PARTICULATE EMISSION TEST SURVEY

FOR

DUNLOP OIL & MARINE LTD

Project No : 74981-87 (1)

19 November 2013

Global Surface Coatings Covered

ENVIRONMENTAL SERVICES TEST REPORT

Project No. 74981-87 (1)

Test Dates 7 November 2013

Report Date 19 November 2013

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CONTENTS

PARTICULATE EMISSION TEST SURVEY

1.0 Introduction

This report presents the test procedures, results, conclusions and recommendations of the test survey carried out on 7 November 2013 by Tim Sullivan MCERTS Accreditation No. MM03456.

Dunlop Oil & Marine Ltd have asked PRA to carry out particulate emission testing of the two dust release points. The Bag Filtration Unit which serves LEV 07 (Banbury Mixer & experimental lab), LEV 40 (bulk carbon black hoppers) and LEV’s 1, 2, 38 & 39 (powder weighing and Banbury Mixer downchute) and the Banbury Mixer release point.

This test survey will enable Dunlop Oil & Marine Ltd to check their compliance against the particulate emission limits given in process guidance note PG6/28 (11) “Guidance for Rubber”.

2.0 Test Procedures

2.1 Location of Sampling Ports

A description of the sampling port location at each release point is given in table 1.0. Diagrams of the stacks and sampling ports are shown in appendix 1.

Table 1 Sample point locations

Release Point	Test Parameters
1. Bag Filtration Unit	Particulate emission
2. Banbury Mixer	Particulate emission

2.2 Flow

The gas velocity at release point 2 (Banbury Mixer) was measured using an ellipsoidal nose pitot tube and calibrated micromanometer in accordance with ISO 10780 “Measurement of velocity and volume flowrate of gas streams in ducts”.

The gas velocity at the exit grill of release point 1 was too turbulent to measure using a pitot tube and micromanometer, therefore a rotating vane anemometer was used to give an indication of the gas velocity.

The gas temperature was measured using a calibrated digital temperature indicator and K type probe. The temperature was measured at the same sampling points as the flow measurements.

2.3 Particulate Emission

The particulate emission was measured using a gravimetric filter technique in accordance with BS ISO 9096 : 2003 “Manual determination of mass concentration of particulate matter.”

For release point 1 (bag filtration unit) the flow did not meet the criteria stated in BS ISO 9096. However indicative flow measurement was taken using a hand held rotating vane anemometer.

For release point 2 (Banbury Mixer) the angle of gas flow was less than 15° with respect to the duct axis, no negative gas flow was found, the minimum pitot static reading was greater than 5 Pa and the ratio of the highest and lowest pitot static readings was less than 3 :1. The temperature across the ducts did not vary by more than 5 % from the mean temperature. Therefore the flow in the sampling plane met the criteria stated in BS ISO 9096.

For release point 1 (bag filtration unit) the duct area was between 0.38 and 1.50 m^2 therefore nine point cumulative sampling at 0.25D, 0.50D and 0.75D along three sample lines was used.

For release point 2 the duct diameter was between 0.35 and 0.70 m therefore five point cumulative sampling at 0.113D, 0.50D and 0.887D along two stack diameters would normally be used. However because the working platform only gave access one side of the duct, it was decided to carry out five point sampling at 0.059D, 0.211D, 0.50D, 0.789D and 0.941D along a single stack diameter. It is considered that this sampling procedure would provide representative sample of the particulate emission.

The particulate sampling train (J.S. Holdings Stack Sampler) was checked for leaks under pressure (i.e. the sampling train was assembled, the sample pump was switched on, the nozzle of the probe was covered and the flow rate was checked to ensure a stable vacuum was maintained). The test showed the sample train was leak free.

The sampled gas was extracted at a rate that ensured the gas velocity at the sampler nozzle was equal to the gas velocity in the stack at the point of sampling (i.e. isokinetic sampling).

One particulate concentration determination was taken for each of the release points in order to sample for longer and try to ensure a measurable weight gain on the filter.

The uncertainty in the particulate concentration due to deviations from BS ISO 9096 was estimated using guidelines given by the Source Testing Association.

3.0 Results

This section presents a summary of the test results. All test results are reported at reference conditions 273 K and 1013 m.bar without correction for water vapour.

The measurements for were taken under what was considered typical production conditions.

The methods for calculating the gas velocity, volume flow, particulate concentration, and isocyanate concentration are shown in appendix 2. The test data for flow, volume sampled, % isokinetic and uncertainty of measurement are shown in appendix 3.

3.1 Flow

The gas velocity and volume flow for each release point are shown in table 2.

Table 2 Flow

Release Point	Date	Gas Velocity (m/s)	Volume Flow at STP (m^3/h)
1 Bag Filtration Unit	7 November - 10.40	8.10	10669
2 Banbury Mixer	7 November – 13.30	9.48	8853

3.2 Particulate Emission

3.2.1 Release Point 1 – Bag Filtration Unit

The particulate concentration measured at release point 1 is shown in table 3.

Table 3 Particulate emission concentration

Test No.	**Date/Time**	**% Isokinetic**	**Sampling Period (mins)**	**Weight of Particulate (mg)**	**Volume Sampled (m^3)**	**Particulate Conc. ($mg.m^{-3}$)**
1	7 November 10.55	99	81	0.5	1.0238	0.5 ± 0.4

3.2.2 Release Point 2 – Banbury Mixer

The particulate concentration measured at the Banbury Mixer extract duct is shown in table 4.

Table 4 Particulate emission concentration

Test No.	**Date/Time**	**% Isokinetic**	**Sampling Period (mins)**	**Weight of Particulate (mg)**	**Volume Sampled (m^3)**	**Particulate Conc. ($mg.m^{-3}$)**
1	7 November 13.45	95	50	0.5	0.7139	0.7 ± 0.5

3.2.3 Particulate Blank

The blank particulate concentration is shown in table 5.

Table 5 Blank Particulate emission concentration

Test No.	**Date**	**Weight of Blank (mg)**	**Average Volume Sampled (m^3)**	**Blank Particulate Conc. ($mg.m^{-3}$)**
1	7 November	0.3	0.8688	0.3

4.0 Conclusions

The particulate emission concentration (0.5 $mg.m^{-3}$) from release point 1 – Bag Filtration Unit - is below the emission limit of 10 $mg.m^{-3}$ for the storage, handling or mixing of carbon black as set out in process guidance note PG6/28 (04) “Guidance for Rubber”.

The particulate emission concentration (0.7 $mg.m^{-3}$) from release point 2 - Banbury Mixer is below the emission limit of 50 $mg.m^{-3}$ for any source other than carbon black.

APPENDIX 1

Diagram 1.0 Sampling Points for Bag Filtration Unit

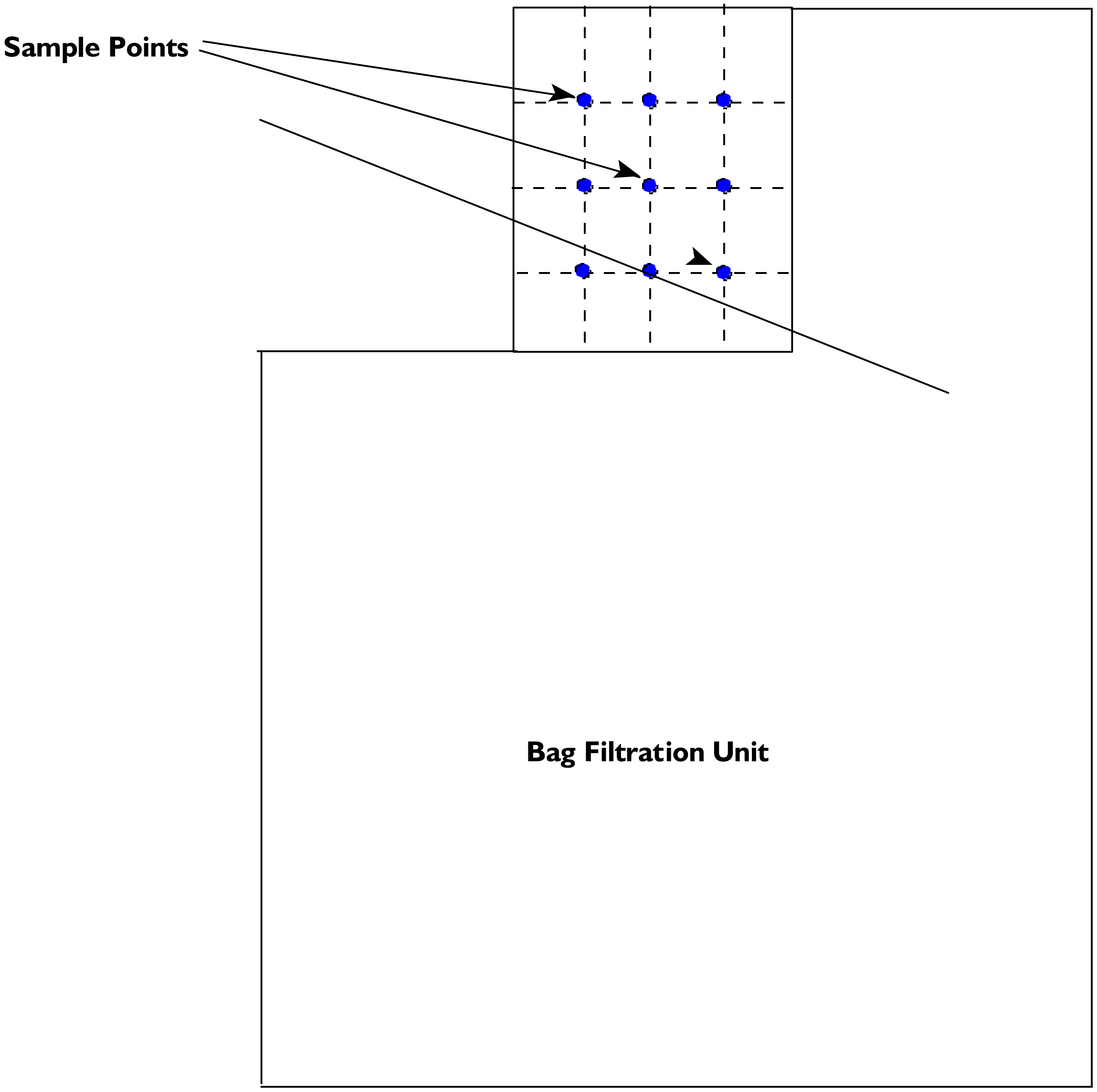
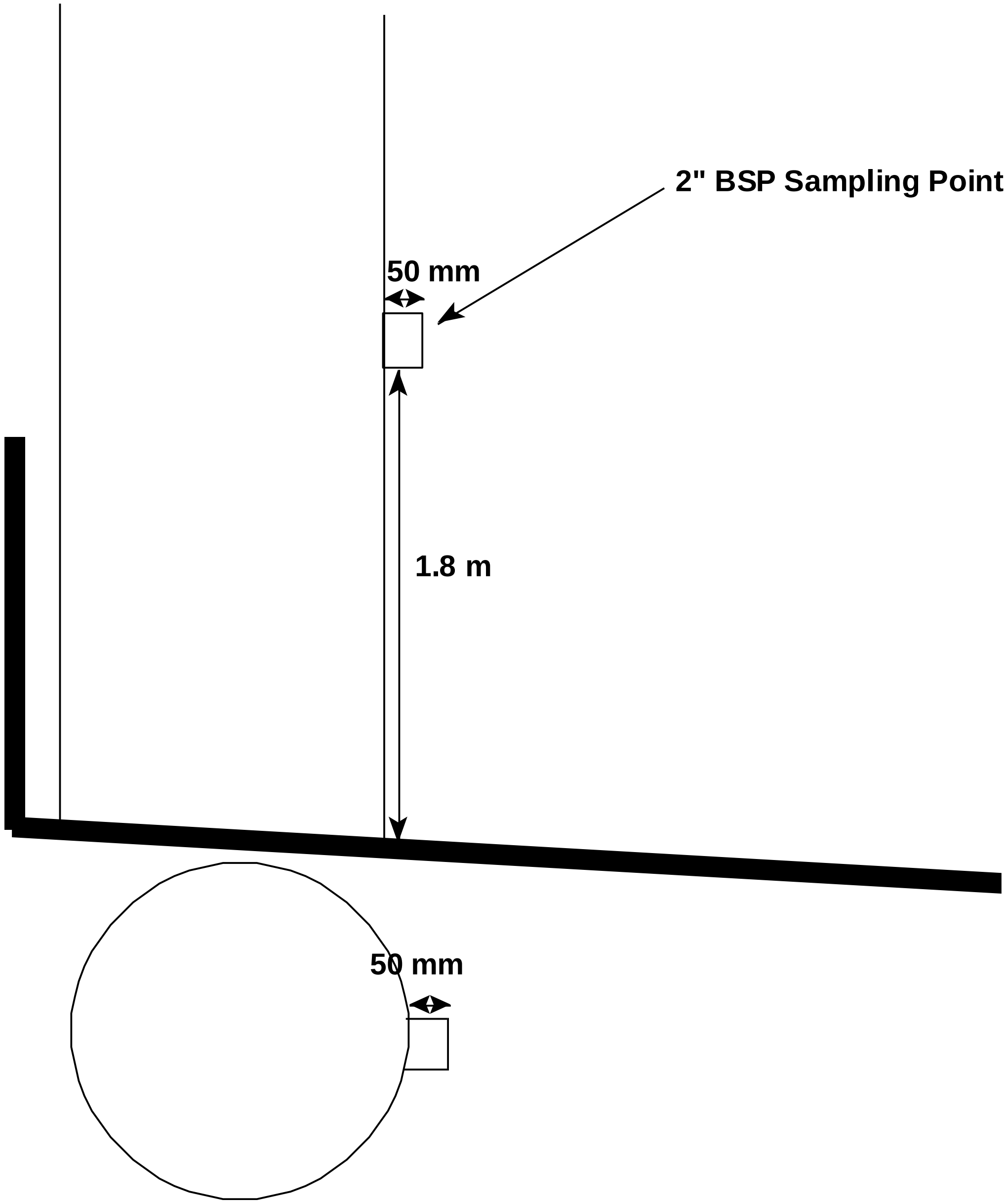


Diagram 2. Sample Point for Banbury Mixer



APPENDIX 2

Calculations

1.0 Gas Flow Calculations

i) Gas velocity at S.T.P (273 K and 1013 m.bar)

$$V_{STP} = K_p \times 1.29 \times \sqrt{H_V}$$

where V_{STP} = gas velocity at STP (m/s)
K_p = pitot correction factor
= 0.996
1.29 = gas density at 273 K and 1013 m.bar
H_V = mean velocity pressure (Pa)

ii) Actual gas velocity (V_A)

$$V_A = V_{STP} \times \sqrt{\frac{T}{273} \times \frac{1013}{0.01(H_S) + B}}$$

where V_{STP} = gas velocity at STP (m/s)
T = temperature of gas in duct (K)
H_S = static pressure (Pa)
B = atmospheric pressure (m.bar)

iii) Actual Gas Flowrate (Q)

$$Q = V_A \times A \times 3600$$

where Q = gas flowrate (m^3/h)
V_A = actual gas velocity (m/s)
A = X sectional area of vent (m^2)

iv) Gas flowrate at STP (Q_{STP})

$$Q_{STP} = Q \times \frac{273}{T} \times \frac{B}{1013}$$

where Q = gas flowrate at STP (m^3/h)
T = temperature of gas in stack (K)
B = barometric atmospheric pressure (m.bar)

2.0 Particulate Emission Concentration

2.1 Weight of Particulate

a) weight of particulate on filter = $(F_2 - F_1) - (C_2 - C_1)$

where F_2 = final weight of test filter (g)
F_1 = initial weight of test filter (g)
C_2 = final weight of control filter (g)
C_1 = initial weight of control filter (g)

b) weight of particulate in washings = $(E_2 - E_1) - (C_2 - C_1)$

where E_2 = final weight of evaporated washing + dish (g)
E_1 = initial weight of dish (g)
C_2 = final weight of control dish (g)
C_1 = initial weight of control dish (g)

c) total weight of particulate = a + b

2.2 Volume Sampled

a) registered volume sampled (V_R) = $M_2 - M_1$

where M_2 = final gas meter reading (m^3)
M_1 = initial gas meter reading (m^3)

b) true volume sampled (V_T) = $V_R \times (100 \times R_E)$

where V_R = registered volume (m^3)
R_E = gas meter correction factor
= 0.988

c) true volume sampled to STP = $V_T \times \frac{273}{T} \times \frac{B}{1013}$

where V_T = true volume sampled (m^3)
273 = standard temperature (K)
T = gas temperature in stack (K)
1013 = standard atmospheric pressure (m.bar)
B = atmospheric pressure (m.bar)

2.3 Particulate Concentration

$$\text{mg.m}^{-3}_{\text{(particulate)}} = \frac{W_t}{V}$$

where W_t = total weight of particulate captured

V = true volume of gas sampled corrected to STP

2.4 Isokinetic Sampling

$$\%\ \text{Isokinetic} = \frac{\text{gas velocity at nozzle (m/s)}}{\text{gas velocity at sample point in duct (m/s)}} \times 100$$

a) gas velocity at nozzle= $\frac{V_T}{A_N \times T_S}$ (m/s)

where V_T = true volume of gas sampled at actual temperature & pressure. (m^3)

A_N = nozzle area (m^2)

T_S = sampling time (secs)

b) gas velocity at sample point in duct

$$= 1.29 \times \sqrt{H_V} \times \sqrt{\frac{T}{273} \times \frac{1013}{B}}$$

where 1.29 = gas density at 273 K and 1013 m.bar

$\sqrt{H_V}$ = mean square root of the velocity pressure (Pa)

T = temperature of gas in duct (K)

B = atmospheric pressure (m.bar)

3.0 Blank Concentration

3.1 Weight of Particulate

a) weight of particulate on blank filter = $(B_2 - B_1) - (C_2 - C_1)$

where B_2 = final weight of blank filter (g)

B_1 = initial weight of blank filter (g)

C_2 = final weight of control filter (g)

C_1 = initial weight of control filter (g)

b) weight of particulate in blank washings = $(W_2 - W_1) - (C_2 - C_1)$

where W_2 = final weight of evaporated blank washing + dish (g)
W_1 = initial weight of dish (g)
C_2 = final weight of control dish (g)
C_1 = initial weight of control dish (g)

c) total weight of blank particulate (M_B) = a + b

3.2 Volume Sampled

a) average volume sampled (V_A) = $\frac{V_1 + V_n}{n}$

where V_1 = volume of gas sampled corrected to STP for test 1(m^3)
V_n = volume of gas sampled corrected to STP for test n (m^3)

3.3 Blank Particulate Concentration

Blank Concentration ($mg.m^{-3}$) = $\frac{M_B}{V_A}$

where M_B = mass of blank (µg)
V_A = average volume sampled at STP from daily tests (m^3)

APPENDIX 3

Test Data

1.0 FLOW MEASUREMENTS

## Dunlop Oil & Marine Ltd		Project No : 74981-87 (1)

Release Point 1 - Bag Filtration Unit

Date:	07/11/2013
Time:	10.40
Gas temperature (K)	297
Atmospheric pressure (m.bar)	1008
Duct Dimensions (m)	0.8 x 0.5
Area (m2)	0.4000

	Face Velocity (m/s)		Average Face Velocity (m/s)
8.9	5.7	6.5	8.10
8.6	8.5	9.7	
9.8	8.3	6.9	

Gas flowrate (m3/h)	11664
Gas flowrate at STP (m3/h)	10669

1.0 FLOW MEASUREMENTS

Dunlop Oil & Marine Ltd Project No: 74981-87 (1)

Release Point 2 - Banbury Mixer

Date:	07/09/2013
Time:	13.30
Gas temperature (K)	296
Atmospheric pressure (m.bar)	1008
Static pressure (m.bar)	0.42
Duct Dimensions (m)	0.6
Area (m2)	0.2827

Distance Along Sample Line	Vel. Pressure Hv (Pa)	Sqrt Hv	Average Sqrt Hv (Pa)	Gas Velocity. (m/s)
0.059D	30	5.48	7.07	9.48
0.211D	34	5.83		
0.500D	45	6.71		
0.789D	75	8.66		
0.941D	75	8.66		

Gas flowrate (m3/h)	9646
Gas flowrate at STP (m3/h)	8853

2. PARTICULATE EMISSION: VOLUME SAMPLED

Dunlop Oil & Marine Ltd **Project No : 74981-87 (1)**

Standard Temperature (K) =	273
Standard Pressure (m.bar) =	1013

2.1 Release Point 1 - Bag Filtration Unit

Test	Date	Time	Temp K	Pressure m.bar	Initial Gas Meter m3	Final Gas Meter m3	Sampled Volume m3	True Volume m3	Volume at STP m3
1	07-Nov	10.55	301	1008	725.2581	726.4063	1.1482	1.1344	1.0238

2.2 Release Point 2 - Banbury MIxer

Test	Date	Time	Temp K	Pressure m.bar	Initial Gas Meter m3	Final Gas Meter m3	Sampled Volume m3	True Volume m3	Volume at STP m3
1	07-Nov	13.45	303	1008	726.4130	727.2189	0.8059	0.7962	0.7139

3. PARTICULATE EMISSION: WEIGHT COLLECTED

Dunlop Oil & Marine Ltd **Project No: 74981-87 (1)**

3.1 Release Point 1 - Bag Filtration Unit

Test	Date	Time	Weight on Filter (mg)	Weight on Control (mg)	Particulate on Filter (mg)	Particulate in Washing (mg)	Total Collected (mg)
1	07-Nov	10.55	0.1	0.0	0.1	0.4	0.5

3.2 Release Point 2 : Banbury Mixer

Test	Date	Time	Weight on Filter (mg)	Weight on Blank Filter (mg)	Particulate on Filter (mg)	Particulate in Washing (mg)	Total Collected (mg)
1	07-Nov	13.45	0.2	0.0	0.2	0.3	0.5

3.3 Blank 1

Test	Date	Time	Weight on Filter (mg)	Weight on Blank Filter (mg)	Particulate on Filter (mg)	Particulate in Washing (mg)	Total Collected (mg)
1	07-Nov	14.50	0.2	0.0	0.2	0.1	0.3

4. PARTICULATE EMISSION: CALCULATION OF % ISOKINETIC SAMPLING

Dunlop Oil & Marine Ltd **Project No : 74981-87 (1)**

Standard Temperature (K)	273
Standard Pressure (m.bar)	1013

4.1 Release Point 1 - Bag Filtration Unit

Test 1 07-Nov-13 10.55
Temp = 301
Press = 1008

	Velocity pressure (Pa)	Nozzle Size	Nozzle Area (m2)	Sampling Flowrate (litres/min)	Time Sampled (secs)	Initial gas meter (m3)	Final gas meter (m3)	Sampled Volume (m3)	True Volume (m3)	Velocity at nozzle (m/s)	SQRT Hv (Pa)	Velocity in Duct (m/s)	% isokinetic
Test 1	37.5	0.006	2.827E-05	13.78	4860	725.2581	726.4063	1.1482	1.1344	8.26	6.12	8.31	99

4.2 Release Point 2 - Banbury Mixer

Test 1 07-Nov-13 13.45
Temp = 303
Press = 1008

Sample Point	Velocity pressure (Pa)	Nozzle Size	Nozzle Area (m2)	Sampling Flowrate (litres/min)	Time Sampled (secs)	Initial gas meter (m3)	Final gas meter (m3)	Sampled Volume (m3)	True Volume (m3)	Velocity at nozzle (m/s)	SQRT Hv (Pa)	Velocity in Duct (m/s)	% isokinetic
Test 1	52.8	0.006	2.827E-05	15.5	3000	726.4130	727.2189	0.8059	0.7962	9.39	7.27	9.87	95

5.0 Uncertainty calculation for EN 13284 Determination of low range mass concentration of dust, Manual Gravimetric Method

v15

5.1 Bag Filter- Test 1

Measurement Equation

$$c = \frac{m}{V} f_c$$

Limit value (ELV)	10	**mg.m^{-3}**	**Reference oxygen**		**% by volume**
Measured concentration	0.50	**mg.m^{-3} (at reference conditions)**			

Measured Quantities	**Symbol**	**Value**	**Standard uncertainty**		**Units**	**Uncertainty as percentage**	**Uncertainty at lv**	**Requirement of std**
Sampled Volume	V_m	1.1344	uV_m	0.001	**m^3**	0.09		<=2%
Sampled gas Temperature	T_m	301	uTm	2	k	0.66		<=1%
Sampled gas Pressure	ρ_m	100.8	$u\rho_m$	1	**kPa**	0.99		<=1%
Sampled gas Humidity	H_m	0	uH_m	1	**% by volume**	1.00		<=1%
Oxygen content	$O_{2,m}$		$uO_{2,m}$	0.1	**% by volume**	#DIV/0!		<=5%
Mass particulate	m	0.5	um	0.18	**mg**	36.43	1.82	<5% of limit value
Note - Sampled gas humidity, temperature and pressure are values at the gas meter								
Leak	L	2			**%**	2.00		<=2%
Uncollected Mass	UCM	0			**mg**	0		<=10%
(Instack filter - no rinse)								

Intermediate calculations						
Factor for std conds	fs	0.90				
uncertainty components	symbol	**sensitivity coeff**		**u (in units of fs)**		
	ρ_m	0.009		0.009		
	H_m	0.009		0.009	$f_s = \frac{(100-H_m)}{100}\frac{273}{T_m}\frac{\rho_m}{101.3}$	
	T_m	0.003		0.006		
	ufs			0.014		1.56
Corrected volume	V	1.02	uV	0.016	m^3 $V = V_m f_s$	1.56
Factor for O2 correction	fc	1.00				
uncertainty components	symbol	**sensitivity coeff**	**u**		$f_c = \frac{21-O_{2,ref}}{21-O_{2,m}}$	
	$O_{2,m}$	0.05		0.005		
Factor for O2 Correction	ufc	1.00		0.005		0.48

Parameter		**Value**	**Units**	**Sensitivity coeff**	**Uncertainty contribution**		**Uncertainty as %**	
Corrected Volume (standard conc	V	1.02	m^3	0.49	0.01	mg.m^{-3}	1.56	%
Mass	m	0.50	mg	1.00	0.18	mg.m^{-3}	36.43	%
Factor for O2 Correction	fc	1.00		0.50	0.00	mg.m^{-3}	0.48	%
Leak	L	0.01	mg.m^{-3}	1.00	0.01	mg.m^{-3}	1.15	%
Uncollected mass	UCM	0.00	mg	1.00	0.00	mg.m^{-3}	0.00	%
Combined measurement uncertainty					**0.18**	mg.m^{-3}		

Expanded uncertainty as percentage of measured value	**72.96**	**% measured of value**	**expressed with a level of confidence of 95% (Using a coverage factor k=2)**
Expanded uncertainty in units of measurement	**0.36**	**mg.m^{-3}**	
Expanded uncertainty as percentage of limit value	**3.65**	**% ELV**	

Note: Enter values into green boxes

Developed for the STA by R Robinson, NPL

5.0 Uncertainty calculation for EN 13284 Determination of low range mass concentration of dust, Manual Gravimetric Method

v15

5.2 Banbury Mixer- Test 1

Measurement Equation

$$c = \frac{m}{V} f_c$$

Limit value (ELV)	10	**mg.m^{-3}**	**Reference oxygen**		**% by volume**
Measured concentration	0.70	**mg.m^{-3} (at reference conditions)**			

Measured Quantities	**Symbol**	**Value**	**Standard uncertainty**		**Units**	**Uncertainty as percentage**	**Uncertainty at lv**	**Requirement of std**
Sampled Volume	V_m	0.7962	uV_m	0.001	**m^3**	0.13		<=2%
Sampled gas Temperature	T_m	303	uTm	2	k	0.66		<=1%
Sampled gas Pressure	ρ_m	100.8	$u\rho_m$	1	**kPa**	0.99		<=1%
Sampled gas Humidity	H_m	0	uH_m	1	**% by volume**	1.00		<=1%
Oxygen content	$O_{2,m}$		$uO_{2,m}$	0.1	**% by volume**	#DIV/0!		<=5%
Mass particulate	m	0.5	um	0.18	**mg**	36.42	2.55	<5% of limit value
Note - Sampled gas humidity, temperature and pressure are values at the gas meter								
Leak	L	2			**%**	2.00		<=2%
Uncollected Mass	UCM	0			**mg**	0		<=10%
(Instack filter - no rinse)								

Intermediate calculations							
Factor for std conds	fs	0.90					
uncertainty components	symbol	**sensitivity coeff**	**u (in units of fs)**				
	ρ_m	0.009		0.009			
	H_m	0.009		0.009		$f_s = \frac{(100 - H_m)}{100} \frac{273}{T_m} \frac{\rho_m}{101.3}$	
	T_m	0.003		0.006			
	ufs			0.014			1.56
Corrected volume	V	0.71	uV	0.011	**m^3**	$V = V_m f_s$	1.56
Factor for O2 correction	fc	1.00					
uncertainty components	symbol	**sensitivity coeff**	**u**			$f_c = \frac{21 - O_{2,ref}}{21 - O_{2,m}}$	
	$O_{2,m}$	0.05		0.005			
Factor for O2 Correction	ufc	1.00		0.005			0.48

Parameter		**Value**	**Units**	**Sensitivity coeff**	**Uncertainty contribution**		**Uncertainty as %**	
Corrected Volume (standard conc	V	0.71	m^3	0.98	0.01	mg.m^{-3}	1.56	%
Mass	m	0.50	mg	1.40	0.25	mg.m^{-3}	36.42	%
Factor for O2 Correction	fc	1.00		0.70	0.00	mg.m^{-3}	0.48	%
Leak	L	0.01	mg.m^{-3}	1.00	0.01	mg.m^{-3}	1.15	%
Uncollected mass	UCM	0.00	mg	1.40	0.00	mg.m^{-3}	0.00	%
Combined measurement uncertainty					**0.26**	mg.m^{-3}		

Expanded uncertainty as percentage of measured value	**72.96**	**% measured of value**	**expressed with a level of confidence of 95%** **(Using a coverage factor k=2)**
Expanded uncertainty in units of measurement	**0.51**	**mg.m^{-3}**	
Expanded uncertainty as percentage of limit value	**5.11**	**% ELV**	

Note: Enter values into green boxes

Developed for the STA by R Robinson, NPL

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