample port size	5" Flange	-	1"
Number of lines used	1	-	1
Number of points / line	1	-	1
Duct orientation	Vertical	-	Vertical
Filtration	In Stack	-	In Stack

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

M1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	Yes
Platform has 2 levels of handrails (approximately 0.5 m & 1.0 m high)	Yes
Platform has vertical base boards (approximately 0.25 m high)	Yes
Platform has removable chains / self closing gates at the top of ladders	Yes
Handrail / obstructions do not hamper insertion of sampling equipment	Yes
Depth of Platform = >Stack depth / diameter + wall and port thickness + 1.5m	Yes

Sampling Platform Improvement Recommendations (if applicable)

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

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Pitot static pressure measurements

During the six hour runs, readings were taken every ten minutes as opposed to the recommended five, however site staff checked settings between this time to ensure continuity.

Sample flow variation

The sample flowrate could not be maintained within 5% of the nominal flow throughout the testing periods (which were over extended periods due to the anticipated low PM emission concentrations). Whilst this will have affected the actual cutpoints achieved by the impactor, the results are all at or very near the LOD for the tests and hence this is anticipated to have limited impact on the outcome of the measurements.

Goose-neck nozzle Validation

Due to the long port sleeve, it was physically impossible to inserted the cascade impactor using the straight entry nozzle setup recommended in BS EN 23210. Therefore the use of a goose-neck setup was used as this was the only feasible method for monitoring. The standard requires that the use of a goose-neck nozzle is validated, however on this occasion it has not been possible to demonstrate that losses in the nozzle meet the criteria in the standard because the measured concentrations were low and the weight of particulate recovered from the nozzle rinses and the filter media were at or near the weighing LoD. In the context of the low emission concentrations detemined during the measurements (all less than 0.1 mg/Nm3), losses in the sampling nozzle are unlikely to increase the concentrations significantly.

Determination of representative sampling location

An assessment of temperature homogeneity was performed in accordance with EN 23210 Annex-G on the first day of monitoring 5th March 2014. There was a feedstock change on the morning of the third day 7th March 2014 from municipal waste to Community Recyling Centre waste. A further homogeneity test was performed on 7th March and the representative sampling point was determined to be at the same location as on 5th March.

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
PM_{10}	SRM - BS EN 23210	AE 136	1015	Yes	4
$PM_{2.5}$	SRM - BS EN 23210	AE 136	1015	Yes	4
CO_2	AM - M22/FTIR	AE 063	1015	Yes	1
O_2	SRM - BS EN 14789	AE 102	1015	Yes	4
H_2O	AM - M22/FTIR	AE 063	1015	Yes	4
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	5

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	P2023	Horiba PG-250 Analyser	-	Laboratory Balance	-
Box Thermocouples	P2023	FT-IR	P2060	Tape Measure	P1935
Meter In Thermocouple	P2023	FT-IR Oven Box	-	Stopwatch	-
Meter Out Thermocouple	P2023	Bernath 3006 FID	-	Protractor	-
Control Box Timer	P2023	Signal 3030 FID	-	Barometer	P2090
Oven Box	-	Servomex	-	Digital Micromanometer	P1599
Probe	-	JCT Heated Head Filter	-	Digital Temperature Meter	P2045
Probe Thermocouple	-	Thermo FID	-	Stack Thermocouple	P2254 + P2055
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	-	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	P2246	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	-	Chiller (JCT/MAK 10)	-	1m Heated Line (3)	-
Last Impinger Arm	P1966	Heated Line Controller (1)	-	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	-	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-	Impactor 1	NR18706	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	-
Inclinometer (Swirl Device)	-		-	20m Heated Line (2)	-

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

CALIBRATION / CHECK GASES

Gas (traceable to ISO 17025)	Cylinder I.D Number	Supplier	ppm	%	Analytical Tolerance +/- %
Oxygen	DA B2	BOC	-	10.06	2
Methane	DA B2	BOC	87.1	-	2
Carbon Dioxide	DA B2	BOC	-	12	2

STACK EMISSIONS MONITORING TEAM

Team Leader	Paul Jones MCERTS Level 2 Te1 Expiry Date - Dec 2016 Te2 Expiry Date - Dec 2016 Te3 Expiry Date - Mar 2018 Te4 Expiry Date - Dec 2016 MM 02 044 MCERTS Expiry Date - Mar 2018 H&S Expiry Date - Sep 2015
Technician	Rad Poremba MCERTS Level 1 MM 10 1069 MCERTS Expiry Date - Jul 2015 H&S Expiry Date - Jul 2015

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PM_{10} SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	09:16 - 15:16 19 March 2014	0.008	0.006	-	1.24
Run 2	16:09 - 19:09 19 March 2014	0.042	0.006	-	6.50
Run 3	07:42 - 13:42 20 March 2014	0.027	0.006	-	4.01
Run 4	14:32 - 17:32 20 March 2014	0.034	0.016	-	5.07
Blank 1	-	0.011	-	-	-
Blank 2	-	0.008	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.
where values are below the LOD the LOD will be reported.

$PM_{2.5}$ SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	09:16 - 15:16 19 March 2014	0.005	0.003	-	0.76
Run 2	16:09 - 19:09 19 March 2014	0.006	0.003	-	0.98
Run 3	07:42 - 13:42 20 March 2014	0.003	0.003	-	0.46
Run 4	14:32 - 17:32 20 March 2014	0.006	0.008	-	0.87
Blank 1	-	0.020	-	-	-
Blank 2	-	0.006	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.
where values are below the LOD the LOD will be reported, where this occurs the quoted uncertainties will be relatively high.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

$PM_{2.5}$ (BF) SAMPLES WEIGHTS				
Test	$PM_{2.5}$ Filter Number	Filter Start Weight g	Filter End Weight g	$PM_{2.5}$ Mass Gained on Filter g
Run 1	QC955	16.34679	16.34687	0.00008
Run 2	QC1017	32.67253	32.67227	-0.00026
Run 3	QC1025	32.70278	32.70203	-0.00075
Run 4	QC1020	31.96708	31.96685	-0.00023
Blank 1	QC973	31.76137	31.76162	0.00025
Blank 2	QC1019	31.64873	31.64881	0.00008

PM_{10} (CP2) SAMPLES WEIGHTS				
Test	PM_{10} Filter Number g	Filter Start Weight g	Filter End Weight g	PM_{10} Mass Gained on Filter g
Run 1	QC962	32.63680	32.63641	-0.00039
Run 2	QC1004	51.80857	51.80885	0.00028
Run 3	QC1025	15.92885	15.92924	0.00039
Run 4	QC127	15.81262	15.81286	0.00024
Blank 1	QC970	15.77666	15.77655	-0.00011
Blank 2	QC1026	15.50902	15.50888	-0.00014

$PM_{2.5}$ & PM_{10} (BF & CP2) SAMPLES WEIGHTS COMBINED							
Test	$PM_{2.5}$ Filter Number	PM_{10} Filter Number	$PM_{2.5}$ Mass Gained on Filter g	PM_{10} Mass Gained on Filter g	Actual $PM_{2.5}$ & PM_{10} Combined Total Mass Gained g	$PM_{2.5}$ & PM_{10} Combined Weighing LOD g	*Reported $PM_{2.5}$ & PM_{10} Combined Total Mass Gained g
Run 1	QC955	QC962	0.00008	-0.00039	-0.00031	0.00010	0.00013
Run 2	QC1017	QC1004	-0.00026	0.00028	0.00002	0.00010	0.00033
Run 3	QC1025	QC1025	-0.00075	0.00039	-0.00036	0.00010	0.00044
Run 4	QC1020	QC127	-0.00023	0.00024	0.00001	0.00010	0.00029
Blank 1	QC973	QC970	0.00025	-0.00011	0.00014	0.00010	0.00014
Blank 2	QC1019	QC1026	0.00008	-0.00014	-0.00006	0.00010	0.00010

* Where weighing values are below the LOD possibly due to loss of filter material, the LOD will be reported.
NOTE - Where the filter weight gain is less than the weighing uncertainty, the weighing uncertainty is used for further calculations. The weighing uncertainty is 0.00005g.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	739.5
Stack static pressure, P_{static}	mm H_2O	2.2
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	739.7
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 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		9.80
Gas meter correction factor, Y_d		1.34
Mean dry gas meter temperature, T_m		25.44
Mean pressure drop across orifice, ΔH	mmH_2O	90.00
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		11.819
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	14.8075
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		6.79
% oxygen reference condition		11
O_2 Reference Factor	O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$	1.42
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	16.795
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.2018
	%	20.18
Moisture by FTIR	%	20.18
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.81
Mean of velocity heads, ΔP_{avg}	mm H_2O	19.89
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.5
Mean stack gas temperature, T_s	°C	146
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	18.16

Molecular weight of dry gas, M_d		
CO_2		9.63
O_2		6.79
Total		16.42
N_2 (100 -Total)		83.58
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.81
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.43
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	3.40
$Q_a = (60)(A_s)(V_s)$	m^3/min	3703.3
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	28.10
Actual Flow Rate @ DGM	l/min	30.5
Isokinetic Rate		108.44
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00005
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00008
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.00878
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.01100
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.00774
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		1.24
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00008
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0054
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0068
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0048
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.76

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 2 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	748.5
Stack static pressure, P_{static}	mm H_2O	2.2
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	748.7
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 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		4.82
Gas meter correction factor, Y_d		1.34
Mean dry gas meter temperature, T_m		27.53
Mean pressure drop across orifice, ΔH	mmH_2O	87.83
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.839
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	7.1670
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		7.64
% oxygen reference condition		11
O_2 Reference Factor: O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		1.34
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	7.801
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1853
	%	18.53
Moisture by FTIR	%	18.53
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.81
Mean of velocity heads, ΔP_{avg}	mm H_2O	19.86
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.46
Mean stack gas temperature, T_s	°C	147
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	17.99

Molecular weight of dry gas, M_d		
CO_2		9.28
O_2		7.64
Total		16.92
N_2 (100 -Total)		83.08
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.79
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.61
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	3.40
$Q_a = (60)(A_s)(V_s)$	m³/min	3667.4
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	29.90
Actual Flow Rate @ DGM	l/min	30.3
Isokinetic Rate		101.41
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00028
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0460
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0565
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0423
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		6.50
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0070
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0086
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0064
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.98

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 3 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	747.8	CO_2		9.42
Stack static pressure, P_{static}	mm H_2O	2.2	O_2		7.39
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	747.9	Total		16.81
			N_2 (100 -Total)		83.19
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.80
Moisture trap weight increase,Vlc	g	H_20 by FTIR	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.56
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		9.98	Area of stack, A_s	m^2	3.40
Gas meter correction factor, Y_d		1.34	$Q_a = (60)(A_s)(V_s)$	m³/min	3573.0
Mean dry gas meter temperature, T_m		25.00	**Percent isokinetic, %I**		
Mean pressure drop across orifice, ΔH	mmH2O	99.58	Required Flow Rate @ DGM	l/min	29.30
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		12.195	Actual Flow Rate @ DGM	l/min	28.5
Volume of gas metered wet, V_{mstw}			Isokinetic Rate		97.30
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	15.0598	Acceptable 90% - 130%		Yes
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Particulate Concentration, C_{PM10}**		
			Mass of particulate collected on PM_{10} filter, M_f		0.00039
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0292
% oxygen measured in gas stream, act%O_2		7.39			
% oxygen reference condition		11	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0361
O_2 Reference Factor O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		1.36	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0265
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	16.599			
Moisture content, B_{wo}			**Particulate Emission Rates, E**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1903	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		4.01
	%	19.03	**Particulate Concentration, $C_{PM2.5}$**		
Moisture by FTIR	%	19.03	Mass of particulate collected on filter, M_f		0.00005
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0033
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.81	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0041
Mean of velocity heads, ΔP_{avg}	mm H_2O	18.82			
Mean square root of velocity heads, √ΔP		4.34	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0030
Mean stack gas temperature, T_s	°C	146			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	17.52	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.46

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 4 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	739.5
Stack static pressure, P_{static}	mm H_2O	2.2
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	739.7
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	$H_2$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		5.25
Gas meter correction factor, Y_d		1.34
Mean dry gas meter temperature, T_m		26.38
Mean pressure drop across orifice, ΔH	mmH₂O	100.56
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		6.322
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	7.8411
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		7.38
% oxygen reference condition		11
O_2 Reference Factor: O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		1.36
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	8.611
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1937
	%	19.37
Moisture by FTIR	%	19.37
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.81
Mean of velocity heads, ΔP_{avg}	mm H_2O	18.94
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.35
Mean stack gas temperature, T_s	°C	146
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	17.70

Molecular weight of dry gas, M_d		
CO_2		9.38
O_2		7.38
Total		16.76
N_2 (100 -Total)		83.24
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.80
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.51
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	3.40
$Q_a = (60)(A_s)(V_s)$	m³/min	3608.6
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	31.70
Actual Flow Rate @ DGM	l/min	30.0
Isokinetic Rate		94.71
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00024
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0370
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0459
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0337
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		5.07
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0064
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0079
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0058
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.87

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PM_{10} & $PM_{2.5}$ 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	30.47	0.10	0.05	381	0.61	Yes
Run 2	30.32	0.05	0.1	381	0.61	Yes
Run 3	28.51	0.1	0.1	381	0.57	Yes
Run 4	30.02	0.1	0.05	381	0.60	Yes

ISOKINETICITY		
Run	Flow Variation %	Acceptable Variation
Run 1	108.4	Yes
Run 2	101.4	Yes
Run 3	97.3	Yes
Run 4	94.7	Yes

Acceptable Flow rate 90 -130%

FILTERS					
Run	Filter Material	Filter Size mm	Max Filtration Temperature °C	Pre-conditioning Filter Temperature °C	Post conditioning Filtration Temperature °C
Run 1	QF	50	150	180	160
Run 2	QF	50	148	180	160
Run 3	QF	50	149	180	160
Run 4	QF	50	147	180	160

QF = Quartz Fibre

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Conformity with relevant aspects of BS EN ISO 23210:2009

GENERAL METHODOLOGY

The equipment employed is a Paul Gothe, Johnas cascade impactor (see pg 13 for serial number) system meeting the requirements of BS EN ISO 23210. The standard cites a two-stage impactor system.

The method for sampling requires the extraction of a representative sample of duct gas isokinetically, into a specially designed in-stack sampling head. The Cascade Impactor is a multi-stage, multi-jet impactor which aerodynamically classifies particulates into multiple size ranges. The cascade impactor uses the principle of inertial separation to size segregate particulate samples from the gas stream. The impactor has two stages for particle size determination. Each stage gives a cut-point based on aerodynamic diameter of the particle.

During sampling, the particles are driven (jetted) toward a collecting surface where they may cling. By changing the velocity (orifice size of the jet), the size of the particles collected is controlled. The size of the jets within each stage is constant, but for each succeeding stage the jets get smaller. Impaction occurs when the particle's inertia overcomes the aerodynamic drag. Otherwise, the particle remains in the air stream and proceeds to the next stage. To keep the cut-point for each stage constant, the impactor is operated at a constant flow rate.

At each stage, the particle impacts on to a conditioned and pre-weighed substrate. Following sampling, the substrates are reconditioned and reweighed to determine the mass collected.

Based on the sampling conditions (sampling rate and gas temperature) the cut size (D50 – diameter of particles having a 50% probability of penetration) associated with each impactor stage may be determined.

An homogeneity assessment based on BS EN ISO 23210, Annex G, is undertaken to determine the most representative sampling point in the sampling plane (temperature, velocity and oxygen are suitable surrogates for particulate matter). The velocity measurement at the chosen point is used to determine an appropriate sampling nozzle/flow rate in order to ensure that isokinetic conditions are maintained throughout sampling to within the 90-130% range allowed in the standard (8.1) and which is consistent with the sampling equipment.

Concurrently, the volume of duct gas sampled is measured. This then enables the particulate concentration at each cut size to be determined.

The outlet gas from the sampling head is passed via a sampling probe through an impinger train with the purpose of removing water prior to entry to the sampling control box. It is not intended that the sampling train be used for additional sampling of condensible determinands and as such the train is unheated.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Conformity with relevant aspects of BS EN ISO 23210:2009

Sampling Plane Validation Criteria				
EA Technical Guidance Note (Monitoring) M1	Result	Units	Requirement	Compliant
Lowest Differential Pressure	181	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	16.69	m/s	-	-
Highest Gas Velocity	17.76	m/s	-	-
Ratio of Gas Velocities	1.06	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	°	< 15°	Yes
No local negative flow	Yes	-	-	Yes

Conformance with BS EN ISO 23210:2009			
Reference	Requirement	Result	Compliant
Section 6.3	Suitable Impcator Used	See statement of conformity for Impactor	Yes
Section 8.1	Sampling position acceptable (as per 13284-1)	As per table "Sampling Plane Validation"	Yes
Section 8.1	Nozzle arrangement	See statement of conformity for Impactor	Yes
Section 8.1	Representative sampling point	See Homogeneity assessment below	Yes
Section 8.1	Constant Sample gas flow, iso-kinetic rate 90% to 130%		
	Run 1 - Required flow 28.1 (LPM)		-
	Run 1 - Minimum permissable flow 25.29 (LPM)	28.14	Yes
	Run 1 - Maximum permissable flow 36.53 (LPM)	33.28	Yes
	Run 2 - Required flow 29.9 (LPM)		-
	Run 2 - Minimum permissable flow 26.91 (LPM)	27.76	Yes
	Run 2 - Maximum permissable flow 38.87 (LPM)	34.07	Yes
	Run 3 - Required flow 29.3 (LPM)		-
	Run 3 - Minimum permissable flow 26.37 (LPM)	26.40	Yes
	Run 3 - Maximum permissable flow 38.09 (LPM)	30.40	Yes
	Run 4 - Required flow 31.7 (LPM)		-
	Run 4 - Minimum permissable flow 28.53 (LPM)	29.00	Yes
	Run 4 - Maximum permissable flow 41.21 (LPM)	32.20	Yes
Section 8.1	Overall blank taken once per day	Yes	Yes
Section 8.2	Impactor cleaned between each measurement	Yes	Yes
Section 8.2	Arrangement of impactor plates	See statement of conformity for Impactor	Yes
Section 8.3.2	Data taken for velocity, composition, temp & pressure	See "Preliminary stack survey" section	Yes
Section 8.3.3	Sampling rate determination in accordance with Annex A	Yes	Yes
Section 8.3.3	Sample flow rate kept +/- 5% of nominal flow rate		
	Run 1 - Max sample flow deviation from nominal (%)	28.0	No
	Run 2 - Max sample flow deviation from nominal (%)	11.2	No
	Run 3 - Max sample flow deviation from nominal (%)	5.2	No
	Run 4 - Max sample flow deviation from nominal (%)	8.6	No
Section 8.3.4	Nozzle selected to allow iso-kinetic rate 90% to 130%	Yes, as above	Yes
Section 8.3.5	Leak check less than 2%		
	Run 1	0.33	Yes
	Run 2	0.16	Yes
	Run 3	0.35	Yes
	Run 4	0.33	Yes
Section 8.3.6	Impactor at flue gas temperature before sampling	Yes	Yes
Section 8.3.6	Angle of nozzle less than 10 Degress to flow	Yes	Yes
Section 8.3.6	Flowrate has checked and recorded every 5 mins	Yes	Yes
Section 8.3.6	Dynamic pressure recorded every 5 mins	Yes	Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Homogeneity assessment

Assessment 1

Point number (i)	Distance along sample line (mm)	Probe Marking (mm)	Temp Deg C grid	Temp Deg C fixed	r_i
1	104	194	145	146	0.993
2	312	402	145	146	0.993
3	520	610	145	146	0.993
4	728	818	145	146	0.993
5	936	1026	145	146	0.993
6	1144	1234	145	146	0.993
7	1352	1442	145	146	0.993
8	1560	1650	145	146	0.993
9	1768	1858	145	146	0.993
10	1976	2066	145	146	0.993
Second Line					
1	104	194	145	146	0.993
2	312	402	145	146	0.993
3	520	610	145	146	0.993
4	728	818	145	146	0.993
5	936	1026	145	146	0.993
6	1144	1234	145	146	0.993
7	1352	1442	145	146	0.993
8	1560	1650	146	147	0.993
9	1768	1858	145	146	0.993
10	1976	2066	145	146	0.993

No. of points	20
S_{grid}	0.22
S_{ref}	0.223
r	0.99
Is $S_{grid} <= S_{ref}$?	No

F Factor	1
$F_{N-1; N-1; 0.95}$	2.17
Is F Factor < $F_{N-1;N-1;0.95}$?	Yes

S_{pos}	0
$t_{N-1;0.95}$	2.093
U_{pos}	0
Permissible Uncertainty	10
Is $U_{pos} < 0.5 * U_{perm}$?	N/A

Sample can be taken from any location

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DAILY OXYGEN SUMMARY

Run	Sampling Times	Concentration %	LOD %
1	09:16 - 15:16 19 March 2014	6.79	0.01
2	16:09 - 19:09 19 March 2014	7.64	0.01
3	07:42 - 13:42 20 March 2014	7.39	0.01
4	14:32 - 17:32 20 March 2014	7.38	0.01

PRE SAMPLING CALIBRATION DATA								
Date	Time of Analyser Checks	Range (%)	Zero Reading at analyser	Span Reading at analyser	Zero Check at analyser	Zero Check down line	Span Check down line	Leak Rate %
19 March 2014	08:52 - 09:00	25	0.00	10.06	0.00	0.21	9.92	-1.41
20 March 2014	15:13 - 15:31	25	0.00	10.06	0.00	0.59	10.25	1.85

POST SAMPLING CALIBRATION DATA					
Date	Time of Analyser Checks	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
19 March 2014	15:13 - 15:31	0.59	10.25	1.52	-0.50
20 March 2014	17:40 - 17:50	0.2	10.26	-1.56	3.98

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GAS SUMMARY

Test	Sampling Times	Concentration %	Analysis Areas	Interference (%) *	LOD %
Moisture Run 1	09:16 - 15:16 19 March 2014	20.2	3200 - 3401	0.7	0.09
Moisture Run 2	16:09 - 19:09 19 March 2014	18.5	3200 - 3401	0.70	0.09
Moisture Run 3	07:42 - 13:42 20 March 2014	19.0	3200 - 3401	0.70	0.09
Moisture Run 4	14:32 - 17:32 20 March 2014	19.4	3200 - 3401	0.70	0.09
Carbon Dioxide Run 1	09:16 - 15:16 19 March 2014	9.6	2000 - 2223	1.31	0.00
Carbon Dioxide Run 2	16:09 - 19:09 19 March 2014	9.3	2000 - 2223	1.31	0.00
Carbon Dioxide Run 3	07:42 - 13:42 20 March 2014	9.4	2000 - 2223	1.31	0.01
Carbon Dioxide Run 4	14:32 - 17:32 20 March 2014	9.4	2000 - 2223	1.31	0.01

*M22 Specifies interference must be <5%.

FTIR CALIBRATION CHECKS

Pre - Sampling Checks - System			Date of Checks	19 March 2014		Time of Checks	08:25	
Post Sampling Checks - System			Date of Checks	19 March 2014		Time of Checks	15:13	
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
H_2O	0.04	-0.01	-0.18	87.1	86.9	-0.24	85.6	-1.49
CO_2(%)	0.00	0.00	0.00	12.0	12.0	-0.11	11.7	-2.06

Pre - Sampling Checks - System			Date of Checks	20 March 2014		Time of Checks	15:52	
Post Sampling Checks - System			Date of Checks	20 March 2014		Time of Checks	17:40	
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
H_2O	0.04	0.01	-0.11	101.0	85.6	-15.25	86.0	0.49
CO_2(%)	0.00	0.00	0.00	8.8	11.7	33.42	11.9	1.75

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.

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	2.08	m
Stack Width, W	-	m
Stack Area, A	3.40	m^2
Average stack gas temperature	146	^oC
Stack static pressure	0.30	kPa
Barometric Pressure	98.64	kPa
Pitot tube calibration coefficient, K_{pt}	0.81	-

Stack Gas Composition & Molecular Weights

Component	Molar Mass M	Density kg/m^3 p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m^3 pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m^3 pi
CO_2	44	1.96	11.86	0.12	0.23	10.34	0.10	0.20
O_2	32	1.43	4.87	0.05	0.07	4.24	0.04	0.06
N_2	28	1.25	83.27	0.83	1.04	72.57	0.73	0.91
H_2O	18	0.80	-	-	-	12.85	0.13	0.10

Where: p = M / 22.41 p*i* = r x p

Calculation of Stack Gas Densities

Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3426	kg/m^3
Wet Density (STP), P_{STW}	1.2732	kg/m^3
Dry Density (Actual), P_{Actual}	0.8534	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.809	kg/m^3

Where:

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

P_{STW} = (P_{STD} + p*i* of H_2O) / (1 + (p*i* 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	19 March 2014
Time of Survey	07:45
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.10	20.0	196	145	17.34	-	<15
2	0.31	20.0	196	145	17.34	-	<15
3	0.52	21.0	206	145	17.76	-	<15
4	0.73	20.5	201	145	17.55	-	<15
5	0.94	21.0	206	145	17.76	-	<15
6	1.14	20.5	201	145	17.55	-	<15
7	1.35	20.0	196	145	17.34	-	<15
8	1.56	20.5	201	145	17.55	-	<15
9	1.77	19.5	191	145	17.12	-	<15
10	1.98	20.0	196	145	17.34	-	<15
Mean	-	20.3	199	145	17.46	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.10	19.5	191	145	17.12	-	<15
2	0.31	20.0	196	144	17.32	-	<15
3	0.52	20.5	201	145	17.55	-	<15
4	0.73	21.0	206	145	17.76	-	<15
5	0.94	20.5	201	145	17.55	-	<15
6	1.14	21.0	206	145	17.76	-	<15
7	1.35	21.0	206	145	17.76	-	<15
8	1.56	20.5	201	145	17.55	-	<15
9	1.77	20.0	196	145	17.34	-	<15
10	1.98	19.5	191	145	17.12	-	<15
Mean	-	20.4	199	145	17.48	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 2

Date of Survey	19 March 2014
Time of Survey	19:45
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl º
1	0.10	19.5	191	147	17.16	-	<15
2	0.31	19.8	194	147	17.29	-	<15
3	0.52	19.5	191	147	17.16	-	<15
4	0.73	19.8	194	147	17.29	-	<15
5	0.94	20.0	196	147	17.38	-	<15
6	1.14	19.5	191	147	17.16	-	<15
7	1.35	19.5	191	147	17.16	-	<15
8	1.56	19.3	189	147	17.07	-	<15
9	1.77	19.3	189	147	17.07	-	<15
10	1.98	19.3	189	147	17.07	-	<15
Mean	-	19.6	192	147	17.18	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl º
1	0.10	19.0	186	147	16.94	-	<15
2	0.31	19.3	189	147	17.07	-	<15
3	0.52	19.5	191	147	17.16	-	<15
4	0.73	19.4	190	147	17.11	-	<15
5	0.94	19.5	191	147	17.16	-	<15
6	1.14	19.8	194	147	17.29	-	<15
7	1.35	19.8	194	147	17.29	-	<15
8	1.56	19.5	191	147	17.16	-	<15
9	1.77	19.3	189	147	17.07	-	<15
10	1.98	19.3	189	147	17.07	-	<15
Mean	-	19.4	191	147	17.13	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 3

Date of Survey	20 March 2014
Time of Survey	07:30
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	0.10	18.8	184	147	16.85	-	<15
2	0.31	19.0	186	147	16.94	-	<15
3	0.52	19.3	189	147	17.07	-	<15
4	0.73	19.4	190	147	17.11	-	<15
5	0.94	19.3	189	147	17.07	-	<15
6	1.14	19.3	189	147	17.07	-	<15
7	1.35	19.0	186	147	16.94	-	<15
8	1.56	19.0	186	147	16.94	-	<15
9	1.77	19.0	186	147	16.94	-	<15
10	1.98	19.0	186	147	16.94	-	<15
Mean	-	19.11	187	147	16.99	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	0.10	19.0	186	147	16.94	-	<15
2	0.31	18.8	184	147	16.85	-	<15
3	0.52	19.0	186	147	16.94	-	<15
4	0.73	19.3	189	147	17.07	-	<15
5	0.94	19.3	189	147	17.07	-	<15
6	1.14	19.0	186	147	16.94	-	<15
7	1.35	19.0	186	147	16.94	-	<15
8	1.56	18.8	184	147	16.85	-	<15
9	1.77	19.0	186	147	16.94	-	<15
10	1.98	18.8	184	147	16.85	-	<15
Mean	-	19.0	186	147	16.94	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 4

Date of Survey	20 March 2014
Time of Survey	14:15
Velocity Measurement Device:	P2246

Sampling Line A							
Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.10	18.8	184	146	16.83	-	<15
2	0.31	19.0	186	146	16.92	-	<15
3	0.52	18.8	184	146	16.83	-	<15
4	0.73	18.8	184	146	16.83	-	<15
5	0.94	19.0	186	146	16.92	-	<15
6	1.14	18.8	184	146	16.83	-	<15
7	1.35	18.8	184	146	16.83	-	<15
8	1.56	18.6	182	146	16.74	-	<15
9	1.77	18.6	182	146	16.74	-	<15
10	1.98	18.5	181	146	16.69	-	<15
Mean	-	18.8	184	146	16.81	-	

Sampling Line B							
Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.10	18.8	184	146	16.83	-	<15
2	0.31	19.0	186	146	16.92	-	<15
3	0.52	19.0	186	146	16.92	-	<15
4	0.73	19.2	188	146	17.01	-	<15
5	0.94	19.0	186	146	16.92	-	<15
6	1.14	18.8	184	146	16.83	-	<15
7	1.35	18.8	184	146	16.83	-	<15
8	1.56	19.0	186	146	16.92	-	<15
9	1.77	18.8	184	146	16.83	-	<15
10	1.98	18.5	181	146	16.69	-	<15
Mean	-	18.9	185	146	16.87	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 5

Date of Survey	20 March 2014
Time of Survey	17:50
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.10	18.5	181	147	16.71	-	<15
2	0.31	18.8	184	147	16.85	-	<15
3	0.52	18.8	184	147	16.85	-	<15
4	0.73	18.5	181	147	16.71	-	<15
5	0.94	19.0	186	147	16.94	-	<15
6	1.14	19.0	186	147	16.94	-	<15
7	1.35	19.2	188	147	17.03	-	<15
8	1.56	18.8	184	147	16.85	-	<15
9	1.77	18.6	182	147	16.76	-	<15
10	1.98	18.5	181	147	16.71	-	<15
Mean	-	18.77	184	147	16.83	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.10	18.8	184	147	16.85	-	<15
2	0.31	18.5	181	147	16.71	-	<15
3	0.52	18.8	184	147	16.85	-	<15
4	0.73	19.2	188	147	17.03	-	<15
5	0.94	19.2	188	147	17.03	-	<15
6	1.14	18.8	184	147	16.85	-	<15
7	1.35	18.5	181	147	16.71	-	<15
8	1.56	19.0	186	147	16.94	-	<15
9	1.77	18.5	181	147	16.71	-	<15
10	1.98	18.5	181	147	16.71	-	<15
Mean	-	18.8	184	147	16.84	-	

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	181	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	16.69	m/s	-	-
Highest Gas Velocity	17.76	m/s	-	-
Ratio of Gas Velocities	1.06	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	^{o}	$< 15^o$	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V

Velocity at Traverse Point, $V = K_{pt} \times (1-\varepsilon) * \sqrt{(2 * \Delta P_{pt} / P_{ActualW})}$

Where:

K_{pt} = Pitot tube calibration coefficient

$(1-\varepsilon)$ = Compressibility correction factor, assumed at a constant 0.998

Average Stack Gas Velocity, Va	**17.02**	m/s

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))

Day 1 | **19 March 2014**

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	146	0	^{o}C
Total Pressure	98.9	101.3	kPa
Oxygen	6.8	11	%
Moisture	20.18	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	17.32		m/s
Stack Area (A)	3.40		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	211837		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	134761		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	107561		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	152825		m^3/hr

Day 2 | **20 March 2014**

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	147	0	^{o}C
Total Pressure	99.0	101.3	kPa
Oxygen	7.5	11	%
Moisture	18.97	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	16.87		m/s
Stack Area (A)	3.40		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	206379		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	131134		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	106253		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	143766		m^3/hr

Nomenclature:

Ts = Absolute Temperature, Standard Conditions, 273 K

Ps = Absolute Pressure, Standard Conditions, 101.3 kPa

Ta = Absolute Temperature, Actual Conditions, K

Pa = Absolute Pressure, Actual Conditions, kPa

Ma = Water vapour, Actual Conditions, % Vol

Ms = Water vapour, Reference Conditions, % Vol

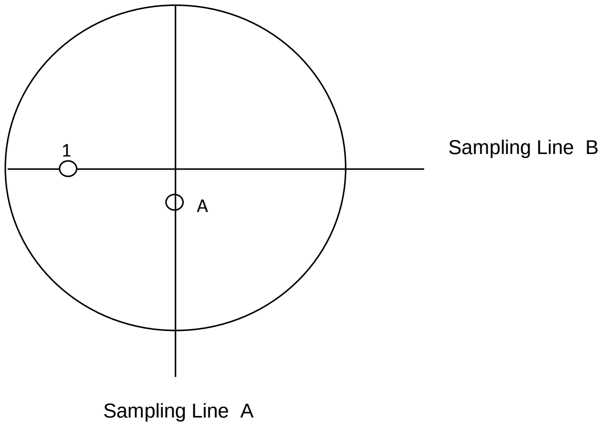
O_2a = Oxygen, Actual Conditions, % Vol

O_2s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK DIAGRAM

	Value	Units
Stack Depth	2.08	m
Stack Width	-	m
Area	3.40	m^2



Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	40	0.83	m

Isokinetic Sampling CEN Methods			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl º
1	85.0	1.77	<15

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

SAMPLING LOCATION

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - PM 10

Run	Sampled m³	Sampled Gas K	Sampled Gas kPa	Sampled Gas % by volume	Oxygen % by volume	Limit of % by mass	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	0.10	-
as a %	0.01	0.48	0.51	1.00	1.47	N/A	0.16
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.10	-
as a %	0.01	0.48	0.50	1.00	1.31	N/A	0.33
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 3	0.001	2	0.5	1	0.1	0.1000	-
as a %	0.01	0.48	0.50	1.00	1.35	N/A	0.35
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 4	0.001	2	0.5	1	0.1	0.10	-
as a %	0.01	0.48	0.51	1.00	1.35	N/A	0.17
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	Mass of particulate mg	O2 Correction -	Leak mg/m³	Combined uncertainty
Run 1	0.0007	0.0595	0.011	1.000	-
MU as mg/m³	0.0001	0.0060	0.0001	0.00001	**76.93**
MU as %	0.0006	76.9	0.704	0.095	-
Run 2	0.0085	0.1282	0.057	1.000	-
MU as mg/m³	0.0005	0.0128	0.0003	0.00008	**30.31**
MU as %	0.0031	30.3	0.749	0.190	-
Run 3	0.0025	0.0602	0.036	1.000	-
MU as mg/m³	0.0003	0.0060	0.0002	0.00005	**22.740**
MU as %	0.0019	22.7	0.735	0.203	-
Run 4	0.0062	0.12	0.046	1.00	-
MU as mg/m³	0.0004	0.01	0.0002	0.00003	**34.49**
MU as %	0.0024	34.5	0.734	0.10	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.01**	**mg/m³**	**153.87**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**mg/m³**	**60.67**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.01**	**mg/m³**	**45.55**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.02**	**mg/m³**	**69.02**	**%**

(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 - PM 2.5

Run	Sampled m³	Sampled Gas K	Sampled Gas kPa	Sampled Gas % by volume	Oxygen % by volume	Limit of % by mass	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	0.05	-
as a %	0.01	0.48	0.51	1.00	1.47	N/A	0.16
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.01	0.48	0.50	1.00	1.31	N/A	0.33
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 3	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.01	0.48	0.50	1.00	1.35	N/A	0.35
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 4	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.01	0.48	0.51	1.00	1.35	0.00	0.17
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	Mass of particulate mg	O2 Correction -	Leak mg/m³	Combined uncertainty
Run 1	0.00	0.0595	0.0068	1.000	-
MU as mg/m^3	0.0001	0.0030	0.0000	0.00000	**62.50**
MU as %	0.0003	62.5000	0.7037	0.09	-
Run 2	0.0013	0.1282	0.0086	1.000	-
MU as mg/m^3	0.0001	0.0064	0.0000	0.00001	**100.00**
MU as %	0.0005	100.0000	0.7485	0.19	-
Run 3	0.0006	0.1282	0.0087	1.000	-
MU as mg/m^3	0.0001	0.0064	0.0000	0.00001	**100.00**
MU as %	0.0005	100.0000	0.7346	0.20	-
Run 4	0.0011	0.1161	0.0079	1.0000	-
MU as mg/m^3	0.0001	0.0058	0.0000	0.00001	**100.00**
MU as %	0.0004	100.0000	0.7342	0.10	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.006**	**mg/m³**	**125.03**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.013**	**mg/m³**	**200.02**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.013**	**mg/m³**	**200.02**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.012**	**mg/m³**	**200.02**	**%**

(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 - CARBON DIOXIDE BY FTIR

Actual Measured Concentration	9.58	% vol
Measured Concentration at Reference Conditions	9.58	% vol
Emission Limit Value	-	% vol
Instrument Range	20	% vol
Check Gas Concentration	12.00	% vol

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)	0.000	<5%	Yes
Span drift (calculated from start and end readings).	-2.058	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	0.990	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.100	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	-1.300	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	1.600	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	1.308	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.080	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	% vol
Uncertainty of linearity (lack of fit) U_{fit}	-0.219
Uncertainty of zero drift $U_{0,dr}$	0.000
Uncertainty of span drift $U_{s,dr}$	-0.238
Uncertainty of volume or pressure flow dependence U_{spress}	0.114
Uncertainty in Ambient Temperature U_{temp}	0.151
Uncertainty in Voltage U_{volt}	0.185
Uncertainty of interferents U_i	0.151
Uncertainty of Repeatability U_r	0.016
Uncertainty of Certified Reference Material U_{cal}	0.069

Measurement Uncertainty	% vol
Combined uncertainty	0.45
Expanded uncertainty at a 95% Confidence Interval	0.90

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	9.39
Expressed as a % of the Measured Concentration at Reference Conditions	9.39
Expressed as a % of the Emission Limit Value	-

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE BY FTIR

Actual Measured Concentration	19.63	% vol
Measured Concentration at Reference Conditions	19.63	% vol
Emission Limit Value	30	% vol
Instrument Range	30	% vol
Check Gas Concentration (Methane was used as a Surrogate)	62.21	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)	-0.180	<5%	Yes
Span drift (calculated from start and end readings).	-1.490	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	0.990	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.100	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	-1.000	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	0.710	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	0.695	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.170	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	% vol
Uncertainty of linearity (lack of fit) U_{fit}	-0.329
Uncertainty of zero drift $U_{0,dr}$	-0.031
Uncertainty of span drift $U_{s,dr}$	-0.258
Uncertainty of volume or pressure flow dependence U_{spress}	0.171
Uncertainty in Ambient Temperature U_{temp}	0.174
Uncertainty in Voltage U_{volt}	0.123
Uncertainty of interferents U_i	0.120
Uncertainty of Repeatability U_r	0.051
Uncertainty of Certified Reference Material U_{cal}	0.359

Measurement Uncertainty	% vol
Combined uncertainty	0.63
Expanded uncertainty at a 95% Confidence Interval	1.26

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	6.42
Expressed as a % of the Measured Concentration at Reference Conditions	6.42
Expressed as a % of the Emission Limit Value	4.20

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 1 - 19 March 2014

Reference	11	%vol
Measured concentration	7.07	%vol
Calibration gas	10.06	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	90	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	620	minutes	-	-
Number of readings in measurement	620	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	1.52	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.50	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	-1.41	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	0.676
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.020
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	-0.058
Uncertainty of calibration gas	ucalib	0.082

Measurement uncertainty (Concentration Measured)	7.07	%vol
Combined uncertainty	0.70	%vol
% of value	9.87	%

Expanded uncertainty expressed with a level of confidence of 95%	**19.74**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**1.40**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 2 - 20 March 2014

Reference	11	%vol
Measured concentration	7.40	%vol
Calibration gas	10.06	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	90	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	574	minutes	-	-
Number of readings in measurement	574	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	-1.56	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	3.98	% vol at span level	<2% volume/24hr	No
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	1.85	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	0.788
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.081
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	0.079
Uncertainty of calibration gas	ucalib	0.085

Measurement uncertainty (Concentration Measured)	7.40	%vol
Combined uncertainty	0.81	%vol
% of value	10.98	%

Expanded uncertainty expressed with a level of confidence of 95%	**21.97**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**1.63**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 4 - Summaries, Calculations, Raw Data and Charts

NOTE - The following data is provided for information only and falls outside ESG's scope of accreditation

COMBINED UNCOLLECTED SUMMARY							
Test	Sampling Times	$>PM_{10}$ Concentration		Probe Rinse Concentration		Combined Unweighed Concentration	
		Measured mg/m³	LOD mg/m³	Measured mg/m³	LOD mg/m³	Measured mg/m³	LOD mg/m³
Run 1	09:16 - 15:16 19 March 2014	0.023	0.003	0.077	0.077	0.080	0.080
Run 2	16:09 - 19:09 19 March 2014	0.006	0.006	0.167	0.167	0.173	0.173
Run 3	07:42 - 13:42 20 March 2014	0.003	0.003	0.078	0.078	0.081	0.081
Run 4	14:32 - 17:32 20 March 2014	0.006	0.006	0.151	0.151	0.157	0.157

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

Where the result is less than the LOD, the LOD is reported.

SAMPLES									
Test	$>PM_{10}$ Filter Number	Filter Start Weight g	Filter End Weight g	Mass Gained on Filter g	Probe Rinse Number	Probe Rinse Start Weight g	Probe Rinse End Weight g	Mass Gained in Rinse g	Combined Total Mass Gained g
Run 1	TQC1032	15.5892	15.5895	0.00038	8423	144.9653	144.9652	-0.00010	0.00028
Run 2	TQC1033	16.1137	16.1136	-0.00013	8424	182.94980	182.94990	0.00010	-0.00003
Run 3	TQC1034	16.1753	16.0975	-0.07780	8425	185.67310	185.67360	0.00050	-0.07730
Run 4	TQC1031	15.1463	15.1463	-0.00006	8427	185.10960	185.10980	0.00020	0.00014
Blank 1	-	-	-	-	8422	196.58970	196.58960	-0.00010	-0.00010
Blank 2	-	-	-	-	8426	194.45480	194.45470	-0.00010	-0.00010

PAUL GOTHE BOCHUM

Manufacturer of Emissions Control Technology
SEIT 1924

DIN ISO 9001

Paul Gothe GmbH Wittener Str. 82 D-44789 Bochum

To our customers

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http://www.paulgothe.de
service@paulgothe.de
VAT-No.: DE 813078723
Trade Register Bochum: HRB-6891

Your ref	Your letter	Our ref	Date 14.03.2007

Calibration of the Johnas Impactor according to **ISO 23210**
6.2 Separation curves and Section 6.3 Verification of the separation curves

The Johnas Impactor from Paul Gothe GmbH was developed before the ISO Guideline was evaluated and after the Germans and the Netherlands Authorities have enough experiences with our impactor. After that the European Delegation creates the ISO Guideline 23210. The section 6.3 is important and was influence by the Germans. They have the experiences and write the rules for the calibration section accordingly it was made for the Johnas-Impactor.
The development from the Johnas impactor starts with a doctoral thesis from Mrs. John at the Gerhard-Mercator-University. She makes the intensive testing and Mr. Geueke from the North Rhine Westphalia State Environment Agency makes additional verifications at the ESA (Emission Simulation Facility) at the Hessian Agency for the Environment and Geology (HLUG).

Most of the literatures and papers are in German, but all well-known:

1. Probenahme und chemische Analytik von korngrößenfraktionierten Immissions- und Emissionsaerosolen. Von der Fakultät für Naturwissenschaften der Gerhard-Mercator-Universität – Gesamthochschule Duisburg zur Erlangung des akademischen Grades eines Dr. rer. nat. genehmigte Dissertation von ASTRID CHRISTIANE JOHN aus Lichtenfels.
2. Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit Luftreinhaltung Forschungsbericht 298 44 280, Korngrößenverteilung (PM10 und PM2,5) von Staubemissionen relevanter stationärer Quellen (Teil II zu 297 44 853), von Dipl.-Ing. A. Dreiseidler, Ing. D. Straub, Prof. Dr.-Ing. G. Baumbach, Universität Stuttgart, Institut für Verfahrenstechnik und Dampfkesselwesen (IVD), Abteilung Reinhaltung der Luft (RdL), Institutsleiter: Prof. Dr.-Ing. K.R.G. Hein, IM AUFTRAG DES UMWELTBUNDESAMTES Juni 2001.
3. VDI 2066, part 10
4. Gefahrstoffe-Reinhaltung der Luft 59 (1999), Nr.11/12, S. 449-453

All this papers shows, that the design of the Johnas Impactor is a proved version for the determination of the PM 2.5 and PM 10. The shape of the separation curves is similar to those specified in ISO 7708:1995 and the separation efficiency at 10 µm and 2,5 µm is 50 % according to section 6.3 of the ISO 23210.

What you need more? There is no authority which has more competence as the listed authorities.

If you still in doubt, you maybe get in contact with Mr. Geueke (phone: ++49-201-7995-1263).

Paul Gothe GmbH

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IBAN DE 24 430500 01 000 120 9840 Swift: WELADED1BOC

Companion: Paul Gothe-Stiftung
Management: Dr. T. Grodten and Th. Hinrichs

PAUL GOTHE BOCHUM

Manufacturer of Emissions Control Technology
SEIT 1924

DIN ISO 9001

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Trade Register Bochum: HRB-6891

Your ref	Your letter	Our ref	Date 14.03.2007

Declaration of conformity

Herewith the company Paul Gothe GmbH in Bochum declare that the manufactured Cascade Impactor Johnas follows the guidelines from the North Rhine Westphalia State Environment Agency according the convention from 24 June 1999 and the PM 4 stage follows the convention of the Federal Environment Agency from 09. March 2005.

Our Cascade Impactor Johnas was developed in cooperation with the North Rhine Westphalia State Environment and the Gerhard-Mercator University Duisburg. This impactor was validated and after that 2004 adopted in the German Standard VDI 2066, part 10 and 2005 in ISO Standard 23210. All sizes of our manufactured impactors are according to these guidelines, individually checked according our strict quality management and named with a specific serial number. Only an impactor with this serial number is according to the Guideline VDI 2066, part 10 and ISO Standard 23210 and can use for the determination of PM 10 and PM 2.5.

Paul Gothe GmbH

Dr. Torsten Grodten
-manager-

Impactor Johnas according to the VDI 2066 and ISO 23210 and the convention from
Umwelt Bundes Amt
Für Mensch und Umwelt
Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen
NRW.

END OF REPORT

Appendix 4 – Stack emissions monitoring report: Veolia ES South Downs Ltd

STACK EMISSIONS MONITORING REPORT

Acacia Building
Vantage Point Business Village
Mitcheldean
GL17 0DD
Tel: 01594 546 343

Your contact at ESG
Laurence Sharrock
Business Manager - South
Tel: 01594 546 343
Email: laurence.sharrock@esg.co.uk

Operator & Address:
Veolia ES South Downs Ltd
Energy Recovery Facility
North Quay Road
Newhaven
East Sussex
BN9 0HE
-
-

Permit
N/A - Investigative Monitoring

Release Point:
Stream 1

Sampling Date(s):
1st and 2nd April 2014

ESG Job Number: Report Date: Version:	LCH00722 17th Feb 2015 1
Report By: MCERTS Number: MCERTS Level: Technical Endorsements:	Chris Houston MM 11 1135 MCERTS Level 1 - Technician
Report Approved By: MCERTS Number: Business Title: Technical Endorsements: Signature:	Andy Tiffen MM 05 640 MCERTS Level 2 - Projects Manager 1, 2 & 4 A.Tiffen.

UKAS TESTING 1015

CONTENTS

EXECUTIVE SUMMARY

Stack Emissions Monitoring Objectives
- Plant
- Operator
- Stack Emissions Monitoring Test House

Emissions Summary
Monitoring Times
Process Details
Monitoring Methods
Analytical Methods
- Sampling Methods with Subsequent Analysis
- On-Site Testing
Sampling Location
- Sampling Plane Validation Criteria
- Duct Characteristics
- Sampling Lines & Sample Points
- Sampling Platform
- Sampling Location / Platform Improvement Recommendations
Sampling and Analytical Method Deviations
Determination of representative sampling location

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

Veolia ES South Downs Ltd operates a waste incineration process at Veolia South Downs

Environmental Scientifics Group Limited were commissioned by Ricardo AEA to carry out stack emissions monitoring to determine the release of PM_{10} & $PM_{2.5}$ from the following Plant under standard operating conditions.

The measurements were commissioned by Ricardo-AEA on behalf of the Department of Environment, Food and Rural Affairs (Defra) to provide information for the UK National Atmospheric Emissions Inventory (NAEI).

Plant

Stream 1

Operator

Veolia ES South Downs Ltd
Energy Recovery Facility
North Quay Road
Newhaven
East Sussex
BN9 0HE
-

Stack Emissions Monitoring Test House

Environmental Scientifics Group Limited - Mitcheldean Laboratory
Acacia Building
Vantage Point Business Village
Mitcheldean
GL17 0DD
UKAS and MCERTS Accreditation Number: 1015

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.
MCERTS accredited results will only be claimed where both the sampling and analytical stages are UKAS accredited.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Limit**	**MCERTS accredited result**
Total Particulate Matter	mg/m³	0.7	0.26	10	✓
Particulate Emission Rate	g/hr	68	23.6	-	
PM_{10} **(Average result of 4 runs)**	mg/m³	0.032	0.04	-	✓
PM_{10} Emission Rate **(Average result of 4 runs)**	g/hr	2.50	3.1	-	
$PM_{2.5}$ **(Average result of 4 runs)**	mg/m³	0.019	0.03	-	✓
$PM_{2.5}$ Emission Rate **(Average result of 4 runs)**	g/hr	1.49	2.30	-	
PM_{10} - Runs					
PM_{10} - Run 1	mg/m³	0.070	0.09	-	✓
PM_{10} Emission Rate - Run 1	g/hr	5.41	6.8	-	
PM_{10} - Run 2	mg/m³	***0.009***	0.01	-	✓
PM_{10} Emission Rate - Run 2	g/hr	0.65	0.8	-	
PM_{10} - Run 3	mg/m³	0.030	0.04	-	✓
PM_{10} Emission Rate - Run 3	g/hr	2.34	3.0	-	
PM_{10} - Run 4	mg/m³	0.021	0.03	-	✓
PM_{10} Emission Rate - Run 4	g/hr	1.59	2.0	-	
$PM_{2.5}$ - Runs					
$PM_{2.5}$ - Run 1	mg/m³	0.056	0.09	-	✓
$PM_{2.5}$ Emission Rate - Run 1	g/hr	5.41	8.3	-	
$PM_{2.5}$ - Run 2	mg/m³	***0.004***	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 2	g/hr	0.33	0.5	-	
$PM_{2.5}$ - Run 3	mg/m³	***0.008***	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 3	g/hr	0.65	1.00	-	
$PM_{2.5}$ - Run 4	mg/m³	0.009	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 4	g/hr	0.66	1.02	-	
Moisture	%	17.0	1.5	-	✓
Stack Gas Temperature	^oC	151	-	-	✓
Stack Gas Velocity	m/s	18.0	-	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	111599	-	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	71782	-	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	57736	-	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	77669	-	-	

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 test specific flow data. Mass emissions for non isokinetic tests and isokinetic tests are calculated using these values

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
Total Particulate Matter Run 1	01 April 2014	10:52 - 17:32	360 minutes
Total Particulate Matter Run 2	02 April 2014	08:29 - 15:25	360 minutes
Total Particulate Matter Run 3	02 April 2014	16:21 - 19:21	180 minutes
Total Particulate Matter Run 4	03 April 2014	09:40 - 12:40	180 minutes
PM_{10} Run 1	01 April 2014	10:52 - 17:32	360 minutes
PM_{10} Run 2	02 April 2014	08:29 - 15:25	360 minutes
PM_{10} Run 3	02 April 2014	16:21 - 19:21	180 minutes
PM_{10} Run 4	03 April 2014	09:40 - 12:40	180 minutes
$PM_{2.5}$ Run 1	01 April 2014	10:52 - 17:32	360 minutes
$PM_{2.5}$ Run 2	02 April 2014	08:29 - 15:25	360 minutes
$PM_{2.5}$ Run 3	02 April 2014	16:21 - 19:21	180 minutes
$PM_{2.5}$ Run 4	03 April 2014	09:40 - 12:40	180 minutes
Stack Gas Flow Rate & Temperature Run 1	31 March 2014	15:00	-
Stack Gas Flow Rate & Temperature Run 2	01 April 2014	08:00	-
Stack Gas Flow Rate & Temperature Run 3	01 April 2014	18:14	-
Stack Gas Flow Rate & Temperature Run 4	02 April 2014	07:35	-
Stack Gas Flow Rate & Temperature Run 5	02 April 2014	16:00	-
Stack Gas Flow Rate & Temperature Run 6	02 April 2014	19:45	-
Stack Gas Flow Rate & Temperature Run 7	03 April 2014	09:00	-
Stack Gas Flow Rate & Temperature Run 8	03 April 2014	12:45	-

EXECUTIVE SUMMARY

PROCESS DETAILS	
Parameter	**Process Details**
Description of process	Waste incineration
Continuous or batch	Continuous
Product Details	Energy from waste
Part of batch to be monitored (if applicable)	N/A
Normal load, throughput or continuous rating	Approx 28 tonnes/hr
Fuel used during monitoring	Waste
Abatement	Bag filter, lime injection
Plume Appearance	Not visible from monitoring location

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by Environmental Scientifics Group Limited 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	0.07 mg/m³	34.8 %
PM_{10}	SRM - BS EN 23210	AE 136	1015	Yes	0.011 mg/m³	126 %
$PM_{2.5}$	SRM - BS EN 23210	AE 136	1015	Yes	0.006 mg/m³	154 %
O_2	SRM - BS EN 14789	AE 102	1015	Yes	0.01%	10.1%
H_2O	AM - M22/FTIR	AE 063	1015	Yes	0.24 %	8.9%
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	5 Pa	-

The measurement uncertainties for the PM_{10} and $PM_{2.5}$ measurements reflect that measured concentrations were near or below the Limit of Detection.

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 Mitcheldean	ESG Mitcheldean	3 months
PM_{10}	Gravimetric	AE 106	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	1 year
$PM_{2.5}$	Gravimetric	AE 106	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	1 year

ON-SITE TESTING							
Species	Analytical Technique	Analytical Procedure	UKAS Lab Number	MCERTS Accredited Analysis	Laboratory	Data Archive Location	Archive Period
-	-	-	-	-	-	-	-
O_2	Paramagnetism	AE 102	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	5 years
H_2O	Fourier Transform - Infra Red	AE 063	1015	Yes	ESG Mitcheldean	ESG Mitcheldean	5 years

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	162	Pa	>= 5 Pa	Yes	BS EN 13284-1
Lowest Gas Velocity	15.70	m/s	-	-	-
Highest Gas Velocity	22.40	m/s	-	-	-
Ratio of Gas Velocities	1.43	-	< 3 : 1	Yes	BS EN 13284-1
Mean Velocity	18.02	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^{o}	Yes	BS EN 13284-1
No local negative flow	Yes	-	-	Yes	BS EN 13284-1

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Circular	-
Depth	1.44	m
Width	-	m
Area	1.63	m^2
Port Depth	400	mm

SAMPLING LINES & POINTS			
	Isokinetic (CEN Methods)	**Isokinetic** (ISO Methods)	**Non-Iso & Gases**
Sample port size	5 inch BSP	-	5 inch BSP
Number of lines used	1	-	1
Number of points / line	1	-	1
Duct orientation	Vertical	-	Vertical
Filtration	In Stack	-	In Stack
Filtration for TPM	In Stack	-	-

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

M1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	Yes
Platform has 2 levels of handrails (approximately 0.5 m & 1.0 m high)	Yes
Platform has vertical base boards (approximately 0.25 m high)	Yes
Platform has removable chains / self closing gates at the top of ladders	N/A
Handrail / obstructions do not hamper insertion of sampling equipment	Yes
Depth of Platform = >Stack depth / diameter + wall and port thickness + 1.5m	Yes

Sampling Platform Improvement Recommendations (if applicable)

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

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

6hr run data collection

Data was collected every ten minutes during the 6hr runs, instead of every five as per the standard. However all readings were checked at five minute nervals to ensure continuity between points.

TPM nozzle size

Due to the additional number of impingers required for a 6hr sample run in a 22% moisture stack, it was not possible to acheive isokinetics with a 6mm nozzle therefore a 5mm was used. During the 6hr sample run it was expected that a more than sufficient gas sample volume will be acheived.

Goose-neck nozzle Validation

Due to the long port sleeve, it was physically impossible to inserted the cascade impactor using the straight entry nozzle setup recommended in BS EN 23210. Therefore the use of a goose-neck setup was used as this was the only feasible method for monitoring. The standard requires that the use of a goose-neck nozzle is validated, however on this occasion it has not been possible to demonstrate that losses in the nozzle meet the criteria in the standard because the measured concentrations were low and the weight of particulate recovered from the nozzle rinses and the filter media were at or near the weighing LoD. In the context of the low emission concentrations detemined during the measurements (all less than 0.1 mg/Nm3), losses in the sampling nozzle are unlikely to increase the concentrations significantly.

Single point TPM sampling

As the TPM run was for comparison purposes with the particle size run, this was also set in the centre of the duct with the particle size head.

Sample flow variation

The sample flowrate could not be maintained within 5% of the nominal flow throughout the testing periods (which were over extended periods due to the anticipated low PM emission concentrations). Whilst this will have affected the actual cutpoints achieved by the impactor, the results are all at or very near the LOD for the tests and hence this is anticipated to have limited impact on the outcome of the measurements.

Determination of representative sampling location

An assessment of temperature homogeneity was performed in accordance with EN 23210 Annex-G on the first day of monitoring 5th March 2014. There was a feedstock change on the morning of the third day 7th March 2014 from municipal waste to Community Recyling Centre waste. A further homogeneity test was performed on 7th March and the representative sampling point was determined to be at the same location as on 5th March.

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	4
PM_{10}	SRM - BS EN 23210	AE 136	1015	Yes	4
$PM_{2.5}$	SRM - BS EN 23210	AE 136	1015	Yes	4
H_2O	AM - M22/FTIR	AE 063	1015	Yes	6
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	10

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	P1760 + P1799	Horiba PG-250 Analyser	-	Laboratory Balance	00-12/00-13
Box Thermocouples	P1760 + P1799	FT-IR	P2060	Tape Measure	24-DJH
Meter In Thermocouple	P1760 + P1799	FT-IR Oven Box	-	Stopwatch	17-DJH
Meter Out Thermocouple	P1760 + P1799	Bernath 3006 FID	-	Protractor	-
Control Box Timer	P1799	Signal 3030 FID	-	Barometer	08-DJH
Oven Box	-	Servomex	-	Digital Micromanometer	01-DJH
Probe	-	JCT Heated Head Filter	-	Digital Temperature Meter	03-DJH
Probe Thermocouple	-	Thermo FID	-	Stack Thermocouple	-
Probe	-	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	P2253 + P2160	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	P2246 + P2158	Anemometer	-	1m Heated Line (1)	18-05
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	-	Chiller (JCT/MAK 10)	-	1m Heated Line (3)	-
Last Impinger Arm	P1966 + P2049	Heated Line Controller (1)	-	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	-	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	P2178	Site temperature Logger	-	10m Heated Line (2)	-
Small DGM	-	Impactor 1	NR18706	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	03-84
Inclinometer (Swirl Device)	P2094		-	20m Heated Line (2)	-

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

CALIBRATION / CHECK GASES

Gas (traceable to ISO 17025)	Cylinder I.D Number	Supplier	ppm	%	Analytical Tolerance +/- %
Oxygen	DA W1	BOC	-	9.52	2
Methane	DA W1	BOC	162.9	-	2
Carbon Dioxide	DA W1	BOC	-	5.18	2

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

STACK EMISSIONS MONITORING TEAM

Team Leader	Paul Jones MCERTS Level 2 Te1 Expiry Date - Dec 2016 Te2 Expiry Date - Dec 2016 Te3 Expiry Date - Mar 2018 Te4 Expiry Date - Dec 2016 MM 02 044 MCERTS Expiry Date - Mar 2018 H&S Expiry Date - Sep 2015
Technician	Rad Poremba MCERTS Level 1 MM 10 1069 MCERTS Expiry Date - Jul 2015 H&S Expiry Date - Jul 2015

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY					
Parameter	**Sampling Times**	**Concentration mg/m³**	**Uncertainty mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	10:52 - 17:32 01 April 2014	0.4	0.14	10	32
Run 2	08:29 - 15:25 02 April 2014	1.3	0.15	10	123
Run 3	16:21 - 19:21 02 April 2014	0.6	0.27	10	53
Run 4	09:40 - 12:40 03 April 2014	0.7	0.29	10	63
Blank	-	0.09	-	-	-
Blank 2	-	0.09	-	-	-
Blank 3	-	0.09	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

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	116150.00	0.15620	0.15480	-0.00140	68.53890	68.54120	0.00230	0.00090
Run 2	116152.00	0.15630	0.16260	0.00630	70.26230	70.26560	0.00330	0.00960
Run 3	116153.00	0.15680	0.15630	-0.00050	74.24400	74.24590	0.00190	0.00140
Run 4	116155.00	0.15790	0.15970	0.00180	72.45760	72.45830	0.00070	0.00250

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	116151	0.15910	0.15900	-0.00010	71.83610	71.83650	0.00040	0.00050
Run 2	116154	0.15730	0.15730	0.00000	71.29260	71.29250	-0.00010	0.00050
Run 3	116156	0.15440	0.15430	-0.00010	71.29260	71.29250	-0.00010	0.00050

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	755.26
Stack static pressure, P_{static}	mm H_2O	18.35
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	756.61
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		5.613
Gas meter correction factor, Y_d		1.0558
Mean dry gas meter temperature, T_m		35.472
Mean pressure drop across orifice, ΔH	mmH_2O	23.580
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.224
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.2930
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		7.5
% oxygen reference condition		11
O_2 Reference Factor: $O_2\ Ref = \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		1.35
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	7.0272
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1699
	%	16.99
Moisture by FTIR	%	19.56725315
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.82
Mean of velocity heads, ΔP_{avg}	mm H_2O	27.67
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.26
Mean stack gas temperature, T_s	°C	151
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	21.30

Molecular weight of dry gas, M_d		
CO_2	%	11.67
O_2	%	7.55
Total	%	19.22
N_2 (100 -Total)	%	80.78
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		30.17
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.10
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	1.63
$Q_a = (60)(A_s)(V_s)$	m³/min	2081.9
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	1107.3
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	1489.64
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	1334.02
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	5.03
Nozzle area, A_n	mm^2	19.87
Total sampling time, θ	min	360
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	107.4
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00020
Mass collected in probe, M_p	g	0.00230
Total mass collected, M_n	g	0.00250
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.397
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.479
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.356
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		31.80

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 2 — TPM

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	755.26
Stack static pressure, P_{static}	mm H_2O	18.35
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	756.61
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		5.524
Gas meter correction factor, Y_d		1.0558
Mean dry gas meter temperature, T_m		30.056
Mean pressure drop across orifice, ΔH	mmH_2O	23.454
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.233
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.3045
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		7.372787194
% oxygen reference condition		11
O_2 Reference Factor: O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		1.36
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	7.1315
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1699
	%	16.99
Moisture by FTIR	%	19.56725315
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.82
Mean of velocity heads, ΔP_{avg}	mm H_2O	28.03
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.29
Mean stack gas temperature, T_s	^oC	151
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	21.45

Molecular weight of dry gas, M_d		
CO_2	%	11.67
O_2	%	7.37
Total	%	19.05
N_2 (100 -Total)	%	80.95
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		30.16
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.10
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	1.63
$Q_a = (60)(A_s)(V_s)$	m³/min	2096.0
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	1114.5
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	1516.02
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	1342.62
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	5.03
Nozzle area, A_n	mm^2	19.87
Total sampling time, θ	min	360
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	106.9
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00630
Mass collected in probe, M_p	g	0.00330
Total mass collected, M_n	g	0.00960
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	1.52
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	1.83
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	1.35
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		122.66

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 3 TPM

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	755.26
Stack static pressure, P_{static}	mm H_2O	18.35
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	756.61
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		2.802
Gas meter correction factor, Y_d		1.0558
Mean dry gas meter temperature, T_m		30.847
Mean pressure drop across orifice, ΔH	mmH_2O	23.832
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		2.648
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	3.1898
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		7.129864607
% oxygen reference condition		11
O_2 Reference Factor $O_2\ Ref = \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		1.39
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	3.6725
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1699
	%	16.99
Moisture by FTIR	%	19.56725315
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.82
Mean of velocity heads, ΔP_{avg}	mm H_2O	28.44
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.33
Mean stack gas temperature, T_s	°C	152
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	21.63

Molecular weight of dry gas, M_d		
CO_2	%	11.67
O_2	%	7.13
Total	%	18.80
N_2 (100 -Total)	%	81.20
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		30.15
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.09
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	1.63
$Q_a = (60)(A_s)(V_s)$	m³/min	2113.4
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	1122.0
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	1553.52
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	1351.73
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	5.03
Nozzle area, A_n	mm^2	19.87
Total sampling time, θ	min	180
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	107.4
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00020
Mass collected in probe, M_p	g	0.00190
Total mass collected, M_n	g	0.0021
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.66
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.79
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.57
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		53.40

ISOKINETIC SAMPLING EQUATIONS - RUN 4 — TPM

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	745.51	CO_2	%	11.67
Stack static pressure, P_{static}	mm H_2O	21.41	O_2	%	7.22
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	747.08	Total	%	18.89
			N_2 (100 -Total)	%	81.11
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		30.16
Moisture trap weight increase,Vlc	g	-	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	28.09
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		2.699	Area of stack, A_s	m^2	1.63
Gas meter correction factor, Y_d		1.059	$Q_a = (60)(A_s)(V_s)$	m³/min	2045.0
Mean dry gas meter temperature, T_m		29.042	**Total flow of stack gas, Q**		
Mean pressure drop across orifice, ΔH	mmH_2O	22.048	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		2.539	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	1074.0
Volume of gas metered wet, V_{mstw}			$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	1476.63
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	3.0583			
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	1293.85
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	**Percent isokinetic, %I**		
			Nozzle diameter, D_n	mm	5.03
% oxygen measured in gas stream, act%O_2		7.222038048	Nozzle area, A_n	mm^2	19.90
% oxygen reference condition		11	Total sampling time, θ	min	180
O_2 Reference Factor O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		1.38	$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	107.5
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	3.4977	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			**Particulate Concentration, C**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1699	Mass collected on filter, M_f	g	0.00180
	%	16.99	Mass collected in probe, M_p	g	0.00070
Moisture by FTIR	%	19.56725315	Total mass collected, M_n	g	0.00250
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.82
Pitot tube velocity constant, K_p					
Velocity pressure coefficient, C_p		34.97	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.98
Mean of velocity heads, ΔP_{avg}	mm H_2O	0.82			
Mean square root of velocity heads, √ΔP		26.35	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.71
Mean stack gas temperature, T_s	°C	5.13			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	151	**Particulate Emission Rates, E**		
		20.92	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		63.46

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER QUALITY ASSURANCE CHECKLIST

LEAK RATE						
Run	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable?
Run 1	16.46	0.2	0.3	304.8	0.33	Yes
Run 2	16.20	0.3	0.3	304.8	0.32	Yes
Run 3	16.44	0.2	0.25	304.8	0.33	Yes
Run 4	15.87	0.3	0.3	304.8	0.32	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	107.39	Yes
Run 2	106.90	Yes
Run 3	107.44	Yes
Run 4	107.48	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m³	5% ELV mg/m³	LOD < 5% ELV
Run 1	0.07	0.5	Yes
Run 2	0.07	0.5	Yes
Run 3	0.14	0.5	Yes
Run 4	0.1	0.5	Yes

The above is based on both the Filter and rinse uncertainty

BLANK VALUE				
Run	Overall Blank Value mg/m³	Daily Emission Limit Value mg/m³	Acceptable Blank Value mg/m³	Overall Blank Acceptable mg/m³
Blank 1	0.09	10	1.0	Yes
Blank 2	0.09	10	1.0	Yes
Blank 3	0.09	10	1.0	Yes

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	153	180	160
Run 2	QF	47	152	180	160
Run 3	QF	47	153	180	160
Run 4	QF	47	152	180	160

GF = Glass Fibre

QF = Quartz Fibre

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PM_{10} SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	10:52 - 17:32 01 April 2014	0.070	0.009	-	5.41
Run 2	08:29 - 15:25 02 April 2014	0.009	0.009	-	0.65
Run 3	16:21 - 19:21 02 April 2014	0.030	0.017	-	2.34
Run 4	09:40 - 12:40 03 April 2014	0.021	0.023	-	1.59
Blank 1	-	0.011	-	-	-
Blank 2	-	0.011	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.
where values are below the LOD the LOD will be reported.

$PM_{2.5}$ SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	10:52 - 17:32 01 April 2014	0.056	0.004	-	4.33
Run 2	08:29 - 15:25 02 April 2014	0.004	0.004	-	0.33
Run 3	16:21 - 19:21 02 April 2014	0.008	0.008	-	0.65
Run 4	09:40 - 12:40 03 April 2014	0.009	0.012	-	0.66
Blank 1	-	0.006	-	-	-
Blank 2	-	0.022	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.
where values are below the LOD the LOD will be reported, where this occurs the quoted uncertainties will be relatively high.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

$PM_{2.5}$ (BF) SAMPLES WEIGHTS				
Test	$PM_{2.5}$ Filter Number	Filter Start Weight g	Filter End Weight g	$PM_{2.5}$ Mass Gained on Filter g
Run 1	QC1003	15.82804	15.82868	0.00064
Run 2	QC1010	32.77095	32.77094	-0.00001
Run 3	QC1049	32.06334	32.06302	-0.00032
Run 4	QC1045	32.73710	32.73682	-0.00028
Blank 1	QC1009	32.58576	32.58548	-0.00028
Blank 2	QC1044	31.65517	31.65536	0.00019

PM_{10} (CP2) SAMPLES WEIGHTS				
Test	PM_{10} Filter Number g	Filter Start Weight g	Filter End Weight g	PM_{10} Mass Gained on Filter g
Run 1	QC1028	15.16626	15.16642	0.00016
Run 2	QC1059	15.82759	15.82754	-0.00005
Run 3	QC1049	15.16123	15.16136	0.00013
Run 4	QC1053	15.27576	15.27583	0.00007
Blank 1	QC1060	16.04445	16.04427	-0.00018
Blank 2	QC1052	15.69773	15.69749	-0.00024

$PM_{2.5}$ & PM_{10} (BF & CP2) SAMPLES WEIGHTS COMBINED							
Test	$PM_{2.5}$ Filter Number	PM_{10} Filter Number	$PM_{2.5}$ Mass Gained on Filter g	PM_{10} Mass Gained on Filter g	Actual $PM_{2.5}$ & PM_{10} Combined Total Mass Gained g	$PM_{2.5}$ & PM_{10} Combined Weighing LOD g	*Reported $PM_{2.5}$ & PM_{10} Combined Total Mass Gained g
Run 1	QC1003	QC1028	0.00064	0.00016	0.00080	0.00010	0.00080
Run 2	QC1010	QC1059	-0.00001	-0.00005	-0.00006	0.00010	0.00010
Run 3	QC1049	QC1049	-0.00032	0.00013	-0.00019	0.00010	0.00018
Run 4	QC1045	QC1053	-0.00028	0.00007	-0.00021	0.00010	0.00012
Blank 1	QC1009	QC1060	-0.00028	-0.00018	-0.00046	0.00010	0.00010
Blank 2	QC1044	QC1052	0.00019	-0.00024	-0.00005	0.00010	0.00010

* Where weighing values are below the LOD possibly due to loss of filter material, the LOD will be reported.
NOTE - Where the filter weight gain is less than the weighing uncertainty, the weighing uncertainty is used for further calculations. The weighing uncertainty is 0.00005g.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	755.3	CO_2		9.39
Stack static pressure, P_{static}	mm H_2O	1.3	O_2		7.55
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	755.4	Total		16.94
			N_2 (100 -Total)		83.06
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.80
Moisture trap weight increase,Vlc	g	H_20 by FTIR	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.49
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		9.91	Area of stack, A_s	m^2	1.63
Gas meter correction factor, Y_d		0.97	$Q_a = (60)(A_s)(V_s)$	m³/min	1848.6
Mean dry gas meter temperature, T_m		39.13	**Percent isokinetic, %I**		
Mean pressure drop across orifice, ΔH	mmH_2O	71.81	Required Flow Rate @ DGM	l/min	28.70
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		8.442	Actual Flow Rate @ DGM	l/min	31.0
Volume of gas metered wet, V_{mstw}			Isokinetic Rate		108.14
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	10.4957	Acceptable 90% - 130%		Yes
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Particulate Concentration, C_{PM10}**		
			Mass of particulate collected on PM_{10} filter, M_f		0.00016
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00064
			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.07622
% oxygen measured in gas stream, act%O_2		7.55			
% oxygen reference condition		11	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.09476
O_2 Reference Factor: O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		1.35	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.07044
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	11.356			
Moisture content, B_{wo}			**Particulate Emission Rates, E**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1957	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		5.41
	%	19.57	**Particulate Concentration, $C_{PM2.5}$**		
Moisture by FTIR	%	19.57	Mass of particulate collected on filter, M_f		0.00064
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0610
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.81	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0758
Mean of velocity heads, ΔP_{avg}	mm H_2O	21.83			
Mean square root of velocity heads, √ΔP		4.7	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0564
Mean stack gas temperature, T_s	°C	151			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	18.92	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		4.33

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 2 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	750.0
Stack static pressure, P_{static}	mm H_2O	1.6
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	750.1
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 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		9.93
Gas meter correction factor, Y_d		0.97
Mean dry gas meter temperature, T_m		33.19
Mean pressure drop across orifice, ΔH	mmH_2O	70.00
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		8.565
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	10.6241
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		7.37
% oxygen reference condition		11
O_2 Reference Factor: O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		1.36
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	11.671
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1938
	%	19.38
Moisture by FTIR	%	19.38
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.81
Mean of velocity heads, ΔP_{avg}	mm H_2O	21.01
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.58
Mean stack gas temperature, T_s	°C	151
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	18.60

Molecular weight of dry gas, M_d		
CO_2		9.71
O_2		7.37
Total		17.09
N_2 (100 -Total)		82.91
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.85
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.55
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	1.63
$Q_a = (60)(A_s)(V_s)$	m^3/min	1817.7
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	31.10
Actual Flow Rate @ DGM	l/min	31.0
Isokinetic Rate		99.66
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00005
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0094
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0117
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0086
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.65
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0047
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0058
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0043
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.33

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 3 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	750.0
Stack static pressure, P_{static}	mm H_2O	1.6
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	750.1
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	H_20 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		5.04
Gas meter correction factor, Y_d		0.97
Mean dry gas meter temperature, T_m		34.61
Mean pressure drop across orifice, ΔH	mmH_2O	71.67
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		4.324
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	5.4267
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		7.13
% oxygen reference condition		11
O_2 Reference Factor: O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		1.39
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	5.998
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.2032
	%	20.32
Moisture by FTIR	%	20.32
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.81
Mean of velocity heads, ΔP_{avg}	mm H_2O	21.81
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.67
Mean stack gas temperature, T_s	°C	152
$V_s = (K_p)(C_p)(\sqrt{\Delta P})\sqrt{\frac{(T_s + 273)}{(M_s)(P_s)}}$	m/s	18.99

Molecular weight of dry gas, M_d		
CO_2		9.97
O_2		7.13
Total		17.10
N_2 (100 -Total)		82.90
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.88
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.47
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	1.63
$Q_a = (60)(A_s)(V_s)$	m³/min	1856.3
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	29.20
Actual Flow Rate @ DGM	l/min	28.0
Isokinetic Rate		95.80
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00013
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0332
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0416
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0300
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		2.34
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0092
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0116
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0083
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.65

ISOKINETIC SAMPLING EQUATIONS RUN 4 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	745.5	CO_2		9.56
Stack static pressure, P_{static}	mm H_2O	-1.6	O_2		7.39
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	745.4	Total		16.95
			N_2 (100 -Total)		83.05
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.83
Moisture trap weight increase,Vlc	g	H_20 by FTIR	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.39
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		4.98	Area of stack, A_s	m^2	1.63
Gas meter correction factor, Y_d		0.97	$Q_a = (60)(A_s)(V_s)$	m³/min	1873.8
Mean dry gas meter temperature, T_m		33.36	**Percent isokinetic, %I**		
Mean pressure drop across orifice, ΔH	mmH_2O	70.97	Required Flow Rate @ DGM	l/min	29.20
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		4.265	Actual Flow Rate @ DGM	l/min	27.6
Volume of gas metered wet, V_{mstw}			Isokinetic Rate		94.68
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	5.3705	Acceptable 90% - 130%		Yes
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Particulate Concentration, C_{PM10}**		
			Mass of particulate collected on PM_{10} filter, M_f		0.00007
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0223
% oxygen measured in gas stream, act%O_2		7.39			
% oxygen reference condition		11	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0281
O_2 Reference Factor: O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		1.36			
			$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0207
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	5.805			
Moisture content, B_{wo}			**Particulate Emission Rates, E**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.2058	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		1.59
	%	20.58	**Particulate Concentration, $C_{PM2.5}$**		
Moisture by FTIR	%	20.58	Mass of particulate collected on filter, M_f		0.00005
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0093
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.81	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0117
Mean of velocity heads, ΔP_{avg}	mm H_2O	22.06			
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.70	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0086
Mean stack gas temperature, T_s	°C	151			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	19.17	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.66

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PM_{10} & $PM_{2.5}$ 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	31.04	0.10	0.6	381	0.62	Yes
Run 2	30.99	0.6	0.6	305	0.62	Yes
Run 3	27.97	0.12	0.22	381	0.56	Yes
Run 4	27.65	0.1	0.1	305	0.55	Yes

ISOKINETICITY		
Run	Flow Variation %	Acceptable Variation
Run 1	108.1	Yes
Run 2	99.7	Yes
Run 3	95.8	Yes
Run 4	94.7	Yes

Acceptable Flow rate 90 -130%

FILTERS					
Run	Filter Material	Filter Size mm	Max Filtration Temperature °C	Pre-conditioning Filter Temperature °C	Post conditioning Filtration Temperature °C
Run 1	QF	50	153	180	160
Run 2	QF	50	152	180	160
Run 3	QF	50	153	180	160
Run 4	QF	50	152	180	160

QF = Quartz Fibre

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Conformity with relevant aspects of BS EN ISO 23210:2009

GENERAL METHODOLOGY

The equipment employed is a Paul Gothe, Johnas cascade impactor (see pg 13 for serial number) system meeting the requirements of BS EN ISO 23210. The standard cites a two-stage impactor system.

The method for sampling requires the extraction of a representative sample of duct gas isokinetically, into a specially designed in-stack sampling head. The Cascade Impactor is a multi-stage, multi-jet impactor which aerodynamically classifies particulates into multiple size ranges. The cascade impactor uses the principle of inertial separation to size segregate particulate samples from the gas stream. The impactor has two stages for particle size determination. Each stage gives a cut-point based on aerodynamic diameter of the particle.

During sampling, the particles are driven (jetted) toward a collecting surface where they may cling. By changing the velocity (orifice size of the jet), the size of the particles collected is controlled. The size of the jets within each stage is constant, but for each succeeding stage the jets get smaller. Impaction occurs when the particle's inertia overcomes the aerodynamic drag. Otherwise, the particle remains in the air stream and proceeds to the next stage. To keep the cut-point for each stage constant, the impactor is operated at a constant flow rate.

At each stage, the particle impacts on to a conditioned and pre-weighed substrate. Following sampling, the substrates are reconditioned and reweighed to determine the mass collected.

Based on the sampling conditions (sampling rate and gas temperature) the cut size (D50 – diameter of particles having a 50% probability of penetration) associated with each impactor stage may be determined.

An homogeneity assessment based on BS EN ISO 23210, Annex G, is undertaken to determine the most representative sampling point in the sampling plane (temperature, velocity and oxygen are suitable surrogates for particulate matter). The velocity measurement at the chosen point is used to determine an appropriate sampling nozzle/flow rate in order to ensure that isokinetic conditions are maintained throughout sampling to within the 90-130% range allowed in the standard (8.1) and which is consistent with the sampling equipment.

Concurrently, the volume of duct gas sampled is measured. This then enables the particulate concentration at each cut size to be determined.

The outlet gas from the sampling head is passed via a sampling probe through an impinger train with the purpose of removing water prior to entry to the sampling control box. It is not intended that the sampling train be used for additional sampling of condensible determinands and as such the train is unheated.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Conformity with relevant aspects of BS EN ISO 23210:2009

Sampling Plane Validation Criteria				
EA Technical Guidance Note (Monitoring) M1	Result	Units	Requirement	Compliant
Lowest Differential Pressure	162	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	15.70	m/s	-	-
Highest Gas Velocity	22.40	m/s	-	-
Ratio of Gas Velocities	1.43	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^{o}	Yes
No local negative flow	Yes	-	-	Yes

Conformance with BS EN ISO 23210:2009			
Reference	Requirement	Result	Compliant
Section 6.3	Suitable Impcator Used	See statement of conformity for Impactor	Yes
Section 8.1	Sampling position acceptable (as per 13284-1)	As per table "Sampling Plane Validation"	Yes
Section 8.1	Nozzle arrangement	See statement of conformity for Impactor	Yes
Section 8.1	Representative sampling point	See Homogeneity assessment below	Yes
Section 8.1	Constant Sample gas flow, iso-kinetic rate 90% to 130%		
	Run 1 - Required flow 28.7 (LPM)		-
	Run 1 - Minimum permissable flow 25.83 (LPM)	26.30	Yes
	Run 1 - Maximum permissable flow 37.31 (LPM)	37.19	Yes
	Run 2 - Required flow 31.1 (LPM)		-
	Run 2 - Minimum permissable flow 27.99 (LPM)	28.27	Yes
	Run 2 - Maximum permissable flow 40.43 (LPM)	33.63	Yes
	Run 3 - Required flow 29.2 (LPM)		-
	Run 3 - Minimum permissable flow 26.28 (LPM)	26.40	Yes
	Run 3 - Maximum permissable flow 37.96 (LPM)	29.38	Yes
	Run 4 - Required flow 29.2 (LPM)		-
	Run 4 - Minimum permissable flow 26.28 (LPM)	26.30	Yes
	Run 4 - Maximum permissable flow 37.96 (LPM)	30.88	Yes
Section 8.1	Overall blank taken once per day	Yes	Yes
Section 8.2	Impactor cleaned between each measurement	Yes	Yes
Section 8.2	Arrangement of impactor plates	See statement of conformity for Impactor	Yes
Section 8.3.2	Data taken for velocity, composition, temp & pressure	See "Preliminary stack survey" section	Yes
Section 8.3.3	Sampling rate determination in accordance with Annex A	Yes	Yes
Section 8.3.3	Sample flow rate kept +/- 5% of nominal flow rate		
	Run 1 - Max sample flow deviation from nominal (%)	58.2	No
	Run 2 - Max sample flow deviation from nominal (%)	22.2	No
	Run 3 - Max sample flow deviation from nominal (%)	9.3	No
	Run 4 - Max sample flow deviation from nominal (%)	11.3	No
Section 8.3.4	Nozzle selectedto allow iso-kinetic rate 90% to 130%	Yes, as above	Yes
Section 8.3.5	Leak check less than 2%		
	Run 1	0.32	Yes
	Run 2	1.94	Yes
	Run 3	0.43	Yes
	Run 4	0.36	Yes
Section 8.3.6	Impactor at flue gas temperature before sampling	Yes	Yes
Section 8.3.6	Angle of nozzle less than 10 Degress to flow	Yes	Yes
Section 8.3.6	Flowrate has checked and recorded every 5 mins	Yes	Yes
Section 8.3.6	Dynamic pressure recorded every 5 mins	Yes	Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Homogeneity assessment

Assessment 1

Point number (i)	Distance along sample line (mm)	Probe Marking (mm)	Temp Deg C grid	Temp Deg C fixed	r_i
1	72	472	150	151	0.993
2	216	616	151	151	1.000
3	360	760	151	151	1.000
4	504	904	151	151	1.000
5	648	1048	151	151	1.000
6	792	1192	151	150	1.007
7	936	1336	151	150	1.007
8	1080	1480	151	150	1.007
9	1224	1624	151	151	1.000
10	1368	1768	151	151	1.000
Second Line					
1	72	472	149	151	0.987
2	216	616	151	151	1.000
3	360	760	151	151	1.000
4	504	904	151	151	1.000
5	648	1048	151	151	1.000
6	792	1192	151	151	1.000
7	936	1336	151	151	1.000
8	1080	1480	151	151	1.000
9	1224	1624	152	150	1.013
10	1368	1768	151	151	1.000

No. of points	20
S_{grid}	0.55
S_{ref}	0.41
F	1
Is $S_{grid} <= S_{ref}$?	No
F Factor	1.812
$F_{N-1; N-1; 0.95}$	2.17
Is F Factor < $F_{N-1;N-1;0.95}$?	Yes
S_{pos}	0.369
$t_{N-1;0.95}$	2.093
U_{pos}	0.7742
Permissible Uncertainty	10
Is $U_{pos} < 0.5 * U_{perm}$?	N/A

Sample can be taken from any location

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DAILY OXYGEN SUMMARY

Run	Sampling Times	Concentration %	LOD %
1	10:52 - 17:32 01 April 2014	7.55	0.01
2	08:29 - 15:25 02 April 2014	7.37	0.01
3	16:21 - 19:21 02 April 2014	7.13	0.01
4	09:40 - 12:40 03 April 2014	7.39	0.01

PRE SAMPLING CALIBRATION DATA								
Date	Time of Analyser Check	Range (%)	Zero Reading at analyser	Span Reading at analyser	Zero Check at analyser	Zero Check down line	Span Check down line	Leak Rate %
31 March 2014	15:34 - 17:13	25	0.00	9.52	0.00	0.01	9.55	0.31
01 April 2014	17:51 - 18:13	25	0.00	9.52	0.00	0.09	9.48	-0.42
02 April 2014	15:36 - 16:00	25	0.00	9.52	0.00	0.05	9.59	0.73

POST SAMPLING CALIBRATION DATA					
Date	Time of Analyser Check	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
01 April 2014	17:51 - 18:13	0.09	9.48	0.32	-1.58
02 April 2014	15:36 - 16:00	0.05	9.59	-0.16	1.58
03 April 2014	12:30 - 13:02	0.01	9.52	-0.16	-0.32

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GAS SUMMARY

Test	Sampling Times	Concentration %	Analysis Areas	Interference (%) *	LOD %
Moisture Run 1	10:52 - 17:32 01 April 2014	19.6	3200 - 3401	0.6	0.24
Moisture Run 2	08:29 - 15:25 02 April 2014	19.4	3200 - 3401	0.58	0.24
Moisture Run 3	16:21 - 19:21 02 April 2014	20.3	3200 - 3401	0.58	0.24
Moisture Run 4	09:40 - 12:40 03 April 2014	20.6	3200 - 3401	0.58	0.24
Carbon Dioxide Run 1	10:52 - 17:32 01 April 2014	9.4	2000 - 2223	1.33	0.01
Carbon Dioxide Run 2	08:29 - 15:25 02 April 2014	9.7	2000 - 2223	1.33	0.01
Carbon Dioxide Run 3	16:21 - 19:21 02 April 2014	10.0	2000 - 2223	1.33	0.01
Carbon Dioxide Run 4	09:40 - 12:40 03 April 2014	9.6	2000 - 2223	1.33	0.01

*M22 Specifies interference must be <5%.

FTIR CALIBRATION CHECKS

Pre - Sampling Checks - System			Date of Checks	31 March 2014		Time of Checks	16:48	
Post Sampling Checks - System			Date of Checks	01 April 2014		Time of Checks	17:51	
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
H_2O	0.26	-0.01	-0.90	162.9	163.5	0.34	166.2	1.65
CO_2(%)	0.00	0.00	0.00	5.2	5.1	-2.41	5.2	3.20

Pre - Sampling Checks - System			Date of Checks	01 April 2014		Time of Checks	17:51	
Post Sampling Checks - System			Date of Checks	02 April 2014		Time of Checks	15:51	
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
H_2O	0.26	0.00	-0.87	162.9	166.2	2.00	169.3	1.89
CO_2(%)	0.00	0.00	0.00	5.2	5.2	0.72	5.1	-1.59

Pre - Sampling Checks - System			Date of Checks	02 April 2014		Time of Checks	15:51	
Post Sampling Checks - System			Date of Checks	03 April 2014		Time of Checks	12:46	
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
H_2O	0.26	0.00	-0.87	162.9	169.3	3.92	166.4	-1.72
CO_2(%)	0.00	0.00	0.00	5.2	5.1	-0.88	5.0	-1.71

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.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	1.44	m
Stack Width, W	-	m
Stack Area, A	1.63	m^2
Average stack gas temperature	151	^oC
Stack static pressure	0.15	kPa
Barometric Pressure	100.1125	kPa
Pitot tube calibration coefficient, K_{pt}	0.81	-

Stack Gas Composition & Molecular Weights

Component	Molar Mass M	Density kg/m^3 p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m^3 pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m^3 pi
CO_2	44	1.96	11.67	0.12	0.23	9.69	0.10	0.19
O_2	32	1.43	9.04	0.09	0.13	7.51	0.08	0.11
N_2	28	1.25	79.28	0.79	0.99	65.81	0.66	0.82
H_2O	18	0.80	-	-	-	16.99	0.17	0.14

Where: p = M / 22.41 p*i* = r x p

Calculation of Stack Gas Densities

Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3487	kg/m^3
Wet Density (STP), P_{STW}	1.2560	kg/m^3
Dry Density (Actual), P_{Actual}	0.8598	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.801	kg/m^3

Where:

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

P_{STW} = (P_{STD} + p*i* of H_2O) / (1 + (p*i* 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	31 March 2014
Time of Survey	15:00
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	18.2	178	149	16.47	-	<15
2	0.22	22.5	221	151	18.36	-	<15
3	0.36	22.5	221	151	18.36	-	<15
4	0.50	22.0	216	151	18.15	-	<15
5	0.65	21.0	206	151	17.73	-	<15
6	0.79	21.0	206	151	17.73	-	<15
7	0.94	20.0	196	151	17.31	-	<15
8	1.08	21.5	211	151	17.94	-	<15
9	1.22	20.0	196	152	17.33	-	<15
10	1.37	20.0	196	151	17.31	-	<15
Mean	-	20.9	205	151	17.67	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	18.2	178	149	16.47	-	<15
2	0.22	22.5	221	151	18.36	-	<15
3	0.36	22.5	221	151	18.36	-	<15
4	0.50	22.0	216	151	18.15	-	<15
5	0.65	21.0	206	151	17.73	-	<15
6	0.79	21.0	206	151	17.73	-	<15
7	0.94	20.0	196	151	17.31	-	<15
8	1.08	21.5	211	151	17.94	-	<15
9	1.22	20.0	196	152	17.33	-	<15
10	1.37	20.0	196	151	17.31	-	<15
Mean	-	20.9	205	151	17.67	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 2

Date of Survey	01 April 2014
Time of Survey	08:00
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	23.0	225	152	18.58	-	<15
2	0.22	24.0	235	152	18.98	-	<15
3	0.36	25.0	245	152	19.37	-	<15
4	0.50	24.5	240	152	19.18	-	<15
5	0.65	25.5	250	152	19.57	-	<15
6	0.79	26.0	255	152	19.76	-	<15
7	0.94	24.0	235	152	18.98	-	<15
8	1.08	23.0	225	152	18.58	-	<15
9	1.22	23.5	230	152	18.78	-	<15
10	1.37	22.0	216	152	18.17	-	<15
Mean	-	24.1	236	152	19.00	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	32.0	314	144	21.71	-	<15
2	0.22	34.0	333	145	22.40	-	<15
3	0.36	34.0	333	145	22.40	-	<15
4	0.50	32.0	314	145	21.74	-	<15
5	0.65	32.0	314	145	21.74	-	<15
6	0.79	30.0	294	145	21.05	-	<15
7	0.94	30.0	294	145	21.05	-	<15
8	1.08	34.0	333	145	22.40	-	<15
9	1.22	32.0	314	145	21.74	-	<15
10	1.37	32.0	314	145	21.74	-	<15
Mean	-	32.2	316	145	21.80	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 3

Date of Survey	01 April 2014
Time of Survey	18:14
Velocity Measurement Device:	P2246

Sampling Line A							
Traverse Point	Distance into duct (m)	ΔP pt mmH$_2$O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	20.0	196	146	17.20	-	<15
2	0.22	23.0	225	148	18.49	-	<15
3	0.36	23.5	230	150	18.74	-	<15
4	0.50	21.5	211	151	17.94	-	<15
5	0.65	22.0	216	150	18.13	-	<15
6	0.79	20.0	196	151	17.31	-	<15
7	0.94	20.5	201	150	17.50	-	<15
8	1.08	19.0	186	150	16.85	-	<15
9	1.22	19.0	186	150	16.85	-	<15
10	1.37	16.5	162	150	15.70	-	<15
Mean	-	20.5	201	149.6	17.47	-	

Sampling Line B							
Traverse Point	Distance into duct (m)	ΔP pt mmH$_2$O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	21.5	211	144	17.80	-	<15
2	0.22	23.0	225	150	18.54	-	<15
3	0.36	23.5	230	150	18.74	-	<15
4	0.50	24.0	235	150	18.94	-	<15
5	0.65	20.5	201	150	17.50	-	<15
6	0.79	19.5	191	150	17.07	-	<15
7	0.94	18.0	176	150	16.40	-	<15
8	1.08	18.5	181	151	16.65	-	<15
9	1.22	19.5	191	150	17.07	-	<15
10	1.37	19.0	186	150	16.85	-	<15
Mean	-	20.7	203	150	17.55	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 4

Date of Survey	02 April 2014
Time of Survey	07:35
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	22.0	216	149	18.11	-	<15
2	0.22	23.0	225	150	18.54	-	<15
3	0.36	22.5	221	151	18.36	-	<15
4	0.50	21.0	206	151	17.73	-	<15
5	0.65	20.0	196	151	17.31	-	<15
6	0.79	19.0	186	151	16.87	-	<15
7	0.94	19.0	186	151	16.87	-	<15
8	1.08	21.0	206	150	17.71	-	<15
9	1.22	19.5	191	150	17.07	-	<15
10	1.37	17.5	172	150	16.17	-	<15
Mean	-	20.5	200	150	17.47	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	22.0	216	153	18.19	-	<15
2	0.22	22.5	221	153	18.40	-	<15
3	0.36	23.5	230	153	18.80	-	<15
4	0.50	21.5	211	153	17.99	-	<15
5	0.65	20.0	196	153	17.35	-	<15
6	0.79	19.0	186	152	16.89	-	<15
7	0.94	18.5	181	152	16.66	-	<15
8	1.08	19.0	186	152	16.89	-	<15
9	1.22	19.5	191	152	17.11	-	<15
10	1.37	19.5	191	152	17.11	-	<15
Mean	-	20.5	201	153	17.54	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 5

Date of Survey	02 April 2014
Time of Survey	16:00
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	18.0	176	151	16.42	-	<15
2	0.22	21.0	206	151	17.73	-	<15
3	0.36	23.0	225	151	18.56	-	<15
4	0.50	22.0	216	151	18.15	-	<15
5	0.65	22.0	216	151	18.15	-	<15
6	0.79	21.0	206	151	17.73	-	<15
7	0.94	19.5	191	151	17.09	-	<15
8	1.08	20.0	196	151	17.31	-	<15
9	1.22	19.0	186	151	16.87	-	<15
10	1.37	19.5	191	151	17.09	-	<15
Mean	-	20.5	201	151	17.51	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	19.0	186	150	16.85	-	<15
2	0.22	20.0	196	151	17.31	-	<15
3	0.36	21.0	206	151	17.73	-	<15
4	0.50	22.0	216	151	18.15	-	<15
5	0.65	22.0	216	151	18.15	-	<15
6	0.79	21.0	206	151	17.73	-	<15
7	0.94	22.0	216	151	18.15	-	<15
8	1.08	22.0	216	152	18.17	-	<15
9	1.22	20.0	196	152	17.33	-	<15
10	1.37	20.0	196	152	17.33	-	<15
Mean	-	20.9	205	151	17.69	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 6

Date of Survey	02 April 2014
Time of Survey	19:45
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	22.0	216	152	18.17	-	<15
2	0.22	21.0	206	152	17.76	-	<15
3	0.36	22.0	216	152	18.17	-	<15
4	0.50	23.0	225	152	18.58	-	<15
5	0.65	22.5	221	152	18.38	-	<15
6	0.79	23.0	225	152	18.58	-	<15
7	0.94	22.0	216	152	18.17	-	<15
8	1.08	23.0	225	152	18.58	-	<15
9	1.22	21.0	206	152	17.76	-	<15
10	1.37	20.0	196	152	17.33	-	<15
Mean	-	22.0	215	152	18.15	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	21.0	206	152	17.76	-	<15
2	0.22	22.0	216	152	18.17	-	<15
3	0.36	24.0	235	152	18.98	-	<15
4	0.50	22.0	216	152	18.17	-	<15
5	0.65	22.0	216	152	18.17	-	<15
6	0.79	23.0	225	152	18.58	-	<15
7	0.94	23.0	225	152	18.58	-	<15
8	1.08	23.5	230	152	18.78	-	<15
9	1.22	22.0	216	152	18.17	-	<15
10	1.37	21.0	206	152	17.76	-	<15
Mean	-	22.4	219	152	18.31	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 7

Date of Survey	03 April 2014
Time of Survey	09:00
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	22.0	216	150	18.13	-	<15
2	0.22	23.0	225	150	18.54	-	<15
3	0.36	22.5	221	150	18.33	-	<15
4	0.50	23.0	225	151	18.56	-	<15
5	0.65	23.0	225	150	18.54	-	<15
6	0.79	23.5	230	151	18.76	-	<15
7	0.94	22.0	216	150	18.13	-	<15
8	1.08	22.0	216	150	18.13	-	<15
9	1.22	21.0	206	150	17.71	-	<15
10	1.37	20.0	196	150	17.29	-	<15
Mean	-	22.2	218	150.2	18.21	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	21.0	206	149	17.69	-	<15
2	0.22	21.0	206	150	17.71	-	<15
3	0.36	22.0	216	150	18.13	-	<15
4	0.50	23.5	230	150	18.74	-	<15
5	0.65	22.0	216	150	18.13	-	<15
6	0.79	22.5	221	150	18.33	-	<15
7	0.94	23.0	225	150	18.54	-	<15
8	1.08	22.0	216	151	18.15	-	<15
9	1.22	22.0	216	151	18.15	-	<15
10	1.37	21.0	206	151	17.73	-	<15
Mean	-	22.0	216	150	18.13	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 8

Date of Survey	03 April 2014
Time of Survey	12:45
Velocity Measurement Device:	P2246

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	21.0	206	149	17.69	-	<15
2	0.22	23.0	225	150	18.54	-	<15
3	0.36	24.0	235	151	18.96	-	<15
4	0.50	21.0	206	151	17.73	-	<15
5	0.65	22.0	216	151	18.15	-	<15
6	0.79	21.0	206	151	17.73	-	<15
7	0.94	22.0	216	152	18.17	-	<15
8	1.08	21.0	206	152	17.76	-	<15
9	1.22	19.0	186	151	16.87	-	<15
10	1.37	19.0	186	151	16.87	-	<15
Mean	-	21.3	209	151	17.85	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	21.0	206	151	17.73	-	<15
2	0.22	21.0	206	152	17.76	-	<15
3	0.36	23.0	225	152	18.58	-	<15
4	0.50	22.0	216	152	18.17	-	<15
5	0.65	21.0	206	152	17.76	-	<15
6	0.79	20.0	196	152	17.33	-	<15
7	0.94	21.0	206	152	17.76	-	<15
8	1.08	21.0	206	152	17.76	-	<15
9	1.22	21.0	206	152	17.76	-	<15
10	1.37	20.0	196	152	17.33	-	<15
Mean	-	21.1	207	152	17.79	-	

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	162	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	15.70	m/s	-	-
Highest Gas Velocity	22.40	m/s	-	-
Ratio of Gas Velocities	1.43	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^{o}	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V

Velocity at Traverse Point, $V = K_{pt} \times (1-\varepsilon) * \sqrt{(2 * \Delta P_{pt} / P_{ActualW})}$

Where:

K_{pt} = Pitot tube calibration coefficient

$(1-\varepsilon)$ = Compressibility correction factor, assumed at a constant 0.998

Average Stack Gas Velocity, Va	**18.02**	m/s

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))

Day 1	01 April 2014

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	150	0	^{o}C
Total Pressure	100.9	101.3	kPa
Oxygen	7.5	11	%
Moisture	19.57	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	19.03		m/s
Stack Area (A)	1.63		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	111599		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	71782		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	57736		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	77669		m^3/hr

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

Day 2	02 April 2014		
Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	151	0	^{o}C
Total Pressure	100.4	101.3	kPa
Oxygen	7.3	11	%
Moisture	20.09	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	17.71		m/s
Stack Area (A)	1.63		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	103860		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	66263		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	52948		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	72554		m^3/hr

Day 3	07 March 2014		
Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	151	0	^{o}C
Total Pressure	99.4	101.3	kPa
Oxygen	7.4	11	%
Moisture	20.25	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	17.83		m/s
Stack Area (A)	1.63		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	104529		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	66012		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	52646		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	71392		m^3/hr

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

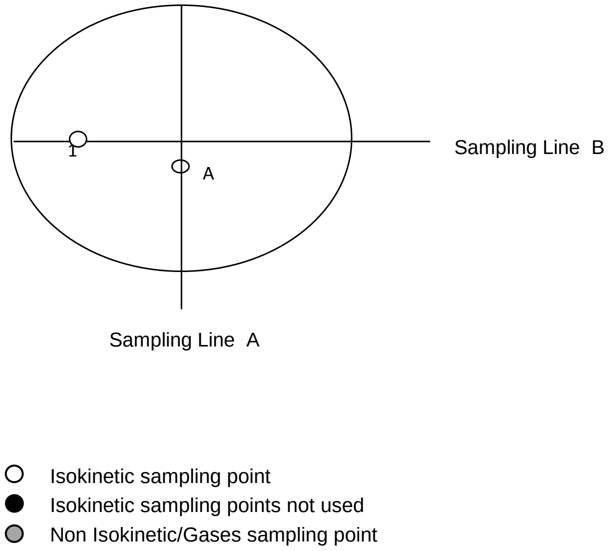
O_2a = Oxygen, Actual Conditions, % Vol

O_2s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK DIAGRAM

	Value	Units
Stack Depth	1.44	m
Stack Width	-	m
Area	1.63	m^2



Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	40	0.58	m

Isokinetic Sampling CEN Methods			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl º
1	85.0	1.22	<15

SAMPLING LOCATION

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - PM 10

Run	Sampled m³	Sampled Gas K	Sampled Gas kPa	Sampled Gas % by volume	Oxygen % by volume	Limit of % by mass	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	0.10	-
as a %	0.01	0.47	0.50	1.00	1.32	N/A	1.93
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.10	-
as a %	0.01	0.47	0.50	1.00	1.36	N/A	1.94
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 3	0.001	2	0.5	1	0.1	0.1000	-
as a %	0.02	0.47	0.50	1.00	1.40	N/A	0.79
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 4	0.001	2	0.5	1	0.1	0.10	-
as a %	0.02	0.47	0.50	1.00	1.35	N/A	0.36
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	Mass of particulate mg	O2 Correction -	Leak mg/m³	Combined uncertainty
Run 1	0.0097	0.0881	0.095	1.000	-
MU as mg/m³	0.0009	0.0088	0.0005	0.00079	**12.57**
MU as %	0.0075	12.5	0.743	1.116	-
Run 2	0.0012	0.0857	0.012	1.000	-
MU as mg/m³	0.0001	0.0086	0.0001	0.00010	**100.01**
MU as %	0.0009	100.0	0.734	1.118	-
Run 3	0.0079	0.1667	0.042	1.000	-
MU as mg/m³	0.0004	0.0167	0.0002	0.00014	**55.562**
MU as %	0.0032	55.6	0.721	0.454	-
Run 4	0.0056	0.17	0.028	1.00	-
MU as mg/m³	0.0003	0.02	0.0002	0.00004	**83.34**
MU as %	0.0022	83.3	0.735	0.21	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.02**	**mg/m³**	**25.26**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.02**	**mg/m³**	**200.03**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**mg/m³**	**111.15**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**mg/m³**	**166.69**	**%**

(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 - PM 2.5

Run	Sampled m³	Sampled Gas K	Sampled Gas kPa	Sampled Gas % by volume	Oxygen % by volume	Limit of % by mass	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	0.05	-
as a %	0.01	0.47	0.50	1.00	1.32	N/A	1.93
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.01	0.47	0.50	1.00	1.36	N/A	1.94
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 3	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.02	0.47	0.50	1.00	1.40	N/A	0.79
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 4	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.02	0.47	0.50	1.00	1.35	0.00	0.36
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	Mass of particulate mg	O2 Correction -	Leak mg/m³	Combined uncertainty
Run 1	0.01	0.0881	0.0758	1.000	-
MU as mg/m³	0.0007	0.0044	0.0004	0.00063	**7.93**
MU as %	0.0060	7.8125	0.7434	1.12	-
Run 2	0.0006	0.0857	0.0058	1.000	-
MU as mg/m³	0.0001	0.0043	0.0000	0.00005	**100.01**
MU as %	0.0005	100.0000	0.7338	1.12	-
Run 3	0.0011	0.0857	0.0059	1.000	-
MU as mg/m³	0.0001	0.0043	0.0000	0.00002	**100.00**
MU as %	0.0005	100.0000	0.7210	0.45	-
Run 4	0.0023	0.1723	0.0117	1.0000	-
MU as mg/m³	0.0001	0.0086	0.0001	0.00002	**100.00**
MU as %	0.0009	100.0000	0.7347	0.21	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.009**	**mg/m³**	**16.04**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.009**	**mg/m³**	**200.03**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.009**	**mg/m³**	**200.02**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.017**	**mg/m³**	**200.02**	**%**

(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 - CARBON DIOXIDE BY FTIR

Actual Measured Concentration	9.39	% vol
Measured Concentration at Reference Conditions	9.39	% vol
Emission Limit Value	-	% vol
Instrument Range	20	% vol
Check Gas Concentration	5.18	% vol

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)	0.000	<5%	Yes
Span drift (calculated from start and end readings).	3.204	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	0.990	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.100	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	-1.300	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	1.600	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	1.333	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.080	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	% vol
Uncertainty of linearity (lack of fit) U_{fit}	-0.219
Uncertainty of zero drift $U_{0,dr}$	0.000
Uncertainty of span drift $U_{s,dr}$	0.370
Uncertainty of volume or pressure flow dependence U_{spress}	0.114
Uncertainty in Ambient Temperature U_{temp}	0.151
Uncertainty in Voltage U_{volt}	0.185
Uncertainty of interferents U_i	0.154
Uncertainty of Repeatability U_r	0.016
Uncertainty of Certified Reference Material U_{cal}	0.030

Measurement Uncertainty	% vol
Combined uncertainty	0.53
Expanded uncertainty at a 95% Confidence Interval	1.06

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	11.27
Expressed as a % of the Measured Concentration at Reference Conditions	11.27
Expressed as a % of the Emission Limit Value	-

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE BY FTIR

Actual Measured Concentration	19.57	% vol
Measured Concentration at Reference Conditions	19.57	% vol
Emission Limit Value	30	% vol
Instrument Range	30	% vol
Check Gas Concentration (Methane was used as a Surrogate)	116.36	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)	-0.900	<5%	Yes
Span drift (calculated from start and end readings).	1.653	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	0.990	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.100	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	-1.000	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	0.710	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	0.583	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.170	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	% vol
Uncertainty of linearity (lack of fit) U_{fit}	-0.329
Uncertainty of zero drift $U_{0,dr}$	-0.156
Uncertainty of span drift $U_{s,dr}$	0.286
Uncertainty of volume or pressure flow dependence U_{spress}	0.171
Uncertainty in Ambient Temperature U_{temp}	0.174
Uncertainty in Voltage U_{volt}	0.123
Uncertainty of interferents U_i	0.101
Uncertainty of Repeatability U_r	0.051
Uncertainty of Certified Reference Material U_{cal}	0.672

Measurement Uncertainty	% vol
Combined uncertainty	0.87
Expanded uncertainty at a 95% Confidence Interval	1.74

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	8.87
Expressed as a % of the Measured Concentration at Reference Conditions	8.87
Expressed as a % of the Emission Limit Value	5.79

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 1 - 31 March 2014

Reference	11	%vol
Measured concentration	7.55	%vol
Calibration gas	9.52	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	60	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	399	minutes	-	-
Number of readings in measurement	399	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.32	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-1.58	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.31	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	-0.536
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.020
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	0.014
Uncertainty of calibration gas	ucalib	0.087

Measurement uncertainty (Concentration Measured)	7.55	%vol
Combined uncertainty	0.56	%vol
% of value	7.45	%

Expanded uncertainty expressed with a level of confidence of 95%	**14.89**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**1.12**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 2 - 01 April 2014

Reference	11	%vol
Measured concentration	7.30	%vol
Calibration gas	9.52	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	60	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	652	minutes	-	-
Number of readings in measurement	652	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	-0.16	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	1.58	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	-0.42	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	0.605
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.081
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	-0.018
Uncertainty of calibration gas	ucalib	0.084

Measurement uncertainty (Concentration Measured)	7.30	%vol
Combined uncertainty	0.63	%vol
% of value	8.66	%

Expanded uncertainty expressed with a level of confidence of 95%	**17.33**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**1.26**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 3 - 02 April 2014

Reference	11	%vol
Measured concentration	7.22	%vol
Calibration gas	9.52	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	60	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	166	minutes	-	-
Number of readings in measurement	166	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	-0.16	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.32	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.73	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	-0.230
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.081
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	0.030
Uncertainty of calibration gas	ucalib	0.083

Measurement uncertainty (Concentration Measured)	7.22	%vol
Combined uncertainty	0.30	%vol
% of value	4.09	%

Expanded uncertainty expressed with a level of confidence of 95%	**8.18**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**0.59**	**% vol**

Developed for the STA by R Robinson, NPL

Standard deviation of repeatability at span level	urs	#DIV/0!

APPENDIX 4 - Summaries, Calculations, Raw Data and Charts

NOTE - The following data is provided for information only and falls outside ESG's scope of accreditation

COMBINED UNCOLLECTED SUMMARY

Test	Sampling Times	>PM_{10} Concentration		Probe Rinse Concentration		Combined Unweighed Concentration	
		Measured mg/m³	LOD mg/m³	Measured mg/m³	LOD mg/m³	Measured mg/m³	LOD mg/m³
Run 1	10:52 - 17:32 01 April 2014	0.004	0.004	0.150	0.114	0.125	0.119
Run 2	08:29 - 15:25 02 April 2014	0.004	0.004	0.111	0.111	0.116	0.116
Run 3	16:21 - 19:21 02 April 2014	0.018	0.008	0.217	0.217	0.225	0.225
Run 4	09:40 - 12:40 03 April 2014	0.009	0.009	0.224	0.224	0.233	0.233

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

Where the result is less than the LOD, the LOD is reported.

SAMPLES

Test	>PM_{10} Filter Number	Filter Start Weight g	Filter End Weight g	Mass Gained on Filter g	Probe Rinse Number g	Probe Rinse Start Weight g	Probe Rinse End Weight g	Mass Gained in Rinse g	Combined Total Mass Gained g
Run 1	QC1038	32.6359	32.6356	-0.00028	8530	195.9576	195.9593	0.00170	0.00142
Run 2	QC1058	15.7474	15.7473	-0.00015	8531	155.95760	155.36090	-0.59670	-0.59685
Run 3	QC1050	14.8199	14.8200	0.00011	8532	208.09270	208.09320	0.00050	0.00061
Run 4	QC1054	16.3255	16.3255	-0.00002	8533	184.45290	184.45320	0.00030	0.00028
Blank 1	QC1060	16.0445	16.0443	-0.00018	8527	181.94280	181.94230	-0.00050	-0.00068
Blank 2	QC1051	15.9013	15.9011	-0.00013	8528	151.00140	151.00100	-0.00040	-0.00053
Blank 3	QC1056	15.3566	15.3564	-0.00017	8529	161.85580	161.85570	-0.00010	-0.00027

PAUL GOTHE BOCHUM

Manufacturer of Emissions Control Technology
SEIT 1924

DIN ISO 9001

Paul Gothe GmbH Wittener Str. 82 D-44789 Bochum

To our customers

Wittener Straße 82
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Fax:++49 234) **30 82 17**
http://www.paulgothe.de
service@paulgothe.de
VAT-No.: DE 813078723
Trade Register Bochum: HRB-6891

Your ref	Your letter	Our ref	Date 14.03.2007

Calibration of the Johnas Impactor according to **ISO 23210**
6.2 Separation curves and Section 6.3 Verification of the separation curves

The Johnas Impactor from Paul Gothe GmbH was developed before the ISO Guideline was evaluated and after the Germans and the Netherlands Authorities have enough experiences with our impactor. After that the European Delegation creates the ISO Guideline 23210. The section 6.3 is important and was influence by the Germans. They have the experiences and write the rules for the calibration section accordingly it was made for the Johnas-Impactor.
The development from the Johnas impactor starts with a doctoral thesis from Mrs. John at the Gerhard-Mercator-University. She makes the intensive testing and Mr. Geueke from the North Rhine Westphalia State Environment Agency makes additional verifications at the ESA (Emission Simulation Facility) at the Hessian Agency for the Environment and Geology (HLUG).

Most of the literatures and papers are in German, but all well-known:

1. Probenahme und chemische Analytik von korngrößenfraktionierten Immissions- und Emissionsaerosolen. Von der Fakultät für Naturwissenschaften der Gerhard-Mercator-Universität – Gesamthochschule Duisburg zur Erlangung des akademischen Grades eines Dr. rer. nat. genehmigte Dissertation von ASTRID CHRISTIANE JOHN aus Lichtenfels.
2. Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit Luftreinhaltung Forschungsbericht 298 44 280, Korngrößenverteilung (PM10 und PM2,5) von Staubemissionen relevanter stationärer Quellen (Teil II zu 297 44 853), von Dipl.-Ing. A. Dreiseidler, Ing. D. Straub, Prof. Dr.-Ing. G. Baumbach, Universität Stuttgart, Institut für Verfahrenstechnik und Dampfkesselwesen (IVD), Abteilung Reinhaltung der Luft (RdL), Institutsleiter: Prof. Dr.-Ing. K.R.G. Hein, IM AUFTRAG DES UMWELTBUNDESAMTES Juni 2001.
3. VDI 2066, part 10
4. Gefahrstoffe-Reinhaltung der Luft 59 (1999), Nr.11/12, S. 449-453

All this papers shows, that the design of the Johnas Impactor is a proved version for the determination of the PM 2.5 and PM 10. The shape of the separation curves is similar to those specified in ISO 7708:1995 and the separation efficiency at 10 µm and 2,5 µm is 50 % according to section 6.3 of the ISO 23210.

What you need more? There is no authority which has more competence as the listed authorities.

If you still in doubt, you maybe get in contact with Mr. Geueke (phone: ++49-201-7995-1263).

Paul Gothe GmbH

Westdeutsche Landesbank for Sparkasse Bochum
IBAN DE 24 430500 01 000 120 9840 Swift: WELADED1BOC

Companion: Paul Gothe-Stiftung
Management: Dr. T. Grodten and Th. Hinrichs

PAUL GOTHE BOCHUM

Manufacturer of Emissions Control Technology
SEIT 1924

DIN ISO 9001

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Trade Register Bochum: HRB-6891

Your ref	Your letter	Our ref	Date 14.03.2007

Declaration of conformity

Herewith the company Paul Gothe GmbH in Bochum declare that the manufactured Cascade Impactor Johnas follows the guidelines from the North Rhine Westphalia State Environment Agency according the convention from 24 June 1999 and the PM 4 stage follows the convention of the Federal Environment Agency from 09. March 2005.

Our Cascade Impactor Johnas was developed in cooperation with the North Rhine Westphalia State Environment and the Gerhard-Mercator University Duisburg. This impactor was validated and after that 2004 adopted in the German Standard VDI 2066, part 10 and 2005 in ISO Standard 23210. All sizes of our manufactured impactors are according to these guidelines, individually checked according our strict quality management and named with a specific serial number. Only an impactor with this serial number is according to the Guideline VDI 2066, part 10 and ISO Standard 23210 and can use for the determination of PM 10 and PM 2.5.

Paul Gothe GmbH

Impactor Johnas according to the VDI 2066 and ISO 23210 and the convention from
Umwelt Bundes Amt
Für Mensch und Umwelt
Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen
NRW.

Dr. Torsten Grodten

-manager-

END OF REPORT

Appendix 5 – Stack emissions monitoring report: MES Environmental Ltd

STACK EMISSIONS MONITORING REPORT

Environmental Scientifics Group

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

Your contact at ESG
Mark Woodruff Business Manager - North Tel: 0161 443 0982 Email: mark.woodruff@esg.co.uk

Operator & Address:
MES Environmental Limited Stoke-on-Trent Energy from Waste Plant Campbell Road Sideway Stoke On trent ST4 4DX

Permit
N/A - Investigative Monitoring

Release Point:
Incinerator Stream 2

Sampling Date(s):
19th - 21st March 2014

ESG Job Number:	LNO 11737
Report Date:	17th Feb 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
Report Approved By:	Andy Tiffen
MCERTS Number:	MM 05 640
Business Title:	MCERTS Level 2 - Projects Manager
Technical Endorsements:	1, 2 & 4
Signature:	A. Tiffen.

UKAS TESTING 1015

MCERTS THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

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
Determination of representative sampling location

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

MES Environmental Limited operates a incinerator process at Stoke-on-Trent Energy from Waste Plant

Environmental Scientifics Group Limited were commissioned by Ricardo AEA to carry out stack emissions monitoring to determine the release of PM_{10} & $PM_{2.5}$ from the following Plant under standard operating conditions.

The measurements were commissioned by Ricardo-AEA on behalf of the Department of Environment, Food and Rural Affairs (Defra) to provide information for the UK National Atmospheric Emissions Inventory (NAEI).

Plant

Incinerator Stream 2

Operator

MES Environmental Limited
Stoke-on-Trent Energy from Waste Plant
Campbell Road
Sideway
Stoke On trent
ST4 4DX

Stack Emissions Monitoring Test House

Environmental Scientifics Group Limited - 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.
This test report shall not be reproduced, except in full, without written approval of Environmental Scientifics Group Limited.

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	Units	Result	Calculated Uncertainty +/-	Limit	MCERTS accredited result
Total Particulate Matter	mg/m³	0.47	0.07	30	✓
Particulate Emission Rate	g/hr	31	4.6	-	
PM_{10} **(Average result of 4 runs)**	mg/m³	0.043	0.05	-	✓
PM_{10} Emission Rate **(Average result of 4 runs)**	g/hr	2.62	2.9	-	
$PM_{2.5}$ **(Average result of 4 runs)**	mg/m³	0.017	0.03	-	✓
$PM_{2.5}$ Emission Rate **(Average result of 4 runs)**	g/hr	1.04	1.67	-	
PM_{10} - Runs					
PM_{10} - Run 1	mg/m³	***0.014***	0.01	-	✓
PM_{10} Emission Rate - Run 1	g/hr	0.76	0.8	-	
PM_{10} - Run 2	mg/m³	0.012	0.01	-	✓
PM_{10} Emission Rate - Run 2	g/hr	0.77	0.8	-	
PM_{10} - Run 3	mg/m³	***0.059***	0.06	-	✓
PM_{10} Emission Rate - Run 3	g/hr	3.65	4.0	-	
PM_{10} - Run 4	mg/m³	0.088	0.10	-	✓
PM_{10} Emission Rate - Run 4	g/hr	5.32	5.8	-	
$PM_{2.5}$ - Runs					
$PM_{2.5}$ - Run 1	mg/m³	***0.005***	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 1	g/hr	0.76	1.2	-	
$PM_{2.5}$ - Run 2	mg/m³	0.005	0.01	-	✓
$PM_{2.5}$ Emission Rate - Run 2	g/hr	0.32	0.5	-	
$PM_{2.5}$ - Run 3	mg/m³	***0.010***	0.02	-	✓
$PM_{2.5}$ Emission Rate - Run 3	g/hr	0.63	1.01	-	
$PM_{2.5}$ - Run 4	mg/m³	0.048	0.08	-	✓
$PM_{2.5}$ Emission Rate - Run 4	g/hr	2.91	4.69	-	
Oxygen	% v/v	12	0.73	-	✓
Moisture	%	16.0	1.0	-	✓
Stack Gas Temperature	^{o}C	151	-	-	✓
Stack Gas Velocity	m/s	20.6	-	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	120419	-	-	
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	78080	-	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	61073	-	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	69915	-	-	

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 test specific flow data. Mass emissions for non isokinetic tests and isokinetic tests are calculated using these values

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
Total Particulate Matter Run 1	19 March 2014	13:00 - 19:00	360 minutes
Total Particulate Matter Run 2	20 March 2014	09:00 - 15:00	360 minutes
Total Particulate Matter Run 3	20 March 2014	15:46 - 18:46	180 minutes
Total Particulate Matter Run 4	21 March 2014	08:45 - 11:45	180 minutes
PM_{10} Run 1	19 March 2014	13:00 - 19:00	360 minutes
PM_{10} Run 2	20 March 2014	09:00 - 15:00	360 minutes
PM_{10} Run 3	20 March 2014	15:46 - 18:46	180 minutes
PM_{10} Run 4	21 March 2014	08:45 - 11:45	180 minutes
$PM_{2.5}$ Run 1	19 March 2014	13:00 - 19:00	360 minutes
$PM_{2.5}$ Run 2	20 March 2014	09:00 - 15:00	360 minutes
$PM_{2.5}$ Run 3	20 March 2014	15:46 - 18:46	180 minutes
$PM_{2.5}$ Run 4	21 March 2014	08:45 - 11:45	180 minutes
Stack Gas Flow Rate & Temperature Run 1	19 March 2014	09:00	-
Stack Gas Flow Rate & Temperature Run 2	19 March 2014	19:10	-
Stack Gas Flow Rate & Temperature Run 3	20 March 2014	08:32	-
Stack Gas Flow Rate & Temperature Run 4	20 March 2014	15:10	-
Stack Gas Flow Rate & Temperature Run 5	20 March 2014	18:55	-
Stack Gas Flow Rate & Temperature Run 6	21 March 2014	08:05	-
Stack Gas Flow Rate & Temperature Run 7	21 March 2014	12:00	-

EXECUTIVE SUMMARY

PROCESS DETAILS	
Parameter	**Process Details**
Description of process	Incinerator
Continuous or batch	Continuous
Product Details	Waste
Part of batch to be monitored (if applicable)	Steady state
Normal load, throughput or continuous rating	11 - 12.5 Tonnes/Hour
Fuel used during monitoring	Oil / Waste
Abatement	Bag Filtration, activated carbon scrubbing, urea injection, lime semi dry scrubbing
Plume Appearance	Not visible from the sample location during time of testing.

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by Environmental Scientifics Group Limited 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	0.02 mg/m³	14.9 %
PM_{10}	SRM - BS EN 23210	AE 136	1015	Yes	0.014 mg/m³	109 %
$PM_{2.5}$	SRM - BS EN 23210	AE 136	1015	Yes	0.007 mg/m³	161 %
O_2	SRM - BS EN 14789	AE 102	1015	Yes	0.01%	6.1%
H_2O	AM - M22/FTIR	AE 063	1015	Yes	0.1 %	6.0%
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	5 Pa	-

The measurement uncertainties for the PM_{10} and $PM_{2.5}$ measurements reflect that measured concentrations were near or below the Limit of Detection.

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
PM_{10}	Gravimetric	AE 106	1015	Yes	ESG Stockport	ESG Stockport	1 year
$PM_{2.5}$	Gravimetric	AE 106	1015	Yes	ESG Stockport	ESG Stockport	1 year

ON-SITE TESTING							
Species	**Analytical Technique**	**Analytical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Analysis**	**Laboratory**	**Data Archive Location**	**Archive Period**
O_2	Paramagnetism	AE 102	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	157	Pa	>= 5 Pa	Yes	BS EN 13284-1
Lowest Gas Velocity	16.05	m/s	-	-	-
Highest Gas Velocity	22.99	m/s	-	-	-
Ratio of Gas Velocities	1.43	-	< 3 : 1	Yes	BS EN 13284-1
Mean Velocity	20.56	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	^{o}	< 15^{o}	Yes	BS EN 13284-1
No local negative flow	Yes	-	-	Yes	BS EN 13284-1

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Circular	-
Depth	1.45	m
Width	-	m
Area	1.65	m^2
Port Depth	100	mm

SAMPLING LINES & POINTS			
	Isokinetic (CEN Methods)	**Isokinetic** (ISO Methods)	**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	In Stack	-	In Stack
Filtration for TPM	In Stack	-	-

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

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

Sampling Platform Improvement Recommendations (if applicable)

The sampling location ports could ideally be relocated to a different plane to avoid the CEM probes in the stack and to meet all the requirements as specified in EA Guidance Note M1.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

Sample Points

Total particulate and PM10 & 2.5 were performed on 2 separate lines on a single point nearest to each other to achieve the most representative sample.

Flow Traverse

A reduced number of velocity traverse points could only be monitored, due to various CEM probes causing obstructions on the same sample plane.

Sample flow variation

The sample flowrate could not be maintained within 5% of the nominal flow throughout the testing periods (which were over extended periods due to the anticipated low PM emission concentrations). Whilst this will have affected the actual cutpoints achieved by the impactor, the results are all at or very near the LOD for the tests and hence this is anticipated to have limited impact on the outcome of the measurements.

Goose-neck nozzle Validation

Due to the long port sleeve, it was physically impossible to inserted the cascade impactor using the straight entry nozzle setup recommended in BS EN 23210. Therefore the use of a goose-neck setup was used as this was the only feasible method for monitoring. The standard requires that the use of a goose-neck nozzle is validated, however on this occasion it has not been possible to demonstrate that losses in the nozzle meet the criteria in the standard because the measured concentrations were low and the weight of particulate recovered from the nozzle rinses and the filter media were at or near the weighing LoD. In the context of the low emission concentrations detemined during the measurements (all less than 0.1 mg/Nm3), losses in the sampling nozzle are unlikely to increase the concentrations significantly.

Determination of representative sampling location

An assessment of temperature homogeneity was performed in accordance with EN 23210 Annex-G on the first day of monitoring. A reduced number of points could only be monitored, due to various CEM probes causing obstructions on the same sample plane.

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	4
PM_{10}	SRM - BS EN 23210	AE 136	1015	Yes	4
$PM_{2.5}$	SRM - BS EN 23210	AE 136	1015	Yes	4
O_2	SRM - BS EN 14789	AE 102	1015	Yes	4
H_2O	AM - M22/FTIR	AE 063	1015	Yes	4
Flow Rate / Temp.	SRM - BS EN 13284-1	AE 122	1015	Yes	7

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

CALIBRATEABLE EQUIPMENT CHECKLIST PARTICLE SIZING

Extractive Sampling		Instrumental Analyser/s		Miscellaneous	
Equipment	**Equipment I.D.**	**Equipment**	**Equipment I.D.**	**Equipment**	**Equipment I.D.**
Control Box DGM	LNO 13-11, 13-05	Horiba PG-250 Analyser	-	Laboratory Balance	LNO 00-12/00-13
Box Thermocouples	LNO 03-11, 03-05	FT-IR	LNO 0750	Tape Measure	LNO 24-DJH
Meter In Thermocouple	LNO 03-11, 03-05	FT-IR Oven Box	LNO 1207	Stopwatch	LNO 17-DJH
Meter Out Thermocouple	LNO 03-11, 03-05	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17-11, 17-05	Signal 3030 FID	-	Barometer	LNO 08-DJH
Oven Box	-	Servomex	LNO 21-22	Digital Micromanometer	LNO 01-DJH
Probe	LNO 11-41	JCT Heated Head Filter	-	Digital Temperature Meter	LNO 03-DJH
Probe Thermocouple	LNO 10-41	Thermo FID	-	Stack Thermocouple	-
Probe	LNO 11-44	Stackmaster	-	Mass Flow Controller	-
Probe Thermocouple	LNO 10-44	FTIR Heater Box for Heated Line	-	MFC Display module	-
S-Pitot	LNO 06-DJH, 06-LM	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	-	Chiller (JCT/MAK 10)	LNO 21-40	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	Impactor 1	LNO NR18706	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	-		-	20m Heated Line (1)	LNO 03-84
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	Supplier	ppm	%	Analytical
Oxygen	HPC770	BOC	-	10.01	2
Methane	HPC763	BOC	101	-	2
Carbon Dioxide	HPC752	BOC	-	8.11	2

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

STACK EMISSIONS MONITORING TEAM

Team Leader	Dominic Houghton MCERTS Level 2 MM 04 529 Te1 Expiry Date - Dec 2016 Te2 Expiry Date - Dec 2016 Te3 Expiry Date - Mar 2018 Te4 Expiry Date - Dec 2016 H&S Expiry Date - Jul 2017
Team Leader	Lawrence Mason MCERTS Level 2 MM 07 849 Te1 Expiry Date - Dec 2018 Te2 Expiry Date - Dec 2015 Te3 Expiry Date - Mar 2016 Te4 Expiry Date - Dec 2015 H&S Expiry Date - Jul 2017
Technician	Ryan Murphy MCERTS Level 1 MM 07 826 MCERTS Expiry Date - Mar 2018 H&S Expiry Date - Apr 2017
Technician	Mark Derbyshire MCERTS Level 1 MM 07 824 MCERTS Expiry Date - Dec 2017 H&S Expiry Date - Apr 2017

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY

Parameter	Sampling Times	Concentration mg/m³	Uncertainty mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	13:00 - 19:00 19 March 2014	0.34	0.05	30	21
Run 2	09:00 - 15:00 20 March 2014	0.33	0.04	30	23
Run 3	15:46 - 18:46 20 March 2014	0.75	0.10	30	50
Run 4	08:45 - 11:45 21 March 2014	0.48	0.09	30	31
Blank	-	0.08	-	-	-
Blank 2	-	0.05	-	-	-
Blank 3	-	0.03	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

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	Q8014	0.14927	0.14865	-0.00062	182.94620	182.94890	0.00270	0.00208
Run 2	Q8016	0.14600	0.14390	-0.00210	168.36350	168.36640	0.00290	0.00080
Run 3	Q8017	0.14952	0.14816	-0.00136	164.53050	164.53340	0.00290	0.00154
Run 4	G8019	0.15307	0.15179	-0.00128	187.22610	187.22800	0.00190	0.00062

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	Q8013	0.14169	0.14159	-0.00010	135.46830	135.46890	0.00060	0.00050
Run 2	Q8015	0.14638	0.14621	-0.00017	193.54850	193.54900	0.00050	0.00033
Run 3	G8018	0.15247	0.15237	-0.00010	193.54850	193.54900	0.00050	0.00040

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 1 — TPM

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	765.01	CO_2	%	7.10
Stack static pressure, P_{static}	mm H_2O	-30.59	O_2	%	9.59
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	762.76	Total	%	16.69
			N_2 (100 -Total)	%	83.31
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.52
Moisture trap weight increase,Vlc	g	-	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.12
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		8.105	Area of stack, A_s	m^2	1.65
Gas meter correction factor, Y_d		0.93249	$Q_a = (60)(A_s)(V_s)$	m³/min	1706.0
Mean dry gas meter temperature, T_m		19.375	**Total flow of stack gas, Q**		
Mean pressure drop across orifice, ΔH	mmH_2O	41.691	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		7.131	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) + 273}$	Dry	877.2
Volume of gas metered wet, V_{mstw}			$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) + 273}$	@O_2ref	1001.03
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	9.0042			
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet	1107.63
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	**Percent isokinetic, %I**		
			Nozzle diameter, D_n	mm	6.44
% oxygen measured in gas stream, act%O_2		9.6	Nozzle area, A_n	mm^2	32.58
% oxygen reference condition		11	Total sampling time, θ	min	360
O_2 Reference Factor $O_2 \text{ Ref} = \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		1.14	$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	114.5
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	8.1376	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			**Particulate Concentration, C**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.2080	Mass collected on filter, M_f	g	0.00008
	%	20.80	Mass collected in probe, M_p	g	0.00270
Moisture by FTIR	%	20.80	Total mass collected, M_n	g	0.00278
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.309
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.85	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.390
Mean of velocity heads, ΔP_{avg}	mm H_2O	16.45			
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.06	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.342
Mean stack gas temperature, T_s	°C	149			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	17.22	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		20.52

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 2 — TPM

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	765.01
Stack static pressure, P_{static}	mm H_2O	-30.59
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	762.76
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		8.529
Gas meter correction factor, Y_d		0.93249
Mean dry gas meter temperature, T_m		19.208
Mean pressure drop across orifice, ΔH	mmH_2O	51.952
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		7.517
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	9.5018
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		8.96
% oxygen reference condition		11
O_2 Reference Factor: O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		1.20
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	9.0512
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.2089
	%	20.89
Moisture by FTIR	%	20.9
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.85
Mean of velocity heads, ΔP_{avg}	mm H_2O	20.66
Mean square root of velocity heads, √ΔP		4.54
Mean stack gas temperature, T_s	°C	152
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	19.29

Molecular weight of dry gas, M_d		
CO_2	%	9.03
O_2	%	8.96
Total	%	17.99
N_2 (100 -Total)	%	82.01
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.80
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.34
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	1.65
$Q_a = (60)(A_s)(V_s)$	m³/min	1911.3
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	974.6
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) + 273}$	@O_2ref	1177.00
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet	1231.96
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	6.44
Nozzle area, A_n	mm^2	32.58
Total sampling time, θ	min	360
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	108.6
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00008
Mass collected in probe, M_p	g	0.00290
Total mass collected, M_n	g	0.00298
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.31
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.40
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.33
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		23.18

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 3 TPM

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	765.01	CO_2	%	9.03
Stack static pressure, P_{static}	mm H_2O	-30.59	O_2	%	8.84
$P_s = P_b + \frac{(P_{static})}{13.6}$	mm Hg	762.76	Total	%	17.87
			N_2 (100 -Total)	%	82.13
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.80
Moisture trap weight increase,Vlc	g	-	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.33
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		3.719	Area of stack, A_s	m^2	1.65
Gas meter correction factor, Y_d		0.93249	$Q_a = (60)(A_s)(V_s)$	m³/min	1788.5
Mean dry gas meter temperature, T_m		18.056	**Total flow of stack gas, Q**		
Mean pressure drop across orifice, ΔH	mmH_2O	45.189	Conversion factor (K/mm.Hg)		0.3592
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		3.288	$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	910.8
Volume of gas metered wet, V_{mstw}			$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	1110.87
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	4.1565			
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	1151.32
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	**Percent isokinetic, %I**		
			Nozzle diameter, D_n	mm	6.44
% oxygen measured in gas stream, act%O_2		8.8	Nozzle area, A_n	mm^2	32.58
% oxygen reference condition		11	Total sampling time, θ	min	180
O_2 Reference Factor O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		1.22	$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	101.7
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	3.9987	Acceptable isokinetic range 95% to 115%		Yes
Moisture content, B_{wo}			**Particulate Concentration, C**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.2089	Mass collected on filter, M_f	g	0.00008
	%	20.89	Mass collected in probe, M_p	g	0.00290
Moisture by FTIR	%	20.89	Total mass collected, M_n	g	0.0030
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.72
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.85	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.91
Mean of velocity heads, ΔP_{avg}	mm H_2O	18.06			
Mean square root of velocity heads, √ΔP		4.25	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.75
Mean stack gas temperature, T_s	°C	153			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	18.05	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		49.53

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 4 — TPM

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	765.01
Stack static pressure, P_{static}	mm H_2O	-30.59
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	762.76
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		3.902
Gas meter correction factor, Y_d		0.93249
Mean dry gas meter temperature, T_m		13.361
Mean pressure drop across orifice, ΔH	mmH_2O	43.006
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		3.506
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	4.3673
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		9.23
% oxygen reference condition		11
O_2 Reference Factor: O_2 Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		1.18
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	4.1273
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1972
	%	19.72
Moisture by FTIR	%	19.7
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		
Velocity pressure coefficient, C_p		34.97
Mean of velocity heads, ΔP_{avg}	mm H_2O	0.85
Mean square root of velocity heads, $\sqrt{\Delta P}$		17.37
Mean stack gas temperature, T_s	°C	4.17
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	150
		17.61

Molecular weight of dry gas, M_d		
CO_2	%	8.92
O_2	%	9.23
Total	%	18.15
N_2 (100 -Total)	%	81.85
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.80
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.47
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	1.65
$Q_a = (60)(A_s)(V_s)$	m^3/min	1744.8
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	906.8
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) + 273}$	@O_2ref	1070.61
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) + 273}$	Wet	1129.52
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	6.44
Nozzle area, A_n	mm^2	32.58
Total sampling time, θ	min	180
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(\theta)(1-B_{wo})}$	%	108.9
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00008
Mass collected in probe, M_p	g	0.00190
Total mass collected, M_n	g	0.00198
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.45
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.56
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.48
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		30.73

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	20.99	0.1	0.1	-406.4	0.42	Yes
Run 2	22.09	0.08	0.1	-406.4	0.44	Yes
Run 3	19.26	0.11	0.12	-381	0.39	Yes
Run 4	20.21	0.12	0.11	-457.2	0.40	Yes

ISOKINETICITY

Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	114.47	Yes
Run 2	108.61	Yes
Run 3	101.67	Yes
Run 4	108.89	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	0.02	1.5	Yes
Run 2	0.02	1.5	Yes
Run 3	0.05	1.5	Yes
Run 4	0.0	1.5	Yes

The above is based on both the Filter and rinse uncertainty

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	0.08	30	3.0	Yes
Blank 2	0.05	30	3.0	Yes
Blank 3	0.03	30	3.0	Yes

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	151	180	160
Run 2	QF	47	153	180	160
Run 3	QF	47	153	180	160
Run 4	QF	47	151	180	160

GF = Glass Fibre

QF = Quartz Fibre

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PM_{10} SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	13:00 - 19:00 19 March 2014	0.014	0.010	-	0.76
Run 2	09:00 - 15:00 20 March 2014	0.012	0.010	-	0.77
Run 3	15:46 - 18:46 20 March 2014	0.059	0.020	-	3.7
Run 4	08:45 - 11:45 21 March 2014	0.088	0.020	-	5.3
Blank 1	-	0.007	-	-	-
Blank 2	-	0.022	-	-	-
Blank 3	-	0.010	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.
where values are below the LOD the LOD will be reported.

$PM_{2.5}$ SUMMARY					
Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	13:00 - 19:00 19 March 2014	0.005	0.005	-	0.29
Run 2	09:00 - 15:00 20 March 2014	0.005	0.005	-	0.32
Run 3	15:46 - 18:46 20 March 2014	0.010	0.010	-	0.63
Run 4	08:45 - 11:45 21 March 2014	0.048	0.010	-	2.9
Blank 1	-	0.007	-	-	-
Blank 2	-	0.010	-	-	-
Blank 3	-	0.010	-	-	-

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.
where values are below the LOD the LOD will be reported, where this occurs the quoted uncertainties will be relatively high.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

$PM_{2.5}$ (BF) SAMPLES WEIGHTS				
Test	$PM_{2.5}$ Filter Number	Filter Start Weight g	Filter End Weight g	$PM_{2.5}$ Mass Gained on Filter g
Run 1	QC1022	32.15592	32.15548	-0.00044
Run 2	QC1023	32.90822	32.90806	-0.00016
Run 3	QC1030	32.64649	32.64619	-0.00030
Run 4	QC1036	31.88521	31.88544	0.00023
Blank 1	QC1015	15.82713	15.82700	-0.00013
Blank 2	QC1035	32.64883	32.64890	0.00007
Blank 3	QC1041	15.30896	15.30903	0.00007

PM_{10} (CP2) SAMPLES WEIGHTS				
Test	PM_{10} Filter Number g	Filter Start Weight g	Filter End Weight g	PM_{10} Mass Gained on Filter g
Run 1	QC1016	15.31508	15.31516	0.00008
Run 2	QC1029	15.23483	15.23490	0.00007
Run 3	QC1030	15.57621	15.57645	0.00024
Run 4	QC1040	14.63094	14.63113	0.00019
Blank 1	QC1015	15.82713	15.82700	-0.00013
Blank 2	QC1039	15.81961	15.81970	0.00009
Blank 3	QC1041	15.30896	15.30903	0.00007

$PM_{2.5}$ & PM_{10} (BF & CP2) SAMPLES WEIGHTS COMBINED							
Test	$PM_{2.5}$ Filter Number	PM_{10} Filter Number	$PM_{2.5}$ Mass Gained on Filter g	PM_{10} Mass Gained on Filter g	Actual $PM_{2.5}$ & PM_{10} Combined Total Mass Gained g	$PM_{2.5}$ & PM_{10} Combined Weighing LOD g	*Reported $PM_{2.5}$ & PM_{10} Combined Total Mass Gained g
Run 1	QC1022	QC1016	-0.00044	0.00008	-0.00036	0.00010	0.00013
Run 2	QC1023	QC1029	-0.00016	0.00007	-0.00009	0.00010	0.00012
Run 3	QC1030	QC1030	-0.00030	0.00024	-0.00006	0.00010	0.00029
Run 4	QC1036	QC1040	0.00023	0.00019	0.00042	0.00010	0.00042
Blank 1	QC1015	QC1015	-0.00013	-0.00013	-0.00026	0.00010	0.00010
Blank 2	QC1035	QC1039	0.00007	0.00009	0.00016	0.00010	0.00016
Blank 3	QC1041	QC1041	0.00007	0.00007	0.00014	0.00010	0.00014

* Where weighing values are below the LOD possibly due to loss of filter material, the LOD will be reported.
NOTE - Where the filter weight gain is less than the weighing uncertainty, the weighing uncertainty is used for further calculations. The weighing uncertainty is 0.00005g.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	765.0
Stack static pressure, P_{static}	mm H_2O	-2.2
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	764.8
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	$H_2$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		10.70
Gas meter correction factor, Y_d		1.05
Mean dry gas meter temperature, T_m		25.42
Mean pressure drop across orifice, ΔH	mmH_2O	110.62
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		10.496
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	13.2527
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		11.83
% oxygen reference condition		11
O_2 Reference Factor — O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		0.92
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	9.625
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.2080
	%	20.80
Moisture by FTIR	%	20.80
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, ΔP_{avg}	mm H_2O	22.85
Mean square root of velocity heads, $\sqrt{\Delta P}$		4.8
Mean stack gas temperature, T_s	°C	150
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	20.03

Molecular weight of dry gas, M_d		
CO_2		7.10
O_2		11.83
Total		18.93
N_2 (100 -Total)		81.07
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.61
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.19
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	1.65
$Q_a = (60)(A_s)(V_s)$	m³/min	1984.5
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	29.10
Actual Flow Rate @ DGM	l/min	32.4
Isokinetic Rate		111.17
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00008
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.00981
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.01239
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.01351
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.76
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00005
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0038
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0048
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0052
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.29

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 2 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**	
Barometric pressure, P_b	mm Hg	757.5	CO_2	9.03
Stack static pressure, P_{static}	mm H_2O	-2.2	O_2	11.76
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	757.3	Total	20.79
			N_2 (100 -Total)	79.21
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$	29.92
Moisture trap weight increase,Vlc	g	H_20 by FTIR	**Molecular weight of wet gas, M_s**	
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	27.43
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**	
Volume of gas sample through gas meter, V_m		10.93	Area of stack, A_s — m^2	1.65
Gas meter correction factor, Y_d		1.05	$Q_a = (60)(A_s)(V_s)$ — m³/min	2251.6
Mean dry gas meter temperature, T_m		24.40	**Percent isokinetic, %I**	
Mean pressure drop across orifice, ΔH	mmH_2O	109.52	Required Flow Rate @ DGM — l/min	29.40
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		10.650	Actual Flow Rate @ DGM — l/min	33.1
Volume of gas metered wet, V_{mstw}			Isokinetic Rate	112.57
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	13.4633	Acceptable 90% - 130%	Yes
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Particulate Concentration, C_{PM10}**	
			Mass of particulate collected on PM_{10} filter, M_f	0.00007
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Mass of particulate collected on $PM_{2.5}$ filter, M_f	0.00005
			$C_{wet} = \frac{M_n}{V_{mstw}}$ — mg/m³	0.0089
% oxygen measured in gas stream, act%O_2		11.76		
% oxygen reference condition		11	$C_{dry} = \frac{M_n}{V_{mstd}}$ — mg/m³	0.0113
O_2 Reference Factor — O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		0.92		
			$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$ — mg/m³	0.0122
$V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$	m^3	9.841		
Moisture content, B_{wo}			**Particulate Emission Rates, E**	
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.2089	$E = [(C_{wet})(Q_{stw})(60)] / 1000$	0.77
	%	20.89	**Particulate Concentration, $C_{PM2.5}$**	
Moisture by FTIR	%	20.89	Mass of particulate collected on filter, M_f	0.00005
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$ — mg/m³	0.0037
Pitot tube velocity constant, K_p		34.97		
Velocity pressure coefficient, C_p		0.84	$C_{dry} = \frac{M_n}{V_{mstd}}$ — mg/m³	0.0047
Mean of velocity heads, ΔP_{avg}	mm H_2O	29.17		
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.40	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$ — mg/m³	0.0051
Mean stack gas temperature, T_s	°C	153		
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	22.72	**Particulate Emission Rates, E**	
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$	0.32

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 3 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s			**Molecular weight of dry gas, M_d**		
Barometric pressure, P_b	mm Hg	757.5	CO_2		9.03
Stack static pressure, P_{static}	mm H_2O	-2.2	O_2		11.66
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	757.3	Total		20.69
			N_2 (100 -Total)		79.31
Vol. of water vapour collected, V_{wstd}			$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.91
Moisture trap weight increase,Vlc	g	H_20 by FTIR	**Molecular weight of wet gas, M_s**		
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-	$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.42
Volume of gas metered dry, V_{mstd}			**Actual flow of stack gas, Q_a**		
Volume of gas sample through gas meter, V_m		5.38	Area of stack, A_s	m^2	1.65
Gas meter correction factor, Y_d		1.05	$Q_a = (60)(A_s)(V_s)$	m³/min	2190.5
Mean dry gas meter temperature, T_m		23.11	**Percent isokinetic, %I**		
Mean pressure drop across orifice, ΔH	mmH_2O	110.00	Required Flow Rate @ DGM	l/min	28.70
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.263	Actual Flow Rate @ DGM	l/min	29.9
Volume of gas metered wet, V_{mstw}			Isokinetic Rate		104.08
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.6530	Acceptable 90% - 130%		Yes
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$			**Particulate Concentration, C_{PM10}**		
			Mass of particulate collected on PM_{10} filter, M_f		0.00024
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No	Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00005
			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0436
% oxygen measured in gas stream, act%O_2		11.66			
% oxygen reference condition		11	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0551
O_2 Reference Factor — O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		0.93			
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	4.916	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0590
Moisture content, B_{wo}			**Particulate Emission Rates, E**		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.2089	$E = [(C_{wet})(Q_{stw})(60)] / 1000$		3.65
	%	20.89	**Particulate Concentration, $C_{PM2.5}$**		
Moisture by FTIR	%	20.89	Mass of particulate collected on filter, M_f		0.00005
Velocity of stack gas, V_s			$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0075
Pitot tube velocity constant, K_p		34.97			
Velocity pressure coefficient, C_p		0.84	$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0095
Mean of velocity heads, ΔP_{avg}	mm H_2O	27.57			
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.25	$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0102
Mean stack gas temperature, T_s	°C	154			
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	22.11	**Particulate Emission Rates, E**		
			$E = [(C_{wet})(Q_{stw})(60)] / 1000$		0.63

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 4 — PM_{10} & $PM_{2.5}$

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	738.0
Stack static pressure, P_{static}	mm H_2O	-2.2
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	737.8
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	$H_2$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		5.28
Gas meter correction factor, Y_d		1.05
Mean dry gas meter temperature, T_m		19.09
Mean pressure drop across orifice, ΔH	mmH_2O	110.00
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(\Delta H/13.6))(Y_d)}{T_m + 273}$		5.104
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	6.3582
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		11.65
% oxygen reference condition		11
O_2 Reference Factor — O2 Ref = $\frac{21.0 - act\%O2}{21.0 - ref\%O2}$		0.94
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	4.772
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1972
	%	19.72
Moisture by FTIR	%	19.72
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, ΔP_{avg}	mm H_2O	26.11
Mean square root of velocity heads, $\sqrt{\Delta P}$		5.11
Mean stack gas temperature, T_s	°C	152
$V_s = \frac{(K_p)(C_p)(\sqrt{\Delta P})(\sqrt{(T_s + 273)})}{(M_s)(P_s)}$	m/s	21.70

Molecular weight of dry gas, M_d		
CO_2		8.92
O_2		11.65
Total		20.57
N_2 (100 -Total)		79.43
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		29.89
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$		27.55
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	1.65
$Q_a = (60)(A_s)(V_s)$	m³/min	2150.1
Percent isokinetic, %I		
Required Flow Rate @ DGM	l/min	28.80
Actual Flow Rate @ DGM	l/min	29.3
Isokinetic Rate		101.82
Acceptable 90% - 130%		Yes
Particulate Concentration, C_{PM10}		
Mass of particulate collected on PM_{10} filter, M_f		0.00019
Mass of particulate collected on $PM_{2.5}$ filter, M_f		0.00023
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0661
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0823
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0880
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		5.32
Particulate Concentration, $C_{PM2.5}$		
Mass of particulate collected on filter, M_f		0.00023
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	0.0362
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	0.0451
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	0.0482
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		2.91

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PM_{10} & $PM_{2.5}$ 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	32.35	0.16	0.18	-508	0.65	Yes
Run 2	33.10	0.18	0.2	-508	0.66	Yes
Run 3	29.87	0.14	0.2	-508	0.60	Yes
Run 4	29.32	0.1	0.12	-457	0.59	Yes

ISOKINETICITY		
Run	Flow Variation %	Acceptable Variation
Run 1	111.2	Yes
Run 2	112.6	Yes
Run 3	104.1	Yes
Run 4	101.8	Yes

Acceptable Flow rate 90 -130%

FILTERS					
Run	Filter Material	Filter Size mm	Max Filtration Temperature °C	Pre-conditioning Filter Temperature °C	Post conditioning Filtration Temperature °C
Run 1	QF	50	153	180	160
Run 2	QF	50	154	180	160
Run 3	QF	50	154	180	160
Run 4	QF	50	153	180	160

QF = Quartz Fibre

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Conformity with relevant aspects of BS EN ISO 23210:2009

GENERAL METHODOLOGY
The equipment employed is a Paul Gothe, Johnas cascade impactor (see pg 13 for serial number) system meeting the requirements of BS EN ISO 23210. The standard cites a two-stage impactor system.

The method for sampling requires the extraction of a representative sample of duct gas isokinetically, into a specially designed in-stack sampling head. The Cascade Impactor is a multi-stage, multi-jet impactor which aerodynamically classifies particulates into multiple size ranges. The cascade impactor uses the principle of inertial separation to size segregate particulate samples from the gas stream. The impactor has two stages for particle size determination. Each stage gives a cut-point based on aerodynamic diameter of the particle.

During sampling, the particles are driven (jetted) toward a collecting surface where they may cling. By changing the velocity (orifice size of the jet), the size of the particles collected is controlled. The size of the jets within each stage is constant, but for each succeeding stage the jets get smaller. Impaction occurs when the particle's inertia overcomes the aerodynamic drag. Otherwise, the particle remains in the air stream and proceeds to the next stage. To keep the cut-point for each stage constant, the impactor is operated at a constant flow rate.

At each stage, the particle impacts on to a conditioned and pre-weighed substrate. Following sampling, the substrates are reconditioned and reweighed to determine the mass collected.

Based on the sampling conditions (sampling rate and gas temperature) the cut size (D50 – diameter of particles having a 50% probability of penetration) associated with each impactor stage may be determined.

An homogeneity assessment based on BS EN ISO 23210, Annex G, is undertaken to determine the most representative sampling point in the sampling plane (temperature, velocity and oxygen are suitable surrogates for particulate matter). The velocity measurement at the chosen point is used to determine an appropriate sampling nozzle/flow rate in order to ensure that isokinetic conditions are maintained throughout sampling to within the 90-130% range allowed in the standard (8.1) and which is consistent with the sampling equipment.

Concurrently, the volume of duct gas sampled is measured. This then enables the particulate concentration at each cut size to be determined.

The outlet gas from the sampling head is passed via a sampling probe through an impinger train with the purpose of removing water prior to entry to the sampling control box. It is not intended that the sampling train be used for additional sampling of condensible determinands and as such the train is unheated.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Conformity with relevant aspects of BS EN ISO 23210:2009

Sampling Plane Validation Criteria				
EA Technical Guidance Note (Monitoring) M1	Result	Units	Requirement	Compliant
Lowest Differential Pressure	157	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	16.05	m/s	-	-
Highest Gas Velocity	22.99	m/s	-	-
Ratio of Gas Velocities	1.43	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	o	< 15^{o}	Yes
No local negative flow	Yes	-	-	Yes

Conformance with BS EN ISO 23210:2009			
Reference	Requirement	Result	Compliant
Section 6.3	Suitable Impcator Used	See statement of conformity for Impactor	Yes
Section 8.1	Sampling position acceptable (as per 13284-1)	refer to page 10	No
Section 8.1	Nozzle arrangement	See statement of conformity for Impactor	Yes
Section 8.1	Representative sampling point	refer to page 10	No
Section 8.1	Constant Sample gas flow, iso-kinetic rate 90% to 130%		
	Run 1 - Required flow 29.1 (LPM)		-
	Run 1 - Minimum permissable flow 26.19 (LPM)	27.06	Yes
	Run 1 - Maximum permissable flow 37.83 (LPM)	36.92	Yes
	Run 2 - Required flow 29.4 (LPM)		-
	Run 2 - Minimum permissable flow 26.46 (LPM)	28.77	Yes
	Run 2 - Maximum permissable flow 38.22 (LPM)	38.16	Yes
	Run 3 - Required flow 28.7 (LPM)		-
	Run 3 - Minimum permissable flow 25.83 (LPM)	25.98	Yes
	Run 3 - Maximum permissable flow 37.31 (LPM)	34.00	Yes
	Run 4 - Required flow 28.8 (LPM)		-
	Run 4 - Minimum permissable flow 25.92 (LPM)	25.94	Yes
	Run 4 - Maximum permissable flow 37.44 (LPM)	34.20	Yes
Section 8.1	Overall blank taken once per day	Yes	Yes
Section 8.2	Impactor cleaned between each measurement	Yes	Yes
Section 8.2	Arrangement of impactor plates	See statement of conformity for Impactor	Yes
Section 8.3.2	Data taken for velocity, composition, temp & pressure	See "Preliminary stack survey" section	Yes
Section 8.3.3	Sampling rate determination in accordance with Annex A	Yes	Yes
Section 8.3.3	Sample flow rate kept +/- 5% of nominal flow rate		
	Run 1 - Max sample flow deviation from nominal (%)	7.8	No
	Run 2 - Max sample flow deviation from nominal (%)	8.7	No
	Run 3 - Max sample flow deviation from nominal (%)	0.0	Yes
	Run 4 - Max sample flow deviation from nominal (%)	0.0	Yes
Section 8.3.4	Nozzle selectedto allow iso-kinetic rate 90% to 130%	Yes, as above	Yes
Section 8.3.5	Leak check less than 2%		
	Run 1	0.49	Yes
	Run 2	0.54	Yes
	Run 3	0.47	Yes
	Run 4	0.34	Yes
Section 8.3.6	Impactor at flue gas temperature before sampling	Yes	Yes
Section 8.3.6	Angle of nozzle less than 10 Degress to flow	Yes	Yes
Section 8.3.6	Flowrate has checked and recorded every 5 mins	Yes	Yes
Section 8.3.6	Dynamic pressure recorded every 5 mins	Yes	Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

Homogeneity assessment

Assessment 1

Point number (i)	Distance along sample line (mm)	Probe Marking (mm)	Temp Deg C grid	Temp Deg C fixed	r_i
1	85.6	185.6	149	150	0.993
2	306.4	406.4	149	150	0.993
3	725	825	149	149	1.000
4	1143.6	1243.6	150	150	1.000
5	1364.4	1464.4	151	149	1.013
6					
7					
8					
9					
10					
Second Line					
1	85.6	185.6	148	148	1.000
2	306.4	406.4	150	148	1.014
3	725	825	150	148	1.014
4	1143.6	1243.6	149	148	1.007
5	1364.4	1464.4	149	148	1.007
6					
7					
8					
9					
10					

No. of points	10
S_{grid}	0.84
S_{ref}	0.9189
F	1
Is $S_{grid} <= S_{ref}$?	Yes
F Factor	0.842
$F_{N-1; N-1; 0.95}$	3.18
Is F Factor < $F_{N-1;N-1;0.95}$?	N/A
S_{pos}	N/A
$t_{N-1;0.95}$	2.262
U_{pos}	N/A
Permissible Uncertainty	10
Is $U_{pos} < 0.5 * U_{perm}$?	N/A

Sample can be taken from any location

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DAILY OXYGEN SUMMARY

Run	Sampling Times	Concentration %	LOD %
1	13:00 - 19:00 19 March 2014	9.55	0.01
2	09:00 - 15:00 20 March 2014	9.13	0.01
3	15:46 - 18:46 20 March 2014	9.18	0.01
4	08:45 - 11:45 21 March 2014	9.45	0.01

PRE SAMPLING CALIBRATION DATA

Date	Time of Analyser Check	Range (%)	Zero Reading at analyser	Span Reading at analyser	Zero Check at analyser	Zero Check down line	Span Check down line	Leak Rate %
19 March 2014	08:40 - 09:00	25	0.00	10.01	0.01	0.01	10.02	0.10
20 March 2014	08:20 - 08:50	25	0.00	10.01	-0.01	-0.02	10	-0.10
21 March 2014	08:00 - 08:20	25	0.00	10.01	0.00	-0.01	10.02	0.10

POST SAMPLING CALIBRATION DATA

Date	Time of Analyser Check	Zero Check down line	Span Check down line	Zero Drift (%)	Span Drift (%)
19 March 2014	19:10 - 19:25	0.12	10.1	0.44	-0.30
20 March 2014	18:55 - 19:15	0.12	10.08	0.56	-0.60
21 March 2014	12:00 - 12:20	0.03	9.91	0.16	-1.50

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

COMBUSTION GAS SUMMARY

Test	Sampling Times	Concentration %	Analysis Areas	Interference (%) *	LOD %
Moisture Run 1	13:00 - 19:00 19 March 2014	21.8	3200 - 3401	1.4	0.10
Moisture Run 2	09:00 - 15:00 20 March 2014	20.8	3200 - 3401	1.75	0.02
Moisture Run 3	15:46 - 18:46 20 March 2014	20.6	3200 - 3401	1.75	0.02
Moisture Run 4	08:45 - 11:45 21 March 2014	20.6	3200 - 3401	1.75	0.10
Carbon Dioxide Run 1	13:00 - 19:00 19 March 2014	8.8	2000 - 2223	0.28	0.01
Carbon Dioxide Run 2	09:00 - 15:00 20 March 2014	9.0	2000 - 2223	1.75	0.01
Carbon Dioxide Run 3	15:46 - 18:46 20 March 2014	8.1	2000 - 2223	1.75	0.01
Carbon Dioxide Run 4	08:45 - 11:45 21 March 2014	8.1	2000 - 2223	1.75	0.01

*M22 Specifies interference must be <5%.

FTIR CALIBRATION CHECKS

Pre - Sampling Checks - System			Date of Checks	19 March 2014		Time of Checks	09:45	
Post Sampling Checks - System			Date of Checks	19 March 2014		Time of Checks	19:20	
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
H_2O	0.13	0.14	0.04	101.0	102.0	0.99	102.7	0.65
CO_2(%)	0.00	0.00	-0.01	8.1	8.4	3.16	8.5	1.20

Pre - Sampling Checks - System			Date of Checks	20 March 2014		Time of Checks	08:35	
Post Sampling Checks - System			Date of Checks	20 March 2014		Time of Checks	18:55	
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
H_2O	-0.02	0.14	0.16	101.0	102.0	0.99	102.7	0.65
CO_2(%)	0.00	0.40	4.01	8.1	8.3	2.34	8.4	1.61

Pre - Sampling Checks - System			Date of Checks	21 March 2014		Time of Checks	08:17	
Post Sampling Checks - System			Date of Checks	21 March 2014		Time of Checks	12:03	
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
H_2O	-0.02	0.13	0.15	101.0	102.3	1.32	101.3	-0.98
CO_2(%)	0.00	0.01	0.11	8.1	8.4	3.99	8.5	0.79

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.

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	1.45	m
Stack Width, W	-	m
Stack Area, A	1.65	m^2
Average stack gas temperature	151	^oC
Stack static pressure	-0.30	kPa
Barometric Pressure	100.4285714	kPa
Pitot tube calibration coefficient, K_{pt}	0.84	-

Stack Gas Composition & Molecular Weights

Component	Molar Mass M	Density kg/m^3 p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m^3 pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m^3 pi
CO_2	44	1.96	11.27	0.11	0.22	9.47	0.09	0.19
O_2	32	1.43	11.95	0.12	0.17	10.04	0.10	0.14
N_2	28	1.25	76.78	0.77	0.96	64.51	0.65	0.81
H_2O	18	0.80	-	-	-	15.98	0.16	0.13

Where: p = M / 22.41 p*i* = r x p

Calculation of Stack Gas Densities

Determinand	Result	Units
Dry Density (STP), P_{STD}	1.3510	kg/m^3
Wet Density (STP), P_{STW}	1.2634	kg/m^3
Dry Density (Actual), P_{Actual}	0.8593	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	0.804	kg/m^3

Where:

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

P_{STW} = (P_{STD} + p*i* of H_2O) / (1 + (p*i* 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	19 March 2014
Time of Survey	09:00
Velocity Measurement Device:	S-Type Pitot

Sampling Line A							
Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	0.07	32.0	314	149	22.64	-	<15
2	0.22	32.0	314	149	22.64	-	<15
3	0.36	30.0	294	149	21.92	-	<15
4	0.51	24.2	237	150	19.72	-	<15
5	0.65	16.0	157	151	16.05	-	<15
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	26.8	263	150	20.60	-	

Sampling Line B							
Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 2

Date of Survey	19 March 2014
Time of Survey	19:10
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl º
1	0.07	30.0	294	149	21.92	-	<15
2	0.22	28.0	274	150	21.21	-	<15
3	0.36	26.8	263	150	20.75	-	<15
4	0.51	22.4	220	150	18.97	-	<15
5	0.65	17.4	171	150	16.72	-	<15
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	24.9	244	150	19.91	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ˚C	Velocity m/s	O_2 % Vol	Angle of Swirl º
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 3

Date of Survey	20 March 2014
Time of Survey	08:32
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	0.07	28.0	274	152	21.51	-	<15
2	0.22	30.0	294	152	22.26	-	<15
3	0.36	28.0	274	152	21.51	-	<15
4	0.51	26.0	255	153	20.75	-	<15
5	0.65	19.0	186	153	17.74	-	<15
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	26.2	257	152.4	20.75	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp ^oC	Velocity m/s	O_2 % Vol	Angle of Swirl ^{o}
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 4

Date of Survey	20 March 2014
Time of Survey	15:10
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH$_2$O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	30.0	294	149	22.19	-	<15
2	0.22	28.0	274	150	21.46	-	<15
3	0.36	28.0	274	150	21.46	-	<15
4	0.51	24.0	235	150	19.87	-	<15
5	0.65	20.0	196	150	18.14	-	<15
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	26.0	255	150	20.62	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH$_2$O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 5

Date of Survey	20 March 2014
Time of Survey	18:55
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	32.0	314	154	22.78	-	<15
2	0.22	30.0	294	154	22.05	-	<15
3	0.36	28.0	274	154	21.31	-	<15
4	0.51	24.0	235	154	19.73	-	<15
5	0.65	18.0	176	154	17.08	-	<15
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	26.4	259	154	20.59	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

TRAVERSE 6

Date of Survey	21 March 2014
Time of Survey	08:05
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	30.0	294	152	22.00	-	<15
2	0.22	30.0	294	152	22.00	-	<15
3	0.36	28.6	280	153	21.51	-	<15
4	0.51	24.2	237	152	19.76	-	<15
5	0.65	20.0	196	152	17.97	-	<15
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	26.6	-	152	-	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 7

Date of Survey	21 March 2014
Time of Survey	12:00
Velocity Measurement Device:	S-Type Pitot

Sampling Line A

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	0.07	32.0	314	152	22.99	-	<15
2	0.22	30.0	294	151	22.24	-	<15
3	0.36	26.4	259	151	20.86	-	<15
4	0.51	22.8	223	151	19.39	-	<15
5	0.65	18.8	184	151	17.60	-	<15
6	-	-	-	-	-	-	<15
7	-	-	-	-	-	-	<15
8	-	-	-	-	-	-	<15
9	-	-	-	-	-	-	<15
10	-	-	-	-	-	-	<15
Mean	-	26	255	151.2	20.62	-	

Sampling Line B

Traverse Point	Distance into duct (m)	ΔP pt mmH_2O	ΔP pt Pa	Temp °C	Velocity m/s	O_2 % Vol	Angle of Swirl °
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	

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	157	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	16.05	m/s	-	-
Highest Gas Velocity	22.99	m/s	-	-
Ratio of Gas Velocities	1.43	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	<15	^{o}	$< 15^o$	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V

Velocity at Traverse Point, $V = K_{pt} \times (1-\varepsilon) * \sqrt{(2 * \Delta P_{pt} / P_{ActualW})}$

Where:

K_{pt} = Pitot tube calibration coefficient

(1-ε) = Compressibility correction factor, assumed at a constant 0.998

Average Stack Gas Velocity, Va	**20.56**	m/s

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))

Day 1	19 March 2014

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	150	0	^{o}C
Total Pressure	101.7	101.3	kPa
Oxygen	9.6	11	%
Moisture	21.78	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	20.25		m/s
Stack Area (A)	1.65		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	120419		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	78080		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	61073		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	69915		m^3/hr

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

Day 2	20 March 2014		
Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	152	0	^oC
Total Pressure	100.0	101.3	kPa
Oxygen	9.3	11	%
Moisture	20.64	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	20.65		m/s
Stack Area (A)	1.65		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	122794		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	77808		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	61749		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	72548		m^3/hr

Day 3	21 March 2014		
Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	151	0	^oC
Total Pressure	97.7	101.3	kPa
Oxygen	9.4	11	%
Moisture	16.67	0.00	%
Gas Volumetric Flowrate	Result		Units
Average Stack Gas Velocity (Va)	20.62		m/s
Stack Area (A)	1.65		m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	122578		m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	76084		m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	63399		m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	73242		m^3/hr

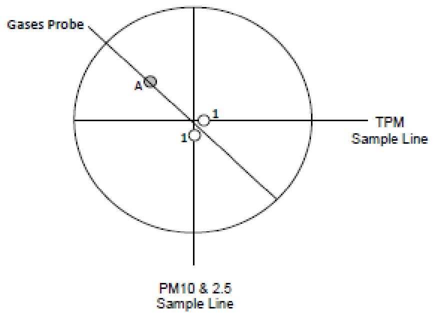
Nomenclature:

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	1.45	m
Stack Width	-	m
Area	1.65	m^2

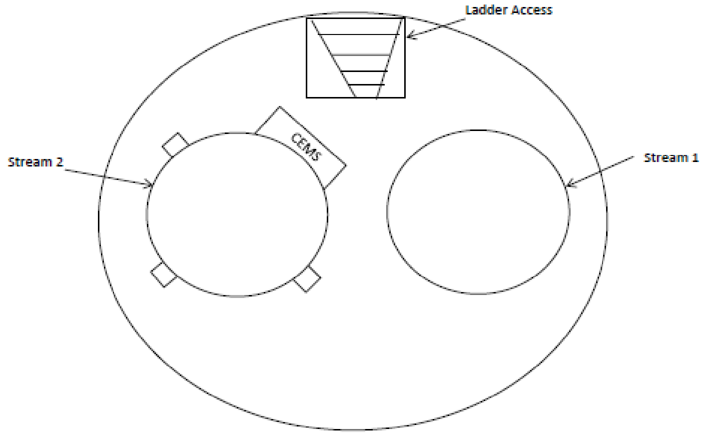


Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	30	0.44	m

Isokinetic Sampling CEN Methods			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl º
1	85.0	1.23	<15

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

SAMPLING LOCATION



APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - TOTAL PARTICULATE MATTER

Run	Sampled Volume m³	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	0.1	0.1900	-	-
as a %	0.01	0.68	0.49	1.00	1.04	0.07783	0.48	0.001
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.190	-	-
as a %	0.01	0.68	0.49	1.00	1.12	0.070	0.45	0.001
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 3	0.001	2	0.5	1	0.1	0.1900	-	-
as a %	0.03	0.69	0.49	1.00	1.13	0.15839	0.62	0.001
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Run 4	0.001	2	0.5	1.00	0.1	0.190	-	-
as a %	0.02	0.70	0.49	1.00	1.08	0.153	0.54	0.001
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Run	Volume (STP) m³	Mass of particulate mg	O_2 Correction -	Leak mg/m³	Uncollected Mass mg	Combined uncertainty
Run 1	7.63	2.7800	0.88	0.001	0.0002	-
MU as mg/m³	0.00	0.0233	0.00	0.001	0.0000	**0.02**
MU as %	1.31	6.8345	-	0.275	0.0071	-
Run 2	8.49	2.9800	0.83	0.001	0.0002	-
MU as mg/m³	0.00	0.0210	0.00	0.001	0.0000	**0.02**
MU as %	1.3	6.3758	-	0.261	0.0066	-
Run 3	3.77	2.9800	0.82	0.003	0.0002	-
MU as mg/m³	0.01	0.0475	0.01	0.003	0.0000	**0.05**
MU as %	1.31	6.3758	-	0.360	0.0066	-
Run 4	3.95	1.98	0.85	0.002	0.0002	-
MU as mg/m³	0.01	0.0460	0.00	0.002	0.0000	**0.05**
MU as %	1.3	9.5960	-	0.314	0.0099	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.05**	**mg/m³**	**14.04**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.04**	**mg/m³**	**13.13**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.10**	**mg/m³**	**13.14**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.09**	**mg/m³**	**19.46**	**%**

(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 - PM 10

Run	Sampled m³	Sampled Gas K	Sampled Gas kPa	Sampled Gas % by volume	Oxygen % by volume	Limit of % by mass	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	0.10	-
as a %	0.01	0.47	0.49	1.00	0.85	N/A	0.56
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.10	-
as a %	0.01	0.47	0.50	1.00	0.85	N/A	0.60
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 3	0.001	2	0.5	1	0.1	0.1000	-
as a %	0.02	0.47	0.50	1.00	0.86	N/A	0.67
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 4	0.001	2	0.5	1	0.1	0.10	-
as a %	0.02	0.47	0.51	1.00	0.86	N/A	0.41
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	Mass of particulate mg	O2 Correction -	Leak mg/m³	Combined uncertainty
Run 1	0.0022	0.1039	0.012	1.000	-
MU as mg/m^3	0.0002	0.0104	0.0001	0.00004	**76.93**
MU as %	0.0017	76.9	1.091	0.321	-
Run 2	0.0019	0.1016	0.011	1.000	-
MU as mg/m^3	0.0001	0.0102	0.0001	0.00004	**83.34**
MU as %	0.0015	83.3	1.082	0.349	-
Run 3	0.0188	0.2034	0.055	1.000	-
MU as mg/m^3	0.0007	0.0203	0.0006	0.00023	**34.502**
MU as %	0.0074	34.5	1.071	0.387	-
Run 4	0.0295	0.21	0.082	1.00	-
MU as mg/m^3	0.0011	0.02	0.0009	0.00021	**23.83**
MU as %	0.0111	23.8	1.070	0.24	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.02**	**mg/m³**	**153.88**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.02**	**mg/m³**	**166.70**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.04**	**mg/m³**	**69.05**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.04**	**mg/m³**	**47.73**	**%**

(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 - PM 2.5

Run	Sampled m³	Sampled Gas K	Sampled Gas kPa	Sampled Gas % by volume	Oxygen % by volume	Limit of % by mass	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**
Run 1	0.001	2	0.5	1	0.1	0.05	-
as a %	0.01	0.47	0.49	1.00	0.85	N/A	0.56
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 2	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.01	0.47	0.50	1.00	0.85	N/A	0.60
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 3	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.02	0.47	0.50	1.00	0.86	N/A	0.67
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run 4	0.001	2	0.5	1.00	0.1	0.05	-
as a %	0.02	0.47	0.51	1.00	0.86	0.00	0.41
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	Mass of particulate mg	O2 Correction -	Leak mg/m³	Combined uncertainty
Run 1	0.00	0.1039	0.0048	1.000	-
MU as mg/m³	0.0001	0.0052	0.0001	0.00002	**100.01**
MU as %	0.0007	100.0000	1.0905	0.32	-
Run 2	0.0008	0.1016	0.0047	1.000	-
MU as mg/m³	0.0001	0.0051	0.0001	0.00002	**100.01**
MU as %	0.0006	100.0000	1.0823	0.35	-
Run 3	0.0016	0.1016	0.0047	1.000	-
MU as mg/m³	0.0001	0.0051	0.0001	0.00002	**100.01**
MU as %	0.0006	100.0000	1.0707	0.39	-
Run 4	0.0162	0.2095	0.0451	1.0000	-
MU as mg/m³	0.0006	0.0105	0.0005	0.00011	**21.77**
MU as %	0.0061	21.7391	1.0695	0.24	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.010**	**mg/m³**	**200.03**	**%**
R2 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.010**	**mg/m³**	**200.03**	**%**
R3 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.010**	**mg/m³**	**200.03**	**%**
R4 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.021**	**mg/m³**	**43.60**	**%**

(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 - CARBON DIOXIDE BY FTIR

Actual Measured Concentration	8.81	% vol
Measured Concentration at Reference Conditions	8.81	% vol
Emission Limit Value	-	% vol
Instrument Range	10	% vol
Check Gas Concentration	8.11	% vol

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)	-0.010	<5%	Yes
Span drift (calculated from start and end readings).	1.195	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	0.990	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.100	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	-1.300	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	1.600	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	0.283	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.080	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	% vol
Uncertainty of linearity (lack of fit) U_{fit}	-0.110
Uncertainty of zero drift $U_{0,dr}$	-0.001
Uncertainty of span drift $U_{s,dr}$	0.069
Uncertainty of volume or pressure flow dependence U_{spress}	0.057
Uncertainty in Ambient Temperature U_{temp}	0.075
Uncertainty in Voltage U_{volt}	0.092
Uncertainty of interferents U_i	0.016
Uncertainty of Repeatability U_r	0.008
Uncertainty of Certified Reference Material U_{cal}	0.047

Measurement Uncertainty	% vol
Combined uncertainty	0.19
Expanded uncertainty at a 95% Confidence Interval	0.38

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	4.35
Expressed as a % of the Measured Concentration at Reference Conditions	4.35
Expressed as a % of the Emission Limit Value	-

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE BY FTIR

Actual Measured Concentration	21.80	% vol
Measured Concentration at Reference Conditions	21.80	% vol
Emission Limit Value	30	% vol
Instrument Range	30	% vol
Check Gas Concentration (Methane was used as a Surrogate)	72.14	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)	0.043	<5%	Yes
Span drift (calculated from start and end readings).	0.654	<5%	Yes
Sensitivity to sample gas pressure: (taken from worst case figure in MCERTS certificate).	0.990	<2%	Yes
Sensitivity to ambient temperature at zero (taken from worst case figure in MCERTS certificate)	0.100	<5%	Yes
Sensitivity to ambient temperature at span (taken from worst case figure in MCERTS certificate)	-1.000	<5%	Yes
Sensitivity to voltage (taken from worst case figure in MCERTS certificate)	0.710	<2%	Yes
Interferents (calculated using M22, Section 8.2, equation 3)	1.383	<5%	Yes
Repeatability / standard deviation (taken from worst figure in MCERTS certificate)	0.170	<2%	Yes
Certified reference material (check gas)	2.000	2% or less	Yes

Uncertainty in Performance Characteristics	% vol
Uncertainty of linearity (lack of fit) U_{fit}	-0.329
Uncertainty of zero drift $U_{0,dr}$	0.008
Uncertainty of span drift $U_{s,dr}$	0.113
Uncertainty of volume or pressure flow dependence U_{spress}	0.171
Uncertainty in Ambient Temperature U_{temp}	0.174
Uncertainty in Voltage U_{volt}	0.123
Uncertainty of interferents U_i	0.239
Uncertainty of Repeatability U_r	0.051
Uncertainty of Certified Reference Material U_{cal}	0.417

Measurement Uncertainty	% vol
Combined uncertainty	0.66
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	6.01
Expressed as a % of the Measured Concentration at Reference Conditions	6.01
Expressed as a % of the Emission Limit Value	4.37

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 1 - 19 March 2014

Reference	11	%vol
Measured concentration	9.55	%vol
Calibration gas	10.01	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	40	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	216	minutes	-	-
Number of readings in measurement	216	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.44	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.30	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.10	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	0.089
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.020
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	0.006
Uncertainty of calibration gas	ucalib	0.110

Measurement uncertainty (Concentration Measured)	9.55	%vol
Combined uncertainty	0.20	%vol
% of value	2.10	%

Expanded uncertainty expressed with a level of confidence of 95%	**4.20**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**0.40**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 2 - 20 March 2014

Reference	11	%vol
Measured concentration	9.15	%vol
Calibration gas	10.01	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	40	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	586	minutes	-	-
Number of readings in measurement	586	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.56	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-0.60	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	-0.10	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	0.007
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.081
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	-0.005
Uncertainty of calibration gas	ucalib	0.106

Measurement uncertainty (Concentration Measured)	9.15	%vol
Combined uncertainty	0.19	%vol
% of value	2.12	%

Expanded uncertainty expressed with a level of confidence of 95%	**4.24**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**0.39**	**% vol**

Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - OXYGEN

DAY 3 - 21 March 2014

Reference	11	%vol
Measured concentration	9.45	%vol
Calibration gas	10.01	%vol
Full Scale	25	%vol

Performance characteristics	Value	Units	specification	MU Met?
Response time	40	seconds	< 200 s	Yes
Logger sampling interval	60	seconds	-	-
Measurement period	180	minutes	-	-
Number of readings in measurement	180	-	-	-
Repeatability at zero	0.015	% by volume	<0.2 % range	Yes
Repeatability at span level	0.014	% by volume	<0.4 % range	Yes
Deviation from linearity	0.13	% vol	<0.3 % volume	Yes
Zero drift (during measurement period)	0.16	% vol at zero level	<2% of volume / 24hr	Yes
Span drift (during measurement period)	-1.50	% vol at span level	<2% volume/24hr	Yes
volume or pressure flow dependence	0.02	% of fs / 10l/h	<1% range	Yes
atmospheric pressure dependence	0.8	% of fs/kPa	< 1.5 % range	Yes
ambient temperature dependence	0.01	% by volume /10K	<0.3% volume 10 K	Yes
Combined interference	0.14	% range	<2% range	Yes
Dependence on voltage	0.1	% by volume /10V	< 0.1%vol /10 volt	Yes
Losses in the line (leak)	0.10	% of value	< 2% of value	Yes
Uncertainty of calibration gas	2	% of value	< 2% of value	Yes

Performance characteristic	Uncertainty	Value of uncertainty quantity
Standard deviation of repeatability at zero	ur0	-
Standard deviation of repeatability at span level	urs	0.001
Lack of fit	ufit	0.075
Drift	u0dr	-0.724
volume or pressure flow dependence	uspres	0.001
atmospheric pressure dependence	uapres	0.115
ambient temperature dependence	utemp	0.003
Combined interference (from mcerts)	-	0.081
dependence on voltage	uvolt	0.029
losses in the line (leak)	uleak	0.005
Uncertainty of calibration gas	ucalib	0.109

Measurement uncertainty (Concentration Measured)	9.45	%vol
Combined uncertainty	0.75	%vol
% of value	7.94	%

Expanded uncertainty expressed with a level of confidence of 95%	**15.88**	**% of value**

Expanded uncertainty expressed with a level of confidence of 95%	**1.50**	**% vol**

Developed for the STA by R Robinson, NPL

Standard deviation of repeatability at span level	urs	#DIV/0!

APPENDIX 4 - Summaries, Calculations, Raw Data and Charts

NOTE - The following data is provided for information only and falls outside ESG's scope of accreditation

COMBINED UNCOLLECTED SUMMARY

Test	Sampling Times	>PM_{10} Concentration		Probe Rinse Concentration		Combined Unweighed Concentration	
		Measured mg/m³	LOD mg/m³	Measured mg/m³	LOD mg/m³	Measured mg/m³	LOD mg/m³
Run 1	13:00 - 19:00 19 March 2014	0.005	0.005	0.083	0.010	0.077	0.016
Run 2	09:00 - 15:00 20 March 2014	0.039	0.005	0.010	0.010	0.028	0.015
Run 3	15:46 - 18:46 20 March 2014	0.010	0.010	0.224	0.020	0.197	0.031
Run 4	08:45 - 11:45 21 March 2014	0.010	0.010	0.105	0.021	0.031	0.031

Reference conditions are 273K, 101.3kPa, dry gas 11% Oxygen.

Where the result is less than the LOD, the LOD is reported.

SAMPLES

Test	>PM_{10} Filter Number	Filter Start Weight g	Filter End Weight g	Mass Gained on Filter g	Probe Rinse Number g	Probe Rinse Start Weight g	Probe Rinse End Weight g	Mass Gained in Rinse g	Combined Total Mass Gained g
Run 1	TQC1031	15.1463	15.1463	-0.00006	QC1016 / QC1022	150.0899	150.0907	0.00080	0.00074
Run 2	TQC1032	15.5892	15.5895	0.00038	QC1029 / QC1023	182.90620	182.90610	-0.00010	0.00028
Run 3	TQC1033	16.1137	16.1136	-0.00013	QC1030 / QC1024	159.87560	159.87670	0.00110	0.00097
Run 4	TQC1034	16.1753	16.0975	-0.07780	QC1040 / QC1036	182.70270	182.70320	0.00050	-0.07730
Blank 1					QC1015 / QC1021	194.78310	194.78380	0.00070	0.00070
Blank 2					QC1039 / QC1035	160.08180	160.08150	-0.00030	-0.00030
Blank 3					QC1041 / QC1037	184.48590	184.48600	0.00010	0.00010

PAUL GOTHE BOCHUM

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To our customers

Your ref	Your letter	Our ref	Date 14.03.2007

Calibration of the Johnas Impactor according to **ISO 23210**
6.2 Separation curves and Section 6.3 Verification of the separation curves

The Johnas Impactor from Paul Gothe GmbH was developed before the ISO Guideline was evaluated and after the Germans and the Netherlands Authorities have enough experiences with our impactor. After that the European Delegation creates the ISO Guideline 23210. The section 6.3 is important and was influence by the Germans. They have the experiences and write the rules for the calibration section accordingly it was made for the Johnas-Impactor.
The development from the Johnas impactor starts with a doctoral thesis from Mrs. John at the Gerhard-Mercator-University. She makes the intensive testing and Mr. Geueke from the North Rhine Westphalia State Environment Agency makes additional verifications at the ESA (Emission Simulation Facility) at the Hessian Agency for the Environment and Geology (HLUG).

Most of the literatures and papers are in German, but all well-known:

1. Probenahme und chemische Analytik von korngrößenfraktionierten Immissions- und Emissionsaerosolen. Von der Fakultät für Naturwissenschaften der Gerhard-Mercator-Universität – Gesamthochschule Duisburg zur Erlangung des akademischen Grades eines Dr. rer. nat. genehmigte Dissertation von ASTRID CHRISTIANE JOHN aus Lichtenfels.
2. Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit Luftreinhaltung Forschungsbericht 298 44 280, Korngrößenverteilung (PM10 und PM2,5) von Staubemissionen relevanter stationärer Quellen (Teil II zu 297 44 853), von Dipl.-Ing. A. Dreiseidler, Ing. D. Straub, Prof. Dr.-Ing. G. Baumbach, Universität Stuttgart, Institut für Verfahrenstechnik und Dampfkesselwesen (IVD), Abteilung Reinhaltung der Luft (RdL), Institutsleiter: Prof. Dr.-Ing. K.R.G. Hein, IM AUFTRAG DES UMWELTBUNDESAMTES Juni 2001.
3. VDI 2066, part 10
4. Gefahrstoffe-Reinhaltung der Luft 59 (1999), Nr.11/12, S. 449-453

All this papers shows, that the design of the Johnas Impactor is a proved version for the determination of the PM 2.5 and PM 10. The shape of the separation curves is similar to those specified in ISO 7708:1995 and the separation efficiency at 10 µm and 2,5 µm is 50 % according to section 6.3 of the ISO 23210.

What you need more? There is no authority which has more competence as the listed authorities.

If you still in doubt, you maybe get in contact with Mr. Geueke (phone: ++49-201-7995-1263).

Paul Gothe GmbH

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Companion: Paul Gothe-Stiftung
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Your ref Your letter Our ref Date 14.03.2007

Declaration of conformity

Herewith the company Paul Gothe GmbH in Bochum declare that the manufactured Cascade Impactor Johnas follows the guidelines from the North Rhine Westphalia State Environment Agency according the convention from 24 June 1999 and the PM 4 stage follows the convention of the Federal Environment Agency from 09. March 2005.

Our Cascade Impactor Johnas was developed in cooperation with the North Rhine Westphalia State Environment and the Gerhard-Mercator University Duisburg. This impactor was validated and after that 2004 adopted in the German Standard VDI 2066, part 10 and 2005 in ISO Standard 23210. All sizes of our manufactured impactors are according to these guidelines, individually checked according our strict quality management and named with a specific serial number. Only an impactor with this serial number is according to the Guideline VDI 2066, part 10 and ISO Standard 23210 and can use for the determination of PM 10 and PM 2.5.

Paul Gothe GmbH

Impactor Johnas according to the VDI 2066 and ISO 23210 and the convention from
Umwelt Bundes Amt
Für Mensch und Umwelt
Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen
NRW.

Dr. Torsten Grodten

-manager-

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END OF REPORT

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