MEASUREMENT OF PARTICULATE EMISSIONS FROM ARRESTMENT PLANT AT SARGINSONS PRECISION COMPONENTS, COVENTRY

Part 1 Executive Summary

Sampling on **15 June 2010**

Sampling at **Sarginsons Precision Components**
Torrington Avenue
Coventry
CV4 9AG

Report prepared for

Sarginsons Precision Components
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A1TPM	Total particulate matter		27
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Dry Arrestor Exhaust

A2FL	Flow		29
A2TPM	Total particulate matter	15 June 2010	33
A2H2O	Water vapour		37

SUMMARY

Sarginsons Precision Components placed a contract with Environmental Scientifics Group Limited (ESG) to undertake an assessment of emissions to atmosphere of particulate species from arrestment plant located at their Coventry site. Measurements were made in the exhausts serving the wet and dry arrestors on the 15 June 2010.

The following results were obtained for the required determinands:

Monitoring Results

Summary of Measurements of Particulate Releases

Permitted Releases – A1 Wet Arrestor

15 June 2010

Determinand	Reported as	Date	Time Start	Time End	Concentration	Emission Limit Value
Total particulate matter	TPM	15.06.10	1435	1540	6 ± 5 mg/m^3	50

Permitted Releases – Dry Arrestor

15 June 2010

Determinand	Reported as	Date	Time Start	Time End	Concentration	Emission Limit Value
Total particulate matter	TPM	15.06.10	1604	1704	4 ± 3 mg/m^3	-

All determinands reported above are expressed at plant reference conditions of 273 K temperature and 101.3 kPa pressure (Standard Temperature & Pressure (STP)) in a wet gas with no correction for oxygen content.

All measurements reported above are UKAS accredited to the MCERTs performance standard.

Monitoring Methods & Accreditation

Sampling Methodology and Accreditation

Sampling Methods

Determinand	Sampling method	Procedure No.
TPM	BS EN 13284-1 using EPA 5-type equipment	AE 104
Velocity	BS EN 13284-1 using a Pitot static tube	AE 122
O_2	BS EN 14789 (zirconium cell analyser)	IEM 002
H_2O	BS EN 14790	AE 105

Summary of Analytical Methods

Determinand	Analytical method	Analysis house
TPM	Gravimetric determination	ESG
H_2O	Gravimetric determination	ESG

A description of the sampling and analytical methods employed in the execution of the measurements reported herein is presented above. All sampling and associated analytical activities were undertaken by ESG.

Summary of UKAS and MCERTs Compliance

Determinand	Sampling		Analysis	
	UKAS Accreditation	MCERTs Compliant	UKAS Accreditation	MCERTs Compliant
TPM	1015	✓	1015	✓
Velocity	1015	✓	not applicable	
O_2	1015	✓	1015	✓
H_2O	1015	✓	1015	✓

Plant Operating Information

Exhaust Gas Measurements and Plant Operating Conditions

A1 - Wet Arrestor Exhaust

Date		**15 June 2010**
Exhaust gas characterisation information		
Test		**A1FL**
Time start		1400
Time end		1409
Velocity	m/s	9.8
Temperature	^{o}C	26
Flow	m^3/s, ref cond.	1.94
Oxygen	%, v/v, dry	20.8
Water vapour	% v/v	1.0

Dry Arrestor Exhaust

Date		**15 June 2010**
Exhaust gas characterisation information		
Test		**A2FL**
Time start		1500
Time end		1515
Velocity	m/s	18.4
Temperature	^{o}C	29
Flow	m^3/s, ref cond.	11.10
Oxygen	%, v/v, dry	20.8
Water vapour	% v/v	0.9

The plant serving the dry and wet arrestors were operating normally during the periods of sampling.

1. INTRODUCTION

Sarginsons Precision Components placed a contract with Environmental Scientifics Group Limited (ESG) to undertake an assessment of emissions to atmosphere of particulate species from arrestment plant exhausts at their Coventry site. Measurements were made at the following release points:

- A1 - Wet Arrestor exhaust
- A2 - Dry Arrestor exhaust

Measurements were made on the 15 June 2010. This report describes the test work undertaken.

The on-site testing of ducted emissions of gaseous and particulate species by ESG is covered by accreditation by the United Kingdom Accreditation Service (UKAS) under UKAS Testing Laboratory No. 1015. Section 3.3 and Table 4c specify the measurements that are within the scope of this accreditation.

The results of the measurements made are summarised in Tables 1a and 1b.

2. TEST PROGRAMME AND OBJECTIVES

The overall objective of this test programme was to provide measurements of releases to atmosphere of particulate species from two release points as part of Sarginson's obligations with regard to routine monitoring of releases to atmosphere.

Sarginsons Precision Components requested that the following determinands be measured:

1. Total particulate matter (TPM)

In addition, measurements of the following determinands were made to enable correction of measured concentrations of the above determinands to plant reference conditions:

2. Oxygen (O_2)
3. Water vapour (H_2O)

It was also requested that flow measurements (exhaust gas velocity and temperature) be undertaken during each sampling period as appropriate.

All of the above determinands were measured at the exhausts of the wet and dry arrestors.

Tables 2a and 2b summarise the test schedule.

Tables 3, 4a, 4b and 4c summarise the methods and resources employed in the execution of these measurements and their accreditation status with regard to UKAS and MCERTs.

3. METHODS OF MEASUREMENT

The methodology employed for the measurement of selected releases to atmosphere was agreed with Sarginsons Precision Components.

3.1 Measurements of Releases to Atmosphere

Sampling for total particulate matter was undertaken in accordance with the requirements of BS EN 13284-1[(1)] using United States Environmental Protection Agency (US EPA) Method 5-type sampling equipment. One determination was undertaken at each release point, each over a sampling period of around 60 minutes.

The waste gas concentration of oxygen was measured using a continuous zirconium cell oxygen analyser in accordance with BS EN 14789[(2)].

Measurements of the waste gas water vapour content were undertaken using a gravimetric technique in accordance with BS EN 14790[(3)]. One determination of water vapour was made at each release point. The result of the measurement was used to correct other, corresponding measurements, where appropriate, to plant reference conditions.

Measurements of the exhaust gas conditions (i.e. exhaust gas velocity and temperature) were undertaken at the beginning of testing at each point, and during testing, as appropriate. Measurement of the exhaust gas temperature was undertaken using a type K thermocouple and digital temperature indicator. Measurements of the exhaust gas velocity were made using an ellipsoidal ('L' type) Pitot static tube in conjunction with an inclined liquid manometer. Temperature and velocity traverses were undertaken as specified within BS EN 13284-1[(1)].

Tables 4a and 4b present a summary of the sampling and analysis methodology employed in the measurements described above.

3.2 Sampling Locations

At the sampling location associated with the wet arrestor exhaust (Figure 1), the sampling plane is of square cross section, of depth 0.47 m and sampling plane area 0.22 m^2. 2 off 4" BSP sockets (A & B) are available for sampling access.

BS EN 13284-1[(1)] requires that sampling be undertaken at a minimum of 4 points over a minimum of two sample lines for this geometry of sampling plane. Sampling for particulate matter was undertaken at two points on each of the two available lines in accordance with the requirements of the standard.

Sampling locations at the wet arrestor exhaust

Determinand	Sampling Socket	Sampling positions on line (fraction of depth, D)
TPM	A & B	0.25, 0.75
Oxygen	A	0.5
Water vapour	A & B	0.25, 0.75
Flow	A & B	0.05, 0.15, 0.25, 0.35, 0.45, 0.55, 0.65, 0.75, 0.85 & 0.95

At the dry arrestor exhaust, the sampling plane is of rectangular cross section, of depth 0.83 m and sampling plane area 0.68 m^2. 2 off 4" BSP sockets (A & B) are available for sampling access.

BS EN 13284-1[(1)] requires that sampling be undertaken at a minimum of 4 points over a minimum of two sample lines for this geometry of sampling plane. Due to the presence of baffles just below the sampling socket there was little indication of flow along line B. As such all sampling was restricted to the sampling line accessible through socket A. Sampling for particulate matter was undertaken at the required two points along line A only. This does not comply with the requirements of the standard.

Sampling locations at the dry arrestor exhaust

Determinand	Sampling Socket	Sampling positions on line (fraction of depth, D)
TPM	A	0.25 & 0.75
Oxygen	A	0.5
Water vapour	A	0.5
Flow	A	0.05, 0.15, 0.25, 0.35, 0.45, 0.55, 0.65, 0.75, 0.85 & 0.95

3.3 Accreditation of Measurements

The accreditation status of the measurements made under the UKAS scheme is summarised in Table 4c. Table 4c also summarises the MCERTs compliance status of the methodology employed.

All sampling and associated analytical activities were undertaken by ESG.

All measurements are UKAS accredited to the MCERTs performance standard.

4. RELEASES TO ATMOSPHERE

The results of the measurements made are summarised in Tables 1a and 1b and are reported in detail in the monitoring report forms (see Contents). In these tables measurements are reported at plant reference conditions of 273K temperature and 101.3 kPa pressure (Standard Temperature and Pressure (STP)) in a wet gas with no correction for oxygen content.

These tables also provide estimates of the discharge rate of each determinand and the measurement uncertainty expressed on a 95% confidence limit basis. It should be noted that discharge rates for all determinands are based on the volume flow rates measured at the beginning of testing.

Full details of all measurements made are presented in the monitoring report forms at the end of this report. Each determination has been given a unique reference number comprising two elements e.g. A1FL

Plant	**Determinand**
A1 Wet arrestor	FL Flow

A1TPM and A2TPM summarise the results of the measurements of total particulate matter at the wet arrestor and dry arrestor exhaust respectively. One determination was undertaken at each point. The result of each measurement is presented, together with the corresponding discharge rate.

A1FL and A2FL summarise the measurements of duct gas conditions (i.e. temperature, velocity and flow) made at the wet arrestor and dry arrestor exhausts respectively. Measurements were made at the beginning of testing.

5. RESULTS AND DISCUSSION

In the following discussion the compliance of the measurements with the requirements of the relevant standards is discussed, along with any issues affecting the representativeness of the measurements made. All emissions of particulate species are presented as a concentration at the applicable plant reference conditions unless otherwise stated.

5.1 Emissions from the wet arrestor exhaust

The results of the measurements made at the wet arrestor exhaust are summarised in Table 1a.

The measurement for total particulate matter complied fully with the main procedural requirements of BS EN 13284-1[(1)].

5.2 Emissions from the dry arrestor exhaust

The results of the measurements made at the dry arrestor exhaust are summarised in Table 1b.

As discussed in Section 3.2, the sampling positions employed did not comply fully with BS EN 13284-1[(1)].

With the exception of the failure to comply meet the sampling position requirements of BS EN 13284-1[(1)], the measurement for total particulate matter complied with the main procedural requirements of the standard.

It is not considered that the noted non-compliances had a significant impact on the representativeness of the measurements made. In all cases uncertainties have been adjusted, where appropriate, to take into account deviations from the requirements of the standard methods.

6. REFERENCES

1. BS EN 13284-1, 'Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual gravimetric method', 2002.

2. BS EN 14789:2005 - 'Stationary source emissions - Determination of volume concentration of oxygen (O_2) – Reference method: Paramagnetism', 16 January 2006

3. BS EN 14790:2005 - 'Stationary source emissions - Determination of the water vapour in ducts', 16 January 2006

TABLE 1a

Summary of Measurements of Particulate Releases

A1 - Wet arrestor exhaust – 15 June 2010

Determinand	Reported as	Test No. (A1)	Concentration		Release kg/h
Total particulate matter	TPM	TPM	6 ± 5	mg/m^3	0.04

Notes to Table 1a:

1. Waste gas concentrations are expressed at the standard reference conditions for this plant of STP in a wet gas with no correction for oxygen content. The measured average oxygen and water vapour contents were:

Date		15 June 2010
Oxygen	% by volume, dry	20.8
Water vapour	% by volume	1.0

These values have been employed to correct the measurements of required determinands to plant reference conditions.

2. Uncertainty is the likely range of the true value around the measured value and is determined in accordance with Internal Procedure 55 and the relevant uncertainty policies. These procedures follow the guidance in BS EN ISO 14956:2002 and ENV 13005 (GUM). For all determinands the uncertainty is expressed in the measurement units on a 95% confidence limit basis.

3. The reported concentration of oxygen is the arithmetic mean of all spot measurements made during the sampling period. The reported concentration of water vapour is the result of a single determination.

4. The measured exhaust gas conditions on the day of testing were:

Date Test		15 June 2010 A1FL
Time start		1400
Time end		1409
Velocity	m/s	9.8
Temperature	^oC	26
Flow	m^3/s, ref cond.	1.94

The above values have been used in the calculation of the discharge rates of measured determinands (see monitoring report forms).

TABLE 1b

Summary of Measurements of Particulate Releases

Dry arrestor exhaust – 15 June 2010

Determinand	Reported as	Test No. (A2)	Concentration		Release kg/h
Total particulate matter	TPM	TPM	4 ± 3	mg/m^3	0.15

Notes to Table 1b:

1. Waste gas concentrations are expressed at the standard reference conditions for this plant of STP in a wet gas with no correction for oxygen content. The measured average oxygen and water vapour contents were:

Date		15 June 2010
Oxygen	% by volume, dry	20.8
Water vapour	% by volume	0.9

These values have been employed to correct the measurements of required determinands to plant reference conditions.

2. Uncertainty is the likely range of the true value around the measured value and is determined in accordance with Internal Procedure 55 and the relevant uncertainty policies. These procedures follow the guidance in BS EN ISO 14956:2002 and ENV 13005 (GUM). For all determinands the uncertainty is expressed in the measurement units on a 95% confidence limit basis.

3. The reported concentration of oxygen is the arithmetic mean of all spot measurements made during the sampling period. The reported concentration of water vapour is the result of a single determination.

4. The measured exhaust gas conditions on the day of testing were:

Date Test		15 June 2010 A2FL
Time start		1500
Time end		1515
Velocity	m/s	18.4
Temperature	^oC	29
Flow	m^3/s, ref cond.	11.10

The above values have been used in the calculation of the discharge rates of measured determinands (see monitoring report forms).

TABLE 2a

Test Programme – A1 Wet arrestor exhaust

Determinand	Determination No.	Determination Code	Time Start	Time End	Duration (min)
15 June 2010					
Total particulate matter	1	A1TPM	1435	1540	60
Water vapour	1	A1H2O	1435	1507	32
Oxygen	1	-	1435	1540	60
Flow	1	A1FL	1400	1409	9

TABLE 2b

Test Programme – A2 Dry arrestor exhaust

Determinand	Determination No.	Determination Code	Time Start	Time End	Duration (min)
15 June 2010					
Total particulate matter	1	A2TPM	1604	1704	60
Water vapour	1	A2H2O	1625	1715	50
Oxygen	1	-	1604	1704	60
Flow	1	A2FL	1500	1515	15

1. The sampling time is the period over which the measurements were undertaken. The sampling duration is the actual period during the sampling time, for which the ducted gases were sampled.

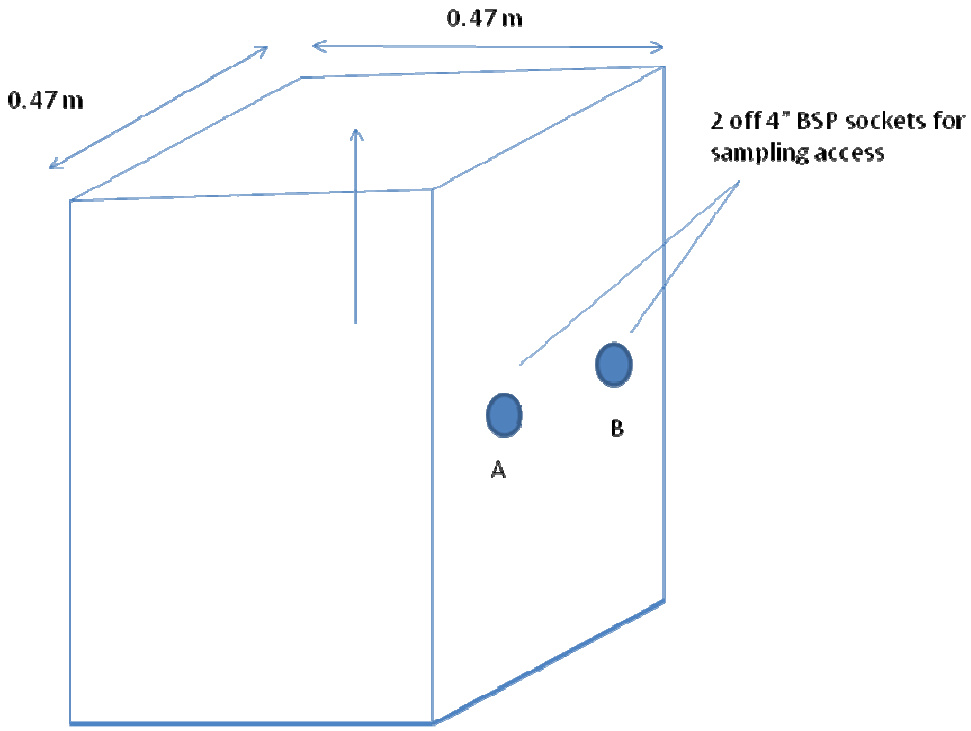

Figure 1 Sampling Positions (Wet arrestor (A1))

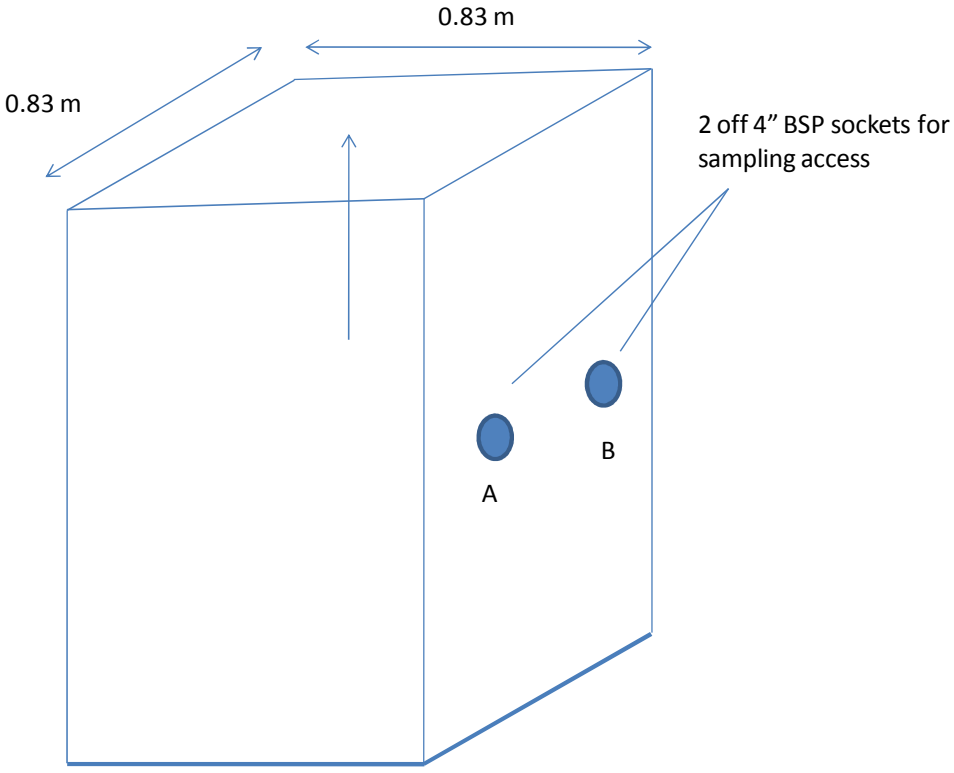

Figure 2 Sampling Positions (Dry arrestor (A2))

MEASUREMENT OF PARTICULATE EMISSIONS FROM ARRESTMENT PLANT AT SARGINSONS PRECISION COMPONENTS, COVENTRY

Part 2 Supporting Information

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Vantage Point Business Village
Mitcheldean
Gloucestershire
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TABLE 3

Summary of UKAS and MCERTs Compliance - Staff Competency

Function	Name	MM	Level	MCERTs Technical Endorsements			
				1	2	3	4
Divisional Manager	N Ford	**02084**	2	12/13	12/13	12/13	12/13
Operations Manager	M Davies	**02087**	2	03/13	06/13	06/13	08/13
Team leader	J Ward	**02080**	2	03/13	05/13	08/11	03/11
Technician	L Mears	**08995**	1		05/15		

1. The qualifications, under the MCERTs scheme, of all staff involved in the execution of the work reported herein are presented above.

TABLE 4a

Summary of Sampling Methods

Determinand	Sampling method	Procedure No.
TPM	BS EN 13284-1 using EPA 5-type equipment	AE 104
Velocity	BS EN 13284-1 using a Pitot static tube	AE 122
O_2	BS EN 14789 (zirconium cell analyser)	IEM 002
H_2O	BS EN 14790	AE105

TABLE 4b

Summary of Analytical Methods

Determinand	Analytical method	Analysis house
TPM	Gravimetric determination	ESG
H_2O	Gravimetric determination	ESG

1. A description of the sampling and analytical methods employed in the execution of the measurements reported herein is presented above. All sampling and associated analytical activities were undertaken by ESG.

TABLE 4c

Summary of UKAS and MCERTs Compliance - Sampling and Analytical Methods

Determinand	Sampling		Analysis	
	UKAS Accreditation	MCERTs Compliant	UKAS Accreditation	MCERTs Compliant
TPM	1015	✓	1015	✓
Velocity	1015	✓	not applicable	
O_2	1015	✓	1015	✓
H_2O	1015	✓	1015	✓

1. The above table provides details of the UKAS accreditation status and compliance with the requirements of MCERTs for the work reported herein.

2. Where an activity is UKAS accredited the accreditation number of the laboratory is provided. Where an activity is not accredited this is marked as ‘not accredited’. Where a measurement has a sampling and an analytical component, UKAS accreditation only applies if both activities are accredited.

3. An activity is determined to comply with the requirements of MCERTs where the laboratories involved have UKAS accreditation to the MCERTs performance standard for the method employed.

SCIENTIFICS MONITORING REPORT FORM
PITOT TRAVERSE (BS EN 13284-1)

Company	Sarginsons	Date	15-Jun-10
Site	Coventry	Test Ref	A1FL
Sample point	A1 - Wet Arrestor	Time Start	1400
Test carried out by	J Ward & L Mears	Time End	1409

SAMPLING PLANE GEOMETRY

Geometry of duct		Rectangular
Dimension traversed by sampling probe (D)	m	0.47
Other dimension (if applicable)	m	0.4700
Cross sectional area of sampling plane (A)	m^2	0.2209

MOLECULAR WEIGHT & DENSITY DETERMINATION

Duct gas conditions

Ambient temperature (T_a)	°C	22.00
Duct static gas pressure	kPa	0.00
Average duct gas temperature (T_{duct})	°C	26.00
Barometric pressure (P_m)	kPa	99.40

Calculation of molecular weight from assumed gas composition

Gas	Vol% Dry gas	Vol% Wet gas	Dry Mol Wt g/gmole	Wet Mol Wt g/gmole
CO_2	0.00	0.00	0.00	0.00
O_2	20.80	20.59	6.66	6.59
CO	0.00	0.00	0.00	0.00
N_2	79.20	78.39	22.18	21.95
H_2O	---------	1.02	---------	0.18
		Total	28.83	28.72

Calculation of dry and wet gas density from molecular weight results

Dry density	kg/m^3	1.29	At STP
Wet density	kg/m^3	1.28	(0°C & 101.3 kPa)
Dry density	kg/m^3	1.15	At Duct Conditions
Wet density (ρ_a)	kg/m^3	1.15	(see above)
Wet specific gravity (sg)		0.99	

Calculation of dew point

Sulphur dioxide concentration	ppm	0
Water dew point	°C	8
Sulphuric acid dew point	°C	n.a.

Compliance with BS EN 13284-1, 5.2

No negative local gas flow
Ratio of highest to lowest flow is less than 3:1
Minimum Pitot static reading is greater than 5 Pa
Angle of gas flow with respect to the axis is below 15 degrees

PITOT TRAVERSE

Details of measurement equipment and supplementary measurements

Manometer calibration temperature °C	17
Scale factor	0.1
Pitot type ('L' or 'S' type)	L
Pitot calibration factor (C_p)	1
Pitot reference No.	P1402
Manometer units	kPa
Manometer reference No.	P1229
Thermocouple reference No.	P1627
Timer reference No.	P1153
Barometric gauge reference No.	P154
Temperature correction factor	-0.00475

Measurement strategy

No. of measurement lines	2

Measurements and calculation of duct gas velocity

Traverse Point	Port	Distance from inside wall of duct (fraction of D, (m))	Scale Pitot Reading kPa	Differential Pressure (h_c) Pa	emperature (T_{duct}) °C	$\sqrt{h_c}$	Angle of gas flow <15°	Gas Velocity (V_{duct}) m/s
1	A	0.05 (0.024)	1.01	100.52	26	10.03	Yes	13.16
2	A	0.15 (0.071)	0.94	93.55	26	9.67	Yes	12.70
3	A	0.25 (0.118)	0.55	54.74	26	7.40	Yes	9.71
4	A	0.35 (0.165)	0.36	35.83	26	5.99	Yes	7.86
5	A	0.45 (0.212)	0.30	29.86	26	5.46	Yes	7.17
6	A	0.55 (0.259)	0.13	12.94	26	3.60	Yes	4.72
7	A	0.65 (0.306)	0.18	17.91	26	4.23	Yes	5.56
8	A	0.75 (0.353)	0.41	40.81	26	6.39	Yes	8.39
9	A	0.85 (0.4)	0.67	66.68	26	8.17	Yes	10.72
10	A	0.95 (0.447)	0.98	97.53	26	9.88	Yes	12.97
11	B	0.05 (0.024)	0.57	56.73	26	7.53	Yes	9.89
12	B	0.15 (0.071)	0.69	68.67	26	8.29	Yes	10.88
13	B	0.25 (0.118)	0.71	70.66	26	8.41	Yes	11.04
14	B	0.35 (0.165)	0.68	67.68	26	8.23	Yes	10.80
15	B	0.45 (0.212)	0.73	72.65	26	8.52	Yes	11.19
16	B	0.55 (0.259)	0.64	63.70	26	7.98	Yes	10.48
17	B	0.65 (0.306)	0.65	64.69	26	8.04	Yes	10.56
18	B	0.75 (0.353)	0.60	59.72	26	7.73	Yes	10.15
19	B	0.85 (0.4)	0.54	53.74	26	7.33	Yes	9.62
20	B	0.95 (0.447)	0.40	39.81	26	6.31	Yes	8.28
					T_{Duct}	$\sqrt{h_c}$		
			Averages		26.00	7.46		

CALCULATION OF VELOCITY & FLOW RATE

$V_{Duct} = C_p \times (1-\varepsilon) \times \sqrt{2/\rho_a} \times \sqrt{h}$ (Reference BS 1042:Section 2.1:1983 (ISO 3966), pages 8&9)

where
- V_{Duct} = gas velocity at sampling point (m/s)
- K_{pt} = pitot calibration factor (dimensionless)
- $1-\varepsilon$ = compressibility correction (assumed constant at 0.995)
- ρ_a = wet gas density under duct conditions (kg/m^3)
- h = differential pressure (Pa)

Average gas velocity (V_{Ducta}) = **9.79 ± 1.00** m/s

Average volume flowrate (Q_{Duct}) = $V_{Ducta} \times A$

= **2.16 ± 0.23** m^3/s

Conversion of actual duct gas flow to reference conditions

Actual Duct Flow Conditions			Reference Conditions		
Average temperature (T_{duct})	°C	26.00	Temperature (T_{Ref})	°C	0
Total pressure (P_{duct})	kPa	99.40	Pressure (P_{Ref})	kPa	101.3
Oxygen (O_{2duct})	% vol,dry	20.80	Oxygen (O_{2Ref})	% vol, dry	20.8
Water vapour (H_2Od_{uct})	% vol	1.02	Water vapour (H_2O_{Ref})	% vol	1.02

Calculation of gas flowrate at STP, Q_{STP}

$Q_{STP} = Q_{duct} \times [(273 \times P_{duct})/(101.3 \times (273 + T_{duct}))]$

Q_{STP} = **1.94 ± 0.21** m^3/s

Calculation of gas flow at reference conditions, Q_{Ref}

Q_{Ref}	=	Q_{duct} ×	$[273 + T_{Ref}]/[273 + T_{duct}]$	Corrections Temperature
			P_{duct}/P_{Ref}	Pressure
			$[100-H_2O_{duct}]/[100-H_2O_{Ref}]$	Water vapour
			$[20.9-O_{2duct}]/[20.9-O_{2Ref}]$	Oxygen

Q_{Ref} = **1.94 ± 0.21** m^3/s

Measurements from other tests

Determinand	Test Reference
Oxygen	Spots - Horiba P1089
Water vapour	A2H20

Uncertainty Calculation Parameters

Standard uncertainty for pressure measurement (U12)	5.0 %
Standard uncertainty for Pitot coefficient (U13)	1.0 %
Standard uncertainty for density estimate (U13)	1.0 %
Standard uncertainty for linear measurement (U14)	1.0 %

Uncertainty budget

Uncertainties		
Pressure measurement (m_p)	%	5.00
Pitot coefficicient (m_K)	%	1.00
Gas density estimate (m_r)	%	1.00
Total for velocity measurement (U_v)	%	5.20
Velocity at 95% confidence interval (U_{v95})	%	10.18
Linear measurement (m_l)	%	1.00
Total for flowrate measurement (U_f)	%	5.49
Flow rate at 95% confidence interval (U_{f95})	%	10.76

Based on Procedure 55 and Uncertainty Policies 13 & 14
(in accordance with requirements of BS EN ISO 14956:2002 and ENV 13005 (GUM))

$U_v = \sqrt{m_p^2 + m_K^2 + m_r^2}$
$U_{v95} = 1.96 \times U_v$
$U_f = \sqrt{U_v^2 + 2m_l^2}$
$U_{f95c} = 1.96 \times U_f$

Prepared by: J Ward **Checked by:** L Mears

CALCULATION OF NOZZLE SIZE & K FACTOR

Exhaust & sample gas conditions

Desired sampling rate at orifice (SR_o)	21.2 l/min	0.749 ft^3/min
Expected meter outlet temperature (T_m)	20 °C	

(guide is a sampling rate of 0.75 ft^3/min or 21.2 l/min at the orifice)

Conditions at nozzle		Conditions at orifice/meter	
Sampling rate (SR_n)	21.86 l/min	Sampling rate (SR_o)	21.20 l/min
Temperature (T_{duct})	26.00 °C	Temperature (T_a)	20.00 °C
Pressure (P_{duct})	99.40 kPa	Pressure (P_m)	99.40 kPa
Water vapour (H_2O_{duct}	1.02 %	Water vapour (H_2O_m)	0 %
Molecular weight (M_{duct})	28.72	Molecular weight (M_m)	28.83

Orifice Parameters

Orifice plate coefficient ($\Delta H_@$)	2.3847 " w.g.

Determination of nozzle diameter

based on isokinetic sampling and the average gas velocity

$D_{nr} = 2000 \times \sqrt{[SR_n / V_{duct} \times \pi \times 60000]}$

where D_{nr} is the recommended nozzle diameter (mm)

Recommended nozzle diameter (D_{nr}	=	6.882 mm
Diameter of nozzle selected (D_n)	=	6 mm

Determination of K Factor

based on preliminary exhaust gas conditions

K Factor is a proportionality factor relating the pressure drop measured with the Pitot tube in the duct (h) with the corresponding pressure drop at the orifice (ΔH), i.e.

$\Delta H = K * h$

$K = 8.038 \times 10^{-5} \times C_p^2 \times \Delta H_@ \times D_n^4 \times (M_m/M_{duct}) \times [(100-H_2O_{duct})/(100-H_2O_m)]^2 . (T_m+273/T_{duct}+273).(P_{duct}/P_m)$

where $\Delta H_@$ is the orifice plate coefficient (mm w.g.)

K Factor	=	*6.0811*
K Factor$_I$ (independent of C_p)	=	6.0811

SCIENTIFICS MONITORING REPORT FORM
TOTAL PARTICULATE MATTER to BS EN 13284-1/BS ISO 9096

Company	Sarginsons	Test Ref	A1TPM
Site	Coventry		
Sample point	A1 - Wet Arrestor		
Test carried out by	J Ward & L Mears		

SAMPLING TIMES

Determination		TPM
Date		15-Jun-10
Time Start		1435
Time End		1540
Duration (t)	min	60

Sampling plane

Dimension traversed by sampling probe (D)	m	0.47
Cross sectional area of sampling plane (A)	m^2	0.22

Duct gas conditions

Determination		TPM
Ambient temperature (T_{Amb})	°C	22.0
Average duct gas temperature (T_{duct})	°C	26.0
Duct static gas pressure (P_{Static})	kPa	0.00
Barometric pressure (P_{Baro})	kPa	99.40
Volume flow rate @ ref. conditions (Q_{Ref})	m^3/s	1.94
Gas compressibility correction (ε)		0.995
Wet gas density (ρ_a)		1.15
Exhaust gas conditions measurements		A1FL

Reference conditions

Determination		TPM
Actual Duct Flow Conditions		
Average temperature (T_{duct})	°C	26.0
Total pressure (P_{duct})	kPa	99.40
Oxygen (O_{2duct})	%vol,dry	20.80
Water vapour (H_2O_{duct})	%vol	1.02
Reference Conditions		
Temperature (T_{Ref})	°C	0
Pressure (P_{Ref})	kPa	101.3
Oxygen (O_{2Ref})	%vol, dry	20.8
Water vapour (H_2O_{Ref})	%vol	1.02

Sampling conditions

Determination				TPM
Nozzle diameter (d)	Ti18	Titanium	mm	6.000
Initial gas meter reading			m^3	7.807
Final gas meter reading			m^3	8.805
Sampled volume (SV_M)			m^3	0.998

Calculation of sample gas volume at reference conditions, SV_{Ref}

$$SV_{Ref} = SV_{Meter} \times \gamma \times [273 + T_{Ref}]/[273 + T_{Meter}] \times P_{Baro}/P_{Ref} \times [100-H_2O_{Meter}]/[100-H_2O_{Ref}] \times [20.9-O_{2Duct}]/[20.9-O_{2Ref}]$$

Corrections
Temperature
Pressure
Water vapour
Oxygen

Determination		TPM
Sampled volume @ ref. conditions (SV_{Ref})	m^3	0.933

Prepared by: J Ward **Checked by:** L Mears

SAMPLING DATA TPM

Test Ref A1TPM

Initial gas meter reading 7807 l Start Time 1435

Distance from Duct Wall Fraction of D	Port	Time of Day h:mm	Run time mm	Gas meter reading l	Pitot Reading (h) cm w.g.	Orifice ΔH cm w.g. Desired (ΔH_d) =h x K_f x Cp^2	Orifice ΔH cm w.g. Actual (ΔH_a)	Isokinetic difference ($\Delta H_a/\Delta H_d$) %	Temperatures Gas (T_{duct}) °C	Probe (T_p) °C	Filter (T_f) °C	Meter (T_M) Inlet °C	Meter (T_M) Outlet °C	Impinger (T_{imp}) °C	Oxygen Content %, v/v, dry
0.250	A	1435	0	7807	0.8	3.43	3.4	99	26	26	26	21	21	n/a	20.8
		1440	5	7901	0.92	3.95	3.8	96	26	26	26	21	21	n/a	20.8
		1445	10	7997	0.96	4.12	4	97	26	26	26	21	21	n/a	20.8
0.750	B	1450	15	8103	0.42	1.80	1.8	100	26	26	26	21	21	n/a	
		1455	20	8154	0.48	2.06	2	97	26	26	26	22	21	n/a	20.8
		1500	25	8213	0.46	1.97	2	101	26	26	26	22	21	n/a	
0.250	A	1510	30	8282	0.8	3.43	3.4	99	26	26	26	22	21	n/a	20.8
		1515	35	8372	0.78	3.35	3.2	96	26	26	26	23	21	n/a	
		1520	40	8462	0.8	3.43	3.4	99	26	26	26	23	22	n/a	20.8
0.750	B	1525	45	8552	0.82	3.52	3.4	97	26	26	26	23	21	n/a	
		1530	50	8633	0.8	3.43	3.4	99	26	26	26	23	22	n/a	20.8
		1535	55	8718	0.8	3.43	3.4	99	26	26	26	24	22	n/a	
		1540	60	8805											
	Averages								26.0	26.0	26.0	21.6		#DIV/0!	20.8

Final gas meter reading 8805 l End Time 1540

Equipment used

Item	File No.
Control box	P1268
Meter coefficient (γ)	1.017
K factor, (K_n independent of C_p)	6.081
Orifice plate pressure units	cm w.g.
Pitot differential pressure units	cm w.g.
Pitot	S Type
Pitot coefficient (C_p)	0.84
Probe liner thermocouple Titanium	N/A
Duct gas thermocouple	P1287
Oven thermocouple	N/A
Impinger exit thermocouple	N/A
Timer	P733

Approach to isokinetic sampling

Average gas velocity (V_{duct})	9.3 m/s
Nozzle diameter (D_n)	6.000 mm
Sampling time (t)	60 min
Theoretical isokinetic sample volume SV_t	946.80 l
Actual sample volume (SV_a)	1040.96 l
Approach to isokinetic sampling (ΔI)	109.9 %

where Vduct is the average duct velocity based on the above measurements

$V_{Duct} = C_p \times (1- \varepsilon) \times \sqrt{2/\rho_a} \times \sqrt{h}$ **(Reference BS 1042:Section 2.1:1983 (ISO 3966), pages 8&9)**

SV_t is the theoretical isokinetic sample volume based on V_{duct} & D_n

$SV_t = V_{duct} \times \pi \times [D_n/2000]^2 \times t \times 60 \times 1000$

SV_a is the sample volume at duct conditions

$SV_a = SV_m \times \gamma \times [(273 + T_{duct})/(273 + T_m)] \times (P_{Baro}/P_{duct}) \times (100 - H_2O_m)/(100-H_2O_{duct})$

Leak check

		Start	End
Start Time		1425	1544
End Time		1427	1546
Initial meter reading	m^3	7.8066	8.8054
Final meter reading	m^3	7.807	8.8056
Duration of leak test	min	2	2
Pump vacuum	"Hg	-15	-15
Leak rate	l/min	0.2	0.1
Less than 2% of normal sampling rate?		Yes	Yes

Determination of exhaust gas flow rate

based on measurements at sample points only

Flow rate at duct conditions (Q_{duct})	2.05 m^3/s
Flow rate at STP (Q_{STP})	1.84 m^3/s
Flow rate at reference conditions (Q_{Ref})	1.84 m^3/s

where

$Q_{duct} = V_{duct} \times A$

$Q_{STP} = Q_{duct} \times [(T_{Ref} + 273)/(T_{duct} + 273)] \times (P_{Baro}/P_{Ref})$

$Q_{Ref} = Q_{STP} \times [(20.9-O_{2Ref})/(20.9-O_{2duct})] \times [(100-H_2O_{duct})/(100-H_2O_{Ref})]$

Glassware

Clean	Yes	Date	15.06.10	Prepared by	LM

SAMPLE LOG

Determination	Method blank	Field blank	Sample
Particulate phase			
Filter No.		02671	02668
Rinsings No.		02671W	02668W
Vapour phase (if collected)			
First stage	No.		
	Volume (ml)		
	Type		
Final stage	No.		
	Volume (ml)		
	Type		

PARTICULATE WEIGHINGS

Test Ref A1TPM

Filters

Determination		Method Blank	Field Blank	TPM
Filter No.		0	02671	02668
Pre-sampling conditioning temperature (±5°C)	°C	180	180	180
Post-sampling conditioning temperature (±5°C)	°C	160	160	160
Diameter	mm	110	110	110
Material		Quartz	Quartz	Quartz
Pre-sampling weights				
after 1 min	g		0.0403	0.0407
after 2 min	g		0.0402	0.0407
after 3 min	g		0.0402	0.0407
Weight extrapolated to zero time (M_{fi0})	g		0.0403	0.0407
Post-sampling weights				
after 1 min	g		0.0403	0.0435
after 2 min	g		0.0403	0.0435
after 3 min	g		0.0403	0.0434
Weight extrapolated to zero time (M_{ff0})	g		0.0403	0.0436

Rinsings

Pre-sampling conditioning temperature (±5°C)	°C	180	180	180
Post-sampling conditioning temperature (±5°C)	°C	160	160	160
Pre-sampling weights (container only)				
after 1 min	g		67.9122	70.3615
after 2 min	g		67.9121	70.3615
after 3 min	g		67.9121	70.3615
Weight extrapolated to zero time (M_{ri0})	g		67.9122	70.3615
Post-sampling weights (container and evaporated rinsings)				
after 1 min	g		67.9136	70.3642
after 2 min	g		67.9135	70.3642
after 3 min	g		67.9134	70.3642
Weight extrapolated to zero time (M_{rf0})	g		67.9137	70.3642

Summary

Determination		Method Blank (M_{mb})	Field Blank	TPM
Mass collected on filter (M_f = (M_{ff0}- M_{fi0}- M_{fmb}))	g	0.0000	0.0000	0.0029
Mass collected in rinsings (M_r = (M_{rf0}-M_{ri0}-M_{rmb}))	g	0.0000	0.0015	0.0027
Total mass collected (M = M_f + M_r)	g	0.0000	0.0014	0.0056

Uncertainty Calculation Parameters

Standard uncertainty for gas volume measurement (U6)	2.9 %
Standard uncertainty for filter weighing (U17)	0.57 mg
Standard uncertainty for washings weighing (U17)	0.50 mg
Limit of detection for filter weighing (U17)	0.50 mg
Limit of detecion for washings weighing (U17)	0.50 mg
Standard uncertainty for oxygen correction (U11)	0.95 %
Standard uncertainty for gas flow measurement (U14)	5.7 %

Emission Limit Value

Emission limit value (ELV) at reference conditions	50 mg/m^3

SUMMARY OF MEASUREMENTS

Test Ref A1TPM

Calculation of Particulate Concentration and Discharge Rate

Particulate concentration (C), mg/m^3 = M x 1000/ SV_{Ref}

Discharge rate, kg/h = C x Q_{Ref} x 0.0036

Determination		Field Blank	TPM
Particulate concentration at reference conditions	mg/m^3	1.54	5.97
Uncertainty	mg/m^3	1.54	4.89
Particulate concentration at duct conditions (raw)	mg/m^3	1.38	5.35
Particulate discharge rate	kg/h	0.01	0.04
Uncertainty	kg/h	0.01	0.03

Note: Field blank results based on average sampling conditions

Uncertainty budget

Uncertainties		Field Blank	TPM
Volume measurement (m_{vol})	mg	0.04	0.16
Filter weighings (m_f)	mg	-0.03	1.66
Rinsings weighings (m_w)	mg	1.26	1.62
Total for uncorrected measurement (U_u)	mg	1.26	2.33
Correction to reference conditions (m_{corr})	mg	0.00	0.00
Total for corrected measurement (U_c)	mg	1.26	2.33
Concentration at 95% confidence interval (U_{95c})	mg/m^3	1.54	4.89

Based on Procedure 55 and Uncertainty Policies 11 & 17
(in accordance with requirements of BS EN ISO 14956:2002 and ENV 13005 (GUM))

$U_u = \sqrt{m_{vol}^2 + m_f^2 + m_w^2}$

$U_c = \sqrt{U_u^2 + m_{corr}^2}$

$U_{95c} = 1.96 \times U_c / SV_{Ref}$

COMPLIANCE WITH BS EN 13284-1:2002/BS ISO 9096 CONDITIONS

Flow conditions (BS EN 13284-1, 5.2 & BS ISO 9096, 5.3)

Standard	EN 13284-1
Angle of gas flow less than 15°	Yes
No local negative gas flow	Yes
Minimum differential pressure greater than 5 Pa	Yes
Ratio of highest to lowest local gas velocites less than 3:1	Yes

Compliance with BS EN 13284-1

Blank value is less than 10% of ELV (Clause 4f)
Nozzle diameter greater than 6 mm (Clause 6.2.4)
Average sampling rate was within -5% and +15% of isokinetic conditions (Clause 8.4)
Leak rate is within 2% of sample rate (Clause 8.4)

SCIENTIFICS MONITORING REPORT FORM
WATER VAPOUR DETERMINATION to BS EN 14790:2005

Company	Sarginsons	Test Ref	A1H20
Site	Coventry	Date	15-Jun-10
Sample point	A1 - Wet Arrestor	Time start	1435
Test carried out by	L Mears & J Ward	Time End	1507
		Duration, t (min)	32

Sampling Rate

Gas meter start reading (SV_{MI})	l	40683.7500
Gas meter end reading (SV_{MI})	l	40733.6600
Volume passed at meter conditions ($SV_M=SV_{MI}-SV_{MI}$))	m^3	0.0499
Sampling rate at meter conditions (SVM/t)	m^3/min	0.0016

Sampling Conditions

Time	Gas Meter		Probe/heated line
	Temperature T_M, °C	Pressure P_M, kPa	temperature °C
1440	19.0	99.4	n/a
1507	20.0	99.4	n/a
Average	19.5	99.4	#DIV/0!

Equipment

Gas meter	P496
Gas meter calibration factor	1.0006
Probe/heated line thermocouple	n/a
Barometer	P154
Timer	P733
Balance	P1244

Leak check

		Start	End
Time start		14:31	15:08
Time end		14:32	15:09
Start volume	l	40680.100	40733.660
End volume	l	40680.120	40733.670
Duration	mins	1	1
Leak rate	l/min	0.02	0.01
Leak rate <2% of sample rate?		Yes	Yes

Balance Check Weighings

Balance No.	P1244		
Check weight no.	P1244	P1244	P1244
Certified weight	1000.0000	1000.0000	1000.0000
Reading (g)	1000.0500	1000.0500	1000.0500
Allowable tolerance (g)	1.0000	1.0000	1.0000
Acceptable response	Yes	Yes	Yes

Test Ref. A1H20

Collection of Water from Gas

Collection Stage (ci)	Initial Mass(Mci_i) g	Final Mass (Mci_f) g	Mass gain (Mci) g
Container 1	59.950	60.310	0.360
Container 2	46.520	46.540	0.020
Container 3	44.370	44.370	0.000
Container 4			
Container 5			
Container 6			
Total (M)	150.840	151.220	0.380

Mass of water collected (M) = $\Sigma(Mc1_f\text{-}Mc1_i)....(Mci_f\text{-}Mci_i)$

Calculation of dry gas sample volume at STP (SV_{STP})

SV_{STP} = $SV_M \times (273/(273 + T_M) \times (P_M/101.3)$

Volume of dry gas sampled at STP (SV_{STP})	m^3	0.0457

Calculation of water vapour content (H_2O_{duct})

H_2O_{duct} = $100 \times (M \times MV_{STP}/MW_{H2O})/[SV_{STP} + (M \times MV_{STP}/MW_{H2O})]$

where
MV_{STP} molecular volume at STP (22.412 m^3/kgmole)
MW_{H2O} molecular weight of water (18 kg/kgmole)

Water vapour content (H_2O_{duct})	%	1.02	±	1.02

Method performance

Water collection efficiency (ε=100-(Mci.100/M))	%	100.0
Water content in final container	%	0.0
Correction for collection efficiency ($Corr_\varepsilon$)	%	0.0

Compliance with BS 14790

Uncertainty greater than 20% of measured value Clause 7.3) - outside standard
Temperature at outlet is less than 4oC based on calculated dew point (Clause 6.4.2)
Leak rate is greater than 2% of sample flow rate (Clause 6.3) - outside standard
Sampling duration is within minimum of 30 minutes (Clause 6.1)
Sample volume is below minimum of 50 l (Clause 6.1) - outside standard
Residual water content at outlet is below 1.25% (Clause 5.8)
Sampling temperature fell below minimum of 120oC (Clause 5.2) - outside standard

Uncertainty Budget (based on BS 14790 and Uncertainty Policy U25)

Volume of sampled gas	V	0.046 m^3
Average temperature of gas at meter	T	19.5 °C
Average barometric pressure at meter	P	994 mb
Sampling line leakage		0.015 m^3/min
Duration of sampling	t	32 min
Total mass weighed	M	151.22 g

Source of uncertainty		Value		Value of standard uncertainty		Relative standard uncertainty (%)	
Measurement of sample gas volume	u_r,V_m	2.0 %	u_v	$u_s,V_m = \frac{u_v V}{\sqrt{3}}$	0.0005 m^3	u_r,V_m	1.15
Measurement of sample gas temperature	u_r,T_m	1.0 %	u_t	$u_s,T_m = \frac{u_t(T+273)}{\sqrt{3}}$	1.6887 K	u_r,T_m	0.58
Measurement of absolute pressure	u_r,P_m	1.0 %	u_p	$u_s,P_m = \frac{u_p P}{\sqrt{3}}$	5.7389 mb	u_r,P_m	0.58
Leakage in sampling line	u_r,L	961.7 %	u_l	$u_s,L = \frac{u_l V}{\sqrt{3}}$	0.2540 m^3	u_r,L	555.26
Measurement of weight - balance uncertainty	u_r,W_m	0.01 %	u_{wm}	$u_s,W_m = \frac{u_{wm} M}{\sqrt{3}}$	0.0087 g		-
Measurement of weight - balance repeatability	u_r,W_r	0.011 g	u_{wr}	$u_s,W_r = u_{wr}$	0.0110 g		-
Total measurement of weight	u_r,W	-	-	$u_s,W =$	0.0197 g	u_r,W	5.19

Total standard relative uncertainty	$u_r = \sqrt{u_r,V_m^2 + u_r,T_m^2 + u_r,P_m^2 + u_r,L^2 + u_r,W^2 + Corr_\varepsilon}$	555.28 %
Total relative uncertainty	$U_r = 1.96 u_r$	100.00 %

Prepared by: L Mears **Checked by:** J Ward

SCIENTIFICS MONITORING REPORT FORM
PITOT TRAVERSE (BS EN 13284-1)

Company	Sarginsons	Date	15-Jun-10
Site	Coventry	Test Ref	A2FL
Sample point	A2 - Dry Arrestor	Time Start	1500
Test carried out by	J Ward & L Mears	Time End	1515

SAMPLING PLANE GEOMETRY

Geometry of duct		Rectangular
Dimension traversed by sampling probe (D)	m	0.83
Other dimension (if applicable)	m	0.8250
Cross sectional area of sampling plane (A)	m^2	0.6806

MOLECULAR WEIGHT & DENSITY DETERMINATION

Duct gas conditions

Ambient temperature (T_a)	°C	22.00
Duct static gas pressure	kPa	-0.08
Average duct gas temperature (T_{duct})	°C	29.00
Barometric pressure (P_m)	kPa	99.40

Calculation of molecular weight from assumed gas composition

Gas	Vol% Dry gas	Vol% Wet gas	Dry Mol Wt g/gmole	Wet Mol Wt g/gmole
CO_2	0.00	0.00	0.00	0.00
O_2	20.80	20.62	6.66	6.60
CO	0.00	0.00	0.00	0.00
N_2	79.20	78.53	22.18	21.99
H_2O	---------	0.85	---------	0.15
		Total	28.83	28.74

Calculation of dry and wet gas density from molecular weight results

Dry density	kg/m^3	1.29	At STP
Wet density	kg/m^3	1.28	(0°C & 101.3 kPa)
Dry density	kg/m^3	1.14	At Duct Conditions
Wet density (ρ_a)	kg/m^3	1.14	(see above)
Wet specific gravity (sg)		0.99	

Calculation of dew point

Sulphur dioxide concentration	ppm	0
Water dew point	°C	8
Sulphuric acid dew point	°C	n.a.

Compliance with BS EN 13284-1, 5.2

No negative local gas flow
Ratio of highest to lowest flow is less than 3:1
Minimum Pitot static reading is greater than 5 Pa
Angle of gas flow with respect to the axis is below 15 degrees

PITOT TRAVERSE

Details of measurement equipment and supplementary measurements

Manometer calibration temperature °C	17
Scale factor	0.1
Pitot type ('L' or 'S' type)	L
Pitot calibration factor (C_p)	1
Pitot reference No.	P1402
Manometer units	kPa
Manometer reference No.	P1229
Thermocouple reference No.	P1627
Timer reference No.	P1153
Barometric gauge reference No.	P154
Temperature correction factor	-0.00475

Measurement strategy

No. of measurement lines	1

Measurements and calculation of duct gas velocity

Traverse Point	Port	Distance from inside wall of duct (fraction of D, (m))	Scale Pitot Reading kPa	Differential Pressure (h_c) Pa	Temperature (T_{duct}) °C	$\sqrt{h_c}$	Angle of gas flow <15°	Gas Velocity (V_{duct}) m/s
1	A	0.05 (0.041)	2.03	202.04	29	14.21	Yes	18.76
2	A	0.15 (0.124)	1.95	194.07	29	13.93	Yes	18.38
3	A	0.25 (0.206)	2.08	207.01	29	14.39	Yes	18.99
4	A	0.35 (0.289)	2.00	199.05	29	14.11	Yes	18.62
5	A	0.45 (0.371)	1.98	197.06	29	14.04	Yes	18.52
6	A	0.55 (0.454)	1.90	189.10	29	13.75	Yes	18.15
7	A	0.65 (0.536)	1.85	184.12	29	13.57	Yes	17.91
8	A	0.75 (0.619)	1.70	169.19	29	13.01	Yes	17.16
9	A	0.85 (0.701)	2.00	199.05	29	14.11	Yes	18.62
10	A	0.95 (0.784)	2.05	204.03	29	14.28	Yes	18.85
					T_{Duct}	$\sqrt{h_c}$		
			Averages		29.00	13.94		

CALCULATION OF VELOCITY & FLOW RATE

$V_{Duct} = C_p \times (1-\varepsilon) \times \sqrt{2/\rho_a} \times \sqrt{h}$ (Reference BS 1042:Section 2.1:1983 (ISO 3966), pages 8&9)

where
- V_{Duct} = gas velocity at sampling point (m/s)
- K_{pt} = pitot calibration factor (dimensionless)
- $1-\varepsilon$ = compressibility correction (assumed constant at 0.995)
- ρ_a = wet gas density under duct conditions (kg/m^3)
- h = differential pressure (Pa)

Average gas velocity (V_{Ducta}) = 18.39 ± 1.87 m/s

Average volume flowrate (Q_{Duct}) = V_{Ducta} x A

= 12.52 ± 1.35 m^3/s

Conversion of actual duct gas flow to reference conditions

Actual Duct Flow Conditions			Reference Conditions		
Average temperature (T_{duct})	°C	29.00	Temperature (T_{Ref})	°C	0
Total pressure (P_{duct})	kPa	99.32	Pressure (P_{Ref})	kPa	101.3
Oxygen (O_{2duct})	% vol,dry	20.80	Oxygen (O_{2Ref})	% vol, dry	20.8
Water vapour (H_2O_{duct})	% vol	0.85	Water vapour (H_2O_{Ref})	% vol	0.85

Calculation of gas flowrate at STP, Q_{STP}

$Q_{STP} = Q_{duct} \times [(273 \times P_{duct})/(101.3 \times (273 + T_{duct}))]$

Q_{STP} = 11.10 ± 1.19 m^3/s

Calculation of gas flow at reference conditions, Q_{Ref}

Q_{Ref}	=	Q_{duct} x	$[273 + T_{Ref}]/[273 + T_{duct}]$	Corrections Temperature
			P_{duct}/P_{Ref}	Pressure
			$[100-H_2O_{duct}]/[100-H_2O_{Ref}]$	Water vapour
			$[20.9-O_{2duct}]/[20.9-O_{2Ref}]$	Oxygen

Q_{Ref} = 11.10 ± 1.19 m^3/s

Measurements from other tests

Determinand	Test Reference
Oxygen	Spots - Horiba P1089
Water vapour	A2H20

Uncertainty Calculation Parameters

Standard uncertainty for pressure measurement (U12)	5.0 %
Standard uncertainty for Pitot coefficient (U13)	1.0 %
Standard uncertainty for density estimate (U13)	1.0 %
Standard uncertainty for linear measurement (U14)	1.0 %

Uncertainty budget

Uncertainties		
Pressure measurement (m_p)	%	5.00
Pitot coefficicient (m_K)	%	1.00
Gas density estimate (m_r)	%	1.00
Total for velocity measurement (U_v)	%	5.20
Velocity at 95% confidence interval (U_{v95})	%	10.18
Linear measurement (m_l)	%	1.00
Total for flowrate measurement (U_f)	%	5.49
Flow rate at 95% confidence interval (U_{f95})	%	10.76

Based on Procedure 55 and Uncertainty Policies 13 & 14
(in accordance with requirements of BS EN ISO 14956:2002 and ENV 13005 (GUM))

$U_v = \sqrt{m_p^2 + m_K^2 + m_r^2}$
$U_{v95} = 1.96 \times U_v$
$U_f = \sqrt{U_v^2 + 2m_l^2}$
$U_{f95c} = 1.96 \times U_f$

Prepared by: J Ward **Checked by:** L Mears

CALCULATION OF NOZZLE SIZE & K FACTOR

Exhaust & sample gas conditions

Desired sampling rate at orifice (SR_o)	21.2 l/min	0.749 ft^3/min
Expected meter outlet temperature (T_m)	20 °C	

(guide is a sampling rate of 0.75 ft^3/min or 21.2 l/min at the orifice)

Conditions at nozzle		Conditions at orifice/meter	
Sampling rate (SR_n)	22.06 l/min	Sampling rate (SR_o)	21.20 l/min
Temperature (T_{duct})	29.00 °C	Temperature (T_a)	20.00 °C
Pressure (P_{duct})	99.32 kPa	Pressure (P_m)	99.40 kPa
Water vapour (H_2O_{duct}	0.85 %	Water vapour (H_2O_m)	0 %
Molecular weight (M_{duct})	28.74	Molecular weight (M_m)	28.83

Orifice Parameters

Orifice plate coefficient ($\Delta H_@$)	2.3847 " w.g.

Determination of nozzle diameter

based on isokinetic sampling and the average gas velocity

$D_{nr} = 2000 \times \sqrt{[SR_n / V_{duct} \times \pi \times 60000]}$

where D_{nr} is the recommended nozzle diameter (mm)

Recommended nozzle diameter (D_{nr}	=	5.044	mm
Diameter of nozzle selected (D_n)	=	6	mm

Determination of K Factor

based on preliminary exhaust gas conditions

K Factor is a proportionality factor relating the pressure drop measured with the Pitot tube in the duct (h) with the corresponding pressure drop at the orifice (ΔH), i.e.

$\Delta H = K * h$

$K = 8.038 \times 10^{-5} \times C_p^2 \times \Delta H_@ \times D_n^4 \times (M_m/M_{duct}) \times [(100-H_2O_{duct})/(100-H_2O_m)]^2. (T_m+273/T_{duct}+273).(P_{duct}/P_m)$

where $\Delta H_@$ is the orifice plate coefficient (mm w.g.)

K Factor	=	*6.0326*
K Factor$_I$ (independent of C_p)	=	6.0326

SCIENTIFICS MONITORING REPORT FORM
TOTAL PARTICULATE MATTER to BS EN 13284-1/BS ISO 9096

Company	Sarginsons	Test Ref	A2TPM
Site	Coventry		
Sample point	A2 - Dry Arrestor		
Test carried out by	J Ward & L Mears		

SAMPLING TIMES

Determination		TPM
Date		15-Jun-10
Time Start		1604
Time End		1704
Duration (t)	min	60

Sampling plane

Dimension traversed by sampling probe (D)	m	0.83
Cross sectional area of sampling plane (A)	m^2	0.68

Duct gas conditions

Determination		TPM
Ambient temperature (T_{Amb})	°C	22.0
Average duct gas temperature (T_{duct})	°C	32.3
Duct static gas pressure (P_{Static})	kPa	-0.08
Barometric pressure (P_{Baro})	kPa	99.40
Volume flow rate @ ref. conditions (Q_{Ref})	m^3/s	11.10
Gas compressibility correction (ε)		0.995
Wet gas density (ρ_a)		1.14
Exhaust gas conditions measurements		A2FL

Reference conditions

Determination		TPM
Actual Duct Flow Conditions		
Average temperature (T_{duct})	°C	32.3
Total pressure (P_{duct})	kPa	99.32
Oxygen (O_{2duct})	% vol,dry	20.80
Water vapour (H_2O_{duct})	% vol	0.85
Reference Conditions		
Temperature (T_{Ref})	°C	0
Pressure (P_{Ref})	kPa	101.3
Oxygen (O_{2Ref})	% vol, dry	20.8
Water vapour (H_2O_{Ref})	% vol	0.85

Sampling conditions

Determination				TPM
Nozzle diameter (d)	Ti18	Titanium	mm	6.000
Initial gas meter reading			m^3	8.855
Final gas meter reading			m^3	10.299
Sampled volume (SV_M)			m^3	1.444

Calculation of sample gas volume at reference conditions, SV_{Ref}

$$SV_{Ref} = SV_{Meter} \times \gamma \times [273 + T_{Ref}]/[273 + T_{Meter}] \times P_{Baro}/P_{Ref} \times [100-H_2O_{Meter}]/[100-H_2O_{Ref}] \times [20.9-O_{2Duct}]/[20.9-O_{2Ref}]$$

Corrections
Temperature
Pressure
Water vapour
Oxygen

Determination		TPM
Sampled volume @ ref. conditions (SV_{Ref})	m^3	1.325

Prepared by: J Ward **Checked by:** L Mears

SAMPLING DATA TPM

Test Ref A2TPM

Initial gas meter reading 8855 l Start Time 1604

Distance from Duct Wall Fraction of D	Port	Time of Day h:mm	Run time mm	Gas meter reading l	Pitot Reading (h) cm w.g.	Orifice ΔH cm w.g. Desired (ΔH_s) =h x K_s x Cp^2	Orifice ΔH cm w.g. Actual (ΔH_a)	Isokinetic difference ($\Delta H_a/\Delta H_s$) %	Temperatures Gas (T_{duct}) °C	Probe (T_p) °C	Filter (T_F) °C	Meter (T_M) Inlet °C	Meter (T_M) Outlet °C	Impinger (T_{imp}) °C	Oxygen Content %, v/v, dry
0.250	A	1604	0	8855	1.46	6.21	6	97	31	31	31	24	24	n/a	20.8
		1609	5	8950	1.46	6.21	6	97	32	32	32	24	23	n/a	
		1614	10	9111	1.56	6.64	6.6	99	33	33	33	26	24	n/a	20.8
	A	1619	15	9181	1.5	6.38	6.2	97	32	32	32	26	24	n/a	
		1624	20	9355	1.66	7.07	7	99	32	32	32	28	26	n/a	20.8
		1629	25	9442	1.7	7.24	7	97	32	32	32	28	26	n/a	
0.750	A	1634	30	9542	1.72	7.32	7.2	98	32	32	32	28	26	n/a	20.8
		1639	35	9677	1.6	6.81	6.6	97	32	32	32	29	26	n/a	
		1644	40	9805	1.64	6.98	6.8	97	32	32	32	29	26	n/a	20.8
	A	1649	45	9928	1.6	6.81	6.6	97	33	33	33	30	27	n/a	
		1654	50	10055	1.6	6.81	6.6	97	33	33	33	30	27	n/a	20.8
		1659	55	10175	1.54	6.56	6.4	98	33	33	33	30	28	n/a	
		1704	60	10299											
	Averages								32.3	32.3	32.3	26.6		#DIV/0!	20.8

Final gas meter reading 10299 l End Time 1704

Equipment used

Item	File No.
Control box	P1268
Meter coefficient (γ)	1.017
K factor, (K_s independent of C_p)	6.033
Orifice plate pressure units	cm w.g.
Pitot differential pressure units	cm w.g.
Pitot	S Type
Pitot coefficient (C_p)	0.84
Probe liner thermocouple Titanium	N/A
Duct gas thermocouple	P1287
Oven thermocouple	N/A
Impinger exit thermocouple	N/A
Timer	P1153

Approach to isokinetic sampling

Average gas velocity (V_{duct})	13.8 m/s
Nozzle diameter (D_n)	6.000 mm
Sampling time (t)	60 min
Theoretical isokinetic sample volume SV_t	1407.12 l
Actual sample volume (SV_a)	1510.92 l
Approach to isokinetic sampling (ΔI)	107.4 %

where Vduct is the average duct velocity based on the above measurements

$V_{Duct} = C_p \times (1-\varepsilon) \times \sqrt{2/\rho_a} \times \sqrt{h}$ **(Reference BS 1042:Section 2.1:1983 (ISO 3966), pages 8&9)**

SV_t is the theoretical isokinetic sample volume based on V_{duct} & D_n

$SV_t = V_{duct} \times \pi \times [D_n/2000]^2 \times t \times 60 \times 1000$

SV_a is the sample volume at duct conditions

$SV_a = SV_m \times \gamma \times [(273 + T_{duct})/(273 + T_m)] \times (P_{Baro}/P_{duct}) \times (100 - H_2O_m)/(100-H_2O_{duct})$

Leak check

		Start	End
Start Time		15:58	17:10
End Time		16:00	17:12
Initial meter reading	m^3	8.8352	10.3432
Final meter reading	m^3	8.8357	10.3436
Duration of leak test	min	2	2
Pump vacuum	"Hg	-15	-15
Leak rate	l/min	0.25	0.2
Less than 2% of normal sampling rate?		Yes	Yes

Determination of exhaust gas flow rate

based on measurements at sample points only

Flow rate at duct conditions (Q_{duct})	9.41 m^3/s
Flow rate at STP (Q_{STP})	8.26 m^3/s
Flow rate at reference conditions (Q_{Ref})	8.26 m^3/s

where

$Q_{duct} = V_{duct} \times A$

$Q_{STP} = Q_{duct} \times [(T_{Ref} + 273)/(T_{duct} + 273)] \times (P_{Baro}/P_{Ref})$

$Q_{Ref} = Q_{STP} \times [(20.9-O_{2Ref})/(20.9-O_{2duct})] \times [(100-H_2O_{duct})/(100-H_2O_{Ref})]$

Glassware

Clean	Yes	Date	15.06.10	Prepared by	LM

SAMPLE LOG

Determination	Method blank	Field blank	Sample
Particulate phase			
Filter No.		02672	02667
Rinsings No.		02672W	02667W
Vapour phase (if collected)			
First stage	No.		
	Volume (ml)		
	Type		
Final stage	No.		
	Volume (ml)		
	Type		

PARTICULATE WEIGHINGS

Test Ref **A2TPM**

Filters

Determination		Method Blank	Field Blank	TPM
Filter No.		0	02672	02667
Pre-sampling conditioning temperature (±5°C)	°C	180	180	180
Post-sampling conditioning temperature (±5°C)	°C	160	160	160
Diameter	mm	110	110	110
Material		Quartz	Quartz	Quartz
Pre-sampling weights				
after 1 min	g		0.0410	0.0414
after 2 min	g		0.0410	0.0414
after 3 min	g		0.0410	0.0414
Weight extrapolated to zero time (M_{fi0})	g		0.0410	0.0414
Post-sampling weights				
after 1 min	g		0.0409	0.0442
after 2 min	g		0.0409	0.0442
after 3 min	g		0.0409	0.0442
Weight extrapolated to zero time (M_{ff0})	g		0.0409	0.0442

Rinsings

Pre-sampling conditioning temperature (±5°C)	°C	180	180	180
Post-sampling conditioning temperature (±5°C)	°C	160	160	160
Pre-sampling weights (container only)				
after 1 min	g		65.8804	68.9995
after 2 min	g		65.8804	68.9994
after 3 min	g		65.8804	68.9994
Weight extrapolated to zero time (M_{ri0})	g		65.8804	68.9995
Post-sampling weights (container and evaporated rinsings)				
after 1 min	g		65.8813	69.0017
after 2 min	g		65.8812	69.0016
after 3 min	g		65.8811	69.0015
Weight extrapolated to zero time (M_{rf0})	g		65.8814	69.0018

Summary

Determination		Method Blank (M_{mb})	Field Blank	TPM
Mass collected on filter (M_f = (M_{ff0}- M_{fi0}- M_{fmb}))	g	0.0000	-0.0001	0.0028
Mass collected in rinsings (M_r = (M_{rf0}-M_{ri0}-M_{rmb}))	g	0.0000	0.0010	0.0023
Total mass collected (M = M_f + M_r)	g	0.0000	0.0009	0.0051

Uncertainty Calculation Parameters

Standard uncertainty for gas volume measurement (U6)	2.9 %
Standard uncertainty for filter weighing (U17)	0.57 mg
Standard uncertainty for washings weighing (U17)	0.50 mg
Limit of detection for filter weighing (U17)	0.50 mg
Limit of detecion for washings weighing (U17)	0.50 mg
Standard uncertainty for oxygen correction (U11)	0.95 %
Standard uncertainty for gas flow measurement (U14)	5.7 %

Emission Limit Value

Emission limit value (ELV) at reference conditions	x	mg/m^3

SUMMARY OF MEASUREMENTS

Test Ref A2TPM

Calculation of Particulate Concentration and Discharge Rate

Particulate concentration (C), mg/m^3 = M x 1000/ SV_{Ref}

Discharge rate, kg/h = C x Q_{Ref} x 0.0036

Determination		Field Blank	TPM
Particulate concentration at reference conditions	mg/m^3	0.68	3.82
Uncertainty	mg/m^3	0.68	3.39
Particulate concentration at duct conditions (raw)	mg/m^3	0.60	3.35
Particulate discharge rate	kg/h	0.03	0.15
Uncertainty	kg/h	0.03	0.15

Note: Field blank results based on average sampling conditions

Uncertainty budget

Uncertainties		Field Blank	TPM
Volume measurement (m_{vol})	mg	0.03	0.15
Filter weighings (m_f)	mg	-0.10	1.66
Rinsings weighings (m_w)	mg	0.94	1.57
Total for uncorrected measurement (U_u)	mg	0.95	2.29
Correction to reference conditions (m_{corr})	mg	0.00	0.00
Total for corrected measurement (U_c)	mg	0.95	2.29
Concentration at 95% confidence interval (U_{95c})	mg/m^3	0.68	3.39

Based on Procedure 55 and Uncertainty Policies 11 & 17
(in accordance with requirements of BS EN ISO 14956:2002 and ENV 13005 (GUM))

$U_u = \sqrt{m_{vol}^2 + m_f^2 + m_w^2}$

$U_c = \sqrt{U_u^2 + m_{corr}^2}$

$U_{95c} = 1.96 \times U_c / SV_{Ref}$

COMPLIANCE WITH BS EN 13284-1:2002/BS ISO 9096 CONDITIONS

Flow conditions (BS EN 13284-1, 5.2 & BS ISO 9096, 5.3)

Standard	EN 13284-1
Angle of gas flow less than 15°	Yes
No local negative gas flow	Yes
Minimum differential pressure greater than 5 Pa	Yes
Ratio of highest to lowest local gas velocites less than 3:1	Yes

Compliance with BS EN 13284-1

Nozzle diameter greater than 6 mm (Clause 6.2.4)
Average sampling rate was within -5% and +15% of isokinetic conditions (Clause 8.4)
Leak rate is within 2% of sample rate (Clause 8.4)

SCIENTIFICS MONITORING REPORT FORM
WATER VAPOUR DETERMINATION to BS EN 14790:2005

Company	Sarginsons	Test Ref	A2H20
Site	Coventry	Date	15-Jun-10
Sample point	A2 - Dry Arrestor	Time start	1625
Test carried out by	L Mears & J Ward	Time End	1715
		Duration, t (min)	50

Sampling Rate

Gas meter start reading (SV_{MI})	l	40737.5000
Gas meter end reading (SV_{MI})	l	40787.0100
Volume passed at meter conditions ($SV_M=SV_{MI}-SV_{MI}$))	m^3	0.0495
Sampling rate at meter conditions (SVM/t)	m^3/min	0.0010

Sampling Conditions

Time	Gas Meter		Probe/heated line
	Temperature T_M, °C	Pressure P_M, kPa	temperature °C
1630	19.0	99.4	n/a
1715	23.0	99.4	n/a
Average	21.0	99.4	#DIV/0!

Equipment

Gas meter	P496
Gas meter calibration factor	1.0006
Probe/heated line thermocouple	n/a
Barometer	P154
Timer	P733
Balance	P1244

Leak check

		Start	End
Time start		16:23	17:18
Time end		16:24	17:19
Start volume	l	40737.210	40787.010
End volume	l	40737.220	40787.020
Duration	mins	1	1
Leak rate	l/min	0.01	0.01
Leak rate <2% of sample rate?		Yes	Yes

Balance Check Weighings

Balance No.	P1244		
Check weight no.	P1245	P1245	P1245
Certified weight	1000.0000	1000.0000	1000.0000
Reading (g)	1000.0500	1000.0500	1000.0500
Allowable tolerance (g)	1.0000	1.0000	1.0000
Acceptable response	Yes	Yes	Yes

Test Ref. A2H20

Collection of Water from Gas

Collection Stage (ci)	Initial Mass(Mci_i) g	Final Mass (Mci_f) g	Mass gain (Mci) g
Container 1	60.150	60.220	0.070
Container 2	55.580	55.820	0.240
Container 3	44.940	44.940	0.000
Container 4			
Container 5			
Container 6			
Total (M)	160.670	160.980	0.310

Mass of water collected (M) = $\Sigma(Mc1_f-Mc1_i)....(Mci_f-Mci_i)$

Calculation of dry gas sample volume at STP (SV_{STP})

$SV_{STP} = SV_M \times (273/(273 + T_M)) \times (P_M/101.3)$

Volume of dry gas sampled at STP (SV_{STP})	m^3	0.0451

Calculation of water vapour content (H_2O_{duct})

$H_2O_{duct} = 100 \times (M \times MV_{STP}/MW_{H2O})/[SV_{STP} + (M \times MV_{STP}/MW_{H2O})]$

where
MV_{STP} molecular volume at STP (22.412 m^3/kgmole)
MW_{H2O} molecular weight of water (18 kg/kgmole)

Water vapour content (H_2O_{duct})	%	0.85	±	0.85

Method performance

Water collection efficiency (ε=100-(Mci.100/M))	%	100.0
Water content in final container	%	0.0
Correction for collection efficiency ($Corr_\varepsilon$)	%	0.0

Compliance with BS 14790

Uncertainty greater than 20% of measured value Clause 7.3) - outside standard
Temperature at outlet is less than 4oC based on calculated dew point (Clause 6.4.2)
Leak rate is greater than 2% of sample flow rate (Clause 6.3) - outside standard
Sampling duration is within minimum of 30 minutes (Clause 6.1)
Sample volume is below minimum of 50 l (Clause 6.1) - outside standard
Residual water content at outlet is below 1.25% (Clause 5.8)
Sampling temperature fell below minimum of 120oC (Clause 5.2) - outside standard

Uncertainty Budget (based on BS 14790 and Uncertainty Policy U25)

Volume of sampled gas	V	0.045 m^3
Average temperature of gas at meter	T	21 °C
Average barometric pressure at meter	P	994 mb
Sampling line leakage		0.01 m^3/min
Duration of sampling	t	50 min
Total mass weighed	M	160.98 g

Source of uncertainty		Value		Value of standard uncertainty		Relative standard uncertainty (%)	
Measurement of sample gas volume	u_i,V_m	2.0 %	u_v	$u_s,V_m = \frac{u_v V}{\sqrt{3}}$	0.0005 m^3	u_r,V_m	1.15
Measurement of sample gas temperature	u_i,T_m	1.0 %	u_t	$u_s,T_m = \frac{u_t(T+273)}{\sqrt{3}}$	1.6974 K	u_r,T_m	0.58
Measurement of absolute pressure	u_i,P_m	1.0 %	u_p	$u_s,P_m = \frac{u_p P}{\sqrt{3}}$	5.7389 mb	u_r,P_m	0.58
Leakage in sampling line	u_i,L	1009.9 %	u_l	$u_s,L = \frac{u_l V}{\sqrt{3}}$	0.2632 m^3	u_r,L	583.06
Measurement of weight - balance uncertainty	u_i,W_m	0.01 %	u_{wm}	$u_s,W_m = \frac{u_{wm} M}{\sqrt{3}}$	0.0093 g		-
Measurement of weight - balance repeatability	u_i,W_r	0.011 g	u_{wr}	$u_s,W_r = u_{wr}$	0.0110 g		-
Total measurement of weight	u_i,W	-	-	$u_s,W =$	0.0203 g	u_r,W	6.55

Total standard relative uncertainty	$u_r = \sqrt{u_r,V_m^2 + u_r,T_m^2 + u_r,P_m^2 + u_r,L^2 + u_r,W^2 + Corr_\varepsilon}$	583.10 %
Total relative uncertainty	$U_r = 1.96u_r$	100.00 %

Prepared by: L Mears **Checked by:** J Ward

END OF REPORT