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Measurement of Particulate Emissions
Respirable Dust Monitoring
L.E.V.E. Plant Test and Inspection
Noise Surveys

MCERTS
THE ENVIRONMENT AGENCY'S
MONITORING CERTIFICATION SCHEME

Environmental Protection Act
Pollution Prevention & Control

PARTICULATE EMISSION TEST
(BS EN 13284-1:2017)

on

COATING PLANT
BAG FILTER EXHAUST

for

MIDLAND QUARRY PRODUCTS
ST. IVES WORKS
MEADOW LANE
ST. IVES
CAMBRIDGESHIRE PE27 4LG

Tested By: A. Yelland

A. Yelland
MCERTS Level 2 Team Leader (MM 02 130)

Date Of Test : 06.06.18
Date Of Report : 24.06.18
Report No : 2824

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EXECUTIVE SUMMARY

EMISSIONS SUMMARY				
Determined	**Units**	**Results**	**Uncertainty +/-**	**Limit**
Particulate Concentration (STP)	mg/m^3	31.51	0.63	50
Mass Emission (STP)	g/hr	2076.6	41.37	-
Stack Temperature	ºC	97	-	-
Gas Velocity	m/s	17.73	-	-
Stack Volume Flow Rate (Actual)	m^3/hr	92701	-	-
Stack Volume Flow Rate (STP)	m^3/hr	67546	-	-

All results are reported at reference conditions of 273K, 101.3kPa, wet gas.

EXECUTIVE SUMMARY

MONITORING TIMES			
Determined	**Sampling Date**	**Sampling Times**	**Sampling Duration**
Total Particulate Matter Run 1	06.06.18	07.32 - 08.04	32 minutes
Total Particulate Matter Run 2	06.06.18	08.10 - 08.42	32 minutes
Preliminary Stack Traverse	06.06.18	07.25	-

EXECUTIVE SUMMARY

PROCESS DETAILS	
Determined	**Process Details**
Process description	COATING PLANT
Continuous or Batch	Continuous - 20mm base @ 110tph.
Particulate type	Aggregate
Abatement	Bag Filter
Appearance of plume	Light visible discharge.

EXECUTIVE SUMMARY

MONITORING METHODS				
Determined	**Method**	**Technical Procedure**	**Limit of Detection**	**Calculated MU +/-%**
TPM	BS EN 13284-1	EL18	0.12	11.7%
Velocity	BS EN ISO 16911-1	EL20	-	-
Volumetric Flow	BS EN ISO 16911-1	EL20	-	-

1. BACKGROUND INFORMATION

Particulate emission testing was undertaken by Yelland Environmental Services, on the roadstone coating plant exhaust at Midland Quarry Products, St Ives site.

The purpose of the emission testing was to ensure compliance with the requirements of the permit issued by the Local Authority under The Environmental Permitting (England and Wales) Regulations 2010.

2. MONITORING PROTOCOL

2.1 Test Method and references

Isokinetic sampling of the contained emission sources was undertaken using the APEX Instruments Inc Method Five isokinetic sampling apparatus in accordance with the main procedural requirements within the following British Standards and Technical Guidance Notes:-

* BS EN 13284-1:2017 - Stationary source emissions. Dertermination of low range mass concentration of dust.

* Environment Agency - Technical Guidance Document (Monitoring) M1 Sampling requirements for monitoring stack emissions to air from industrial installations; and

* Environment Agency - Technical Guidance Document (Monitoring) M2 Monitoring of Stack Emissions to Air.

2.2 Sampling procedure

The work carried out was, as far as was reasonably practical, in accordance with BS EN 13284-1:2017.

Isokinetic flow means that sample gases laden with particulates are drawn off at the same velocity as the free stream velocity in the flue. Isokinetic sampling thus avoids possible inertial effects of particulates approaching the vicinity of the inlet nozzle which may result in significant error.

The Apex Instruments test equipment was designed to meet the sampling requirements of US EPA Method 5 and with a modified nozzle design, meets the sampling requirements of BS EN 13284-1.

The principle of the standard is to draw a known volume of dust laden gas isokinetically through a filter. The weight gain on the filter, after sampling, divided by the gas sample volume equates to the particulate concentration, which in turn can be used to calculate a mass emission.

2.3 Sampling equipment

The test equipment is inspected prior to use and it's calibration status observed. This includes:-

* *Pitot Tube* - All pitot tubes are checked for damage, alignment and that there are no blockages;

* *Manometer* - Check of oil levels, connectors and orientation level;

* *Thermocouple* - Temperature is measured using k type thermocouples. Each thermocouple is inspected for calibration and damage. Digital temperature meters are used in conjunction with k type thermocouples which are also checked for calibration dates;

* Gas meter - The calibration of the gas meter is checked before and after sampling using a critical orifice.

* *Nozzles* - All nozzles used have been constructed in accordance with BS EN 13284-1. Each nozzle is checked for damaged and measured using a vernier calliper on at least 3 planes. Non conforming nozzles will be rejected.

* *Balance* - A Mettler Toledo balance is used to weigh filters. It is calibrated yearly by the manufacturer and checked daily by in-house weights.

* *Filters* - Quartz membrane filters with a collection efficiency of >99.5% at 0.3microns.

2.4 Preparation for sampling

2.4.1 Filter preparation

Filters are pre-conditioned before arrival on site. The filters are dried in an oven at 180°C for a period of at least one hour and then placed to cool in a desiccator for at least four hours. The filters are then weighed on a five figure balance and placed in individual transport containers. Spare Filters are prepared to obtain blank values.

2.4.2 Sampling location

No site visit was undertaken prior to undertaking the sampling procedure, as monitoring had previously been undertaken at the site, during which time the sampling position, working platform, sampling ports, access and safety precautions were found to be satisfactory.

The internal dimension of the flue was known from previous monitoring undertaken. However, further measurements were taken to check that the internal diameter had not changed.

2.4.2 Sampling location - cont.

Prior to sampling a pressure and temperature survey, using a pitot static tube, a micromanometer, a digital thermometer and a nickel-chromium/nickel-aluminium thermocouple, is carried out to check whether the flow conditions meet with the requirements of BS EN 16911. From this initial survey sample locations, isokinetic flow rates, nozzle size, and sample period can be worked out.

2.5 Sample collection

A leak check is carried out before and after sampling to confirm all the suction is drawn through the nozzle.

With the required isokinetic flow rates known the sample probe is inserted into the stack at 90° to the gas flow, this is to stop any particulate matter impinging on the filter before sampling.

The filter head and probe were allowed to obtain the stack gas temperature.

The initial gas meter reading was noted and the suction device and timer started. The correct flow rate for isokinetic sampling was set and the nozzle positioned to face parallel to the gas flow.

Sampling was then carried out for the planned duration and number of sample points, recording all the necessary data for final calculations. On completion, the suction device and timer were stopped and the final gas meter volume recorded.

The probe was removed from the process stack and a further leak test carried out prior to removal of the filter, which was subsequently removed and placed in a storage container.

Any residual particulates upstream of the filter was washed with acetone into an appropriate beaker.

Repeat all of the above procedures to obtain duplicate samples.

At all times during the sampling procedure the sampling technicians were in contact with the process operator to ensure that the plant was in full production and there were no changes in the process that might affect the representative nature of the samples collected.

2.6 Analysis of samples

On returning to the laboratory, the used filters were dried in an oven at 160°C for a minimum of one hour and then desiccated and weighed as before. The water/acetone washings are first evaporated, without boiling, then dried and weighed as above. The total particulate mass is the sum of the differential filter weight added to the differential water/acetone rinsings component.

2.7 Calculation of results

The calculations were made using the formula specified in BS EN 13284-1.

The recorded filter weights, velocity, temperature, sampling duration and internal flue dimensions were then used to calculate:-

* the mass rate of solids emission in kg/hr; and
* the solids concentration in mg/m^3.

3. QUALITY ASSURANCE

3.1 Location

SAMPLING LOCATION					
Determined	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest differential pressure	134	Pa	>= 5Pa	Yes	BS EN 15259
Highest differential pressure	166	Pa	-	-	
Ratio of gas pressures	1.2	Pa	<9:1	No	BS EN 15259
Mean gas velocity	17.7	m/s	-	-	-
Temperature deviation	370	K	<10%	Yes	BS EN 13284
Max angle of flow	<15	o	<15^{o}	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259

Duct Details		
	Value	Units
Shape	Circular	-
Depth	1.36	m
Width		m
Area	1.45	m^2
Port	0.09	m

Duct Details	
	Isokinetic
Sample port size	4" BSP
Number of lines used	2
Number of points/line	4
Duct orientation	Vertical
Filtration for TPM	In stack

3.2 Methods

MONITORING METHODS		
Determined	**Method**	**Technical Procedure**
TPM	Gravimetric	EL18
H2O	Gravimetric	EL5

3.3 Test Team

MONITORING TEAM						
Personnel	**MCERTS Number**	**MCERTS**		**TE/H&S Qualifications**		
		Level	**Expiry**	**TE1**	**H&S**	
Andrew Yelland	MM 02 130	MCERTS Level 2	Jul-19	Apr-23	Jul-19	
Ryan Carkeek	-	-	-	-	-	

4. ON-SITE SUMMARY/MEASURMENTS

TOTAL PARTICULATE MATTER SUMMARY				
Determined	**Sampling Times**	**Concentration mg/m^3**	**Uncertainty mg/m^3**	**Limit mg/m^3**
Run 1	07.32 - 08.04	29.73	0.63	50
Run 2	08.10 - 08.42	33.30	0.68	50
Blank	-	0.12	-	-

FILTER SUMMARY					
Determined	**Filter No**	**Filter Start Weight g**	**Filter Start Weight g**	**Acetone Rinse Weight g**	**Combined Mass Gained g**
Run 1	11	0.05630	0.07618	0.00004	0.01992
Run 2	12	0.05625	0.07925	0.00006	0.02306
Blank	13	0.05608	0.05614	0.00002	0.00008

STANDARD UNCERTAINTY SUMMARY				
Measured Quantities	**Value**	**Standard uncertainty**	**Uncertainty %**	**Requirement of std**
Sampled Volume - V_m	0.7595	uV_m 0.001 **m^3**	0.13	<=2% Pass
Sampled gas Temp - T_m	287	uTm 2 k	0.70	<=1% Pass
Sampled gas Pressure - ρm	99.9	$u\rho_m$ 0.5 **kPa**	0.50	<=1% Pass
Sampled gas Humidity - Hm	2.56	uH_m 0.5 **% by vol**	0.20	<=1% Pass
Oxygen content - O2,m	17	$uO_{2,m}$ 0.1 **% by vol**	0.59	<=5% Pass
Mass particulate - m	19.92	um 0.01 **mg**	0.05	0.03 <5% of limit val
Note - Sampled gas humidity, temperature and pressure are values at the gas meter				
Leak - L	0.33	**%**	0.33	<=2% Pass
Uncollected Mass - UCM (Instack filter - no rinse)	0.08	**mg**	0.40	<=10% Pass

MOISTURE SUMMARY					
RUN	**Trap Start Weight g**	**Trap End Weight g**	**Difference g**	**Volume sampled m^3**	**Bwo %**
Run 1	539.7	553.9	14.2	0.6700	2.56
Run 2	537.4	552.2	14.8	0.6926	2.58

4.1 Preliminary stack survey

On Site Velocity and Flow Data

Company	MIDLAND QUARRY PRODUCTS	Stack Diameter	1.36	m
Site	ST. IVES WORKS	Area	1.45	m^2
Location	COATING PLANT	Sample points required	8	
Job No	2824	Barometric Pressure	99.9	kPa
Operators	AJY/RJC	Stack Pressure	0.02	kPa
		Pitot Tube Coefficient	0.997	

Preliminary readings taken before sampling

	Pitot Traverse A		Pitot Traverse B	
Pitot Settings	Δ P pa	Temp ºC	Δ P pa	Temp ºC
1	149	97	141	96
2	156	97	163	96
3	154	97	166	96
4	150	97	162	97
5	153	96	159	97
6	156	96	156	97
7	154	96	143	97
8	145	96	140	98
9	139	95	134	98
10	134	95	148	97
Mean	149	96	151	97

4.2 Leak check results

PITOT LEAK CHECK						
Run	Pre traverse leak rate			Post traverse leak rate		
	Start value Pa	End value Pa	Difference %	Start value Pa	End value Pa	Difference %
Run 1	250	250	Pass	250	250	Pass
Run 2	250	250	Pass	250	250	Pass

S-TYPE STAGNATION CHECK			
Run	Stagnation Pa	Reference Pa	Difference Permitted +/- 10 Pa
Run 1	45	45	Pass
Run 2	45	45	Pass

SAMPLE TRAIN LEAK CHECK					
Run	Mean Sampling Rate litres/min	Pre-sampling Leak Rate litres/min	Post-sampling Leak Rate litres/min	Acceptable Leak Rate litres/min	Maximum Leak Rate %
Run 1	29.98	0.09	0.10	0.60	Yes
Run 2	30.10	0.10	0.08	0.60	Yes

SAMPLE TRAIN LEAK CHECK				
Run	Blank Value mg/m^3	Emission Limit Value mg/m^3	Acceptable Blank Value mg/m^3	Blank Value Acceptable mg/m^3
Blank 1	0.12	50	5	Yes

5. SAMPLING RECORDS

5.1 Process Conditions

Arrestment Plant:	Bag Filter
Particulate Type:	Aggregate
Plant Loading:	Continuous - 20mm base @ 110tph.
Appearance of plume:	Light visible discharge.

5.2 Sampling Results

	Test Run No. 1.	Test Run No. 2.	Average
Time of Test:	07.32 - 08.04	08.10 - 08.42	
Sampling Duration: (mins)	32	32	
Gas Temperature (°C)	97	95	96
Mean Velocity at Sampling Points: (m/s)	17.67	17.74	17.71
Gas Flow Rate at STP (1): (m^3/min)	1093.8	1102.3	1098.0
Particulate Loading at STP (1): (mg/m^3)	29.73	33.30	31.51
Particulate at Normalised Conditions (2): (mg/m^3)	-----	-----	-----

(1) Particulate stated at 273K, 101.3kPa without correction for water vapour.

(2) State normalised conditions (eg 11% O_2, etc).

5.3 - Calculations Sample Run No. 1

On-site measurements

O_2 = 17 % CO_2 = 2.1 % N_2 = 80.9 %

B_{ws} = 0.03 P_s = 99.9 kPa T_s = 369.5 K

Md = Molecular weight of gas at DGM (g/g mole)

$Md = (0.44 \times \%CO_2) + (0.32 \times \%O_2) + (0.28 \times \%N_2)$

= 29.02 g/g mole

Ms = Molecular weight of gas wet (g/g mole)

= 28.69 g/g mole

Stack gas velocity at sample points

$V = Kp \times Cp \times \sqrt{(Ts.\Delta P/Ps.Ms)}$

= 17.67 m/s

Kp = 4.07

ΔP = 147.1 av. Δp at sample plane

Cp = 1.00 pitot tube coefficient

Stack gas volume at sample points

$Q = V \times A \times 60$

= 1540.3 m^3/min

A = 1.45 area of stack m^2

Volume of water vapour collected, standard conditions (m^3)

$Vwstd = 0.00124 \times Vlc$

= 0.0176 m^3

Vlc = 14 ml

Volume of gas metered, standard conditions (m^3)

$$Vmstd = \frac{2.695 \times Vm \times (Pa + (\Delta H/102)) \times Yd}{(T + Tm)}$$

= 0.67 m^3

Tm = 14 °C

Vm = 0.7595 m^3

Pa = 99.9 kPa

ΔH = 47.9 mm H_2O

Yd = 0.936

Moisture content

$Bwo = Vwstd/(Vwstd + Vmstd)$

= 0.0256

5.3 - Calculations Sample Run No. 1 Cont.

Dry total flow of stack gas, standard conditions (m^3/min)

$$Qstd = \frac{Q \times Ps(2.695)(1 - Bwo)}{Ts + 273}$$

$$= 1094 \text{ m}^3\text{/min}$$

Ts = 96.5 °C
Ps = 99.9 kPa

Percent isokinetic

$$\%I = \frac{(6.184 \times 10^5)(Ts + 273) \times Vmstd}{Ps \times V \times Aa \times t \times (1 - Bwo)}$$

$$= 98.4 \ \%$$

Aa = 28.3 area of nozzle mm^2

Filter & rinsing weights sample no. 1

weight gain on filters = 19.88 mg
weight of acetone wash = 0.04 mg
total weight gain (M) = 19.92 mg

Particulate concentration (mg/m^3)

$$C = M/Vmstd$$

$$= 29.73 \text{ mg/m}^3$$

M = 19.92 mg

Particulate emission rate (kg/hr)

$$E = (C \times Qstd \times 60)/1000000$$

$$= 1.95 \text{ kg/hr}$$

5.3 - Calculations Sample Run No. 2

On-site measurements

$O2 =$ 17.0 % $CO2 =$ 2.1 % $N2 =$ 80.9 %

$Bws =$ 0.03 $Ps =$ 99.9 kPa $Ts =$ 368.0 K

Md = Molecular weight of gas at DGM (g/g mole)

$Md = (0.44 \times \%CO_2) + (0.32 \times \%O_2) + (0.28 \times \%N_2)$

= 29.02 g/g mole

Ms = Molecular weight of gas wet (g/g mole)

= 28.73 g/g mole

Stack gas velocity at sample points

$V = Kp \times Cp \times \sqrt{(Ts.\Delta P/Ps.Ms)}$

= 17.74 m/s

Kp = 4.07

$\Delta P =$ 149.1 av. Δp at sample plane

Cp = 1.00 pitot tube coefficient

Stack gas volume at sample points

$Q = V \times A \times 60$

= 1546.3 m^3/min

A = 1.45 area of stack m^2

Volume of water vapour collected, standard conditions (m^3)

$Vwstd = 0.00124 \times Vlc$

= 0.0184 m^3

Vlc = 15 ml

Volume of gas metered, standard conditions (m^3)

$$Vmstd = \frac{2.695 \times Vm \times (Pa + (\Delta H/102)) \times Yd}{(T + Tm)}$$

= 0.6926 m^3

Tm = 15 ^oC

Vm = 0.7877 m^3

Pa = 99.9 kPa

$\Delta H =$ 49 mm H_2O

Yd = 0.936

Moisture content

Bwo = Vwstd/(Vwstd +Vmstd)

= 0.0258

5.3 - Calculations Sample Run No. 2 Cont.

Dry total flow of stack gas, standard conditions (m^3/min)

$$\mathrm{Qstd} = \frac{\mathrm{Q \times Ps(2.695)(1 - Bwo)}}{\mathrm{Ts} + 273}$$

Ts = 95.0 °C
Ps = 99.9 kPa

= 1102.3 m^3/min

Percent isokinetic

$$\%\mathrm{I} = \frac{(6.184 \times 10^5)(\mathrm{Ts} + 273) \times \mathrm{Vmstd}}{\mathrm{Ps \times V \times Aa \times t \times (1 - Bwo)}}$$

Aa = 28.3 area of nozzle mm^2

= 100.9 %

Filter & rinsing weights sample no. 2

weight gain on filters = 23.00 mg
weight of acetone wash = 0.06 mg
total weight gain (M) = 23.06 mg

Particulate concentration (mg/m^3)

C = M/Vmstd

M = 23.06 mg

= 33.30 mg/m^3

Particulate emission rate (kg/hr)

E = (C x Qstd x 60)/1000000
= 2.20 kg/hr

5.4 - Sample Blank

An overall sample blank was taken after the measurement series, following the sampling procedure in the methodology without starting the suction device and keeping the blank in the duct for 15 minutes with the sampling nozzle 180o from the direction of flow. This leads to an estimation of the the dispersion of results related to the whole procedure.

weight gain on filters = 0.00006 mg

weight of acetone wash = 0.00002 mg

total weight gain (M) = 0.00008 mg

Particulate concentration (mg/m^3)

C = M/Vmstd M = 0.08 mg

= 0.12 mg/m^3

5.5 - Sampling Conditions

	Sample Run No. 1			**Sample Run No. 2**		
Sample Position	Stack Temp ^{o}C	Velocity Pressure ΔP (Pa)	Nozzle Area mm^2	Stack Temp ^{o}C	Velocity Pressure ΔP (Pa)	Nozzle Area mm^2
0.065D	97	149	28.3	96	152	28.3
0.25D	97	154	28.3	95	157	28.3
0.75D	96	145	28.3	95	147	28.3
0.935D	95	134	28.3	94	136	28.3
0.065D	96	141	28.3	95	144	28.3
0.25D	96	166	28.3	96	169	28.3
0.935D	98	140	28.3	95	142	28.3
0.935D	97	148	28.3	94	146	28.3

5.6 - Weighing Results

The below filters and acetone rinsings were weighed on a balance in a temperature controlled room with corrections made for differences in atmospheric pressure. Control parts and blank filters are used to confirm accuracy of weighings.

Sample Run No.1.	Ref No.	Weight gms Before	After	Collected	Sample time at each point (mins)	% weight gain
Filter	11	0.05630	0.07618	0.01988	4.0	35.4%
Acetone	A11	0.05618	0.05622	0.00004		0.1%
			Total weight =	0.01992		
Sample Run No.2.	Ref No.	Weight gms Before	After	Collected	Sample time at each point (mins)	
Filter	12	0.05625	0.07925	0.02300	4.0	40.9%
Acetone	A12	0.05647	0.05653	0.00006		0.1%
			Total weight =	0.02306		
Sample Blank	Ref No.	Weight gms Before	After	Collected	Sample time at each point (mins)	
Filter	13	0.05608	0.05614	0.00006	n/a	0.1%
Acetone	A13	0.05639	0.05641	0.00002	n/a	0.0%
			Total weight =	0.00008		

6. Uncertainty calculation for EN 13284-1:2017

Sample Run No. 1

Measurement Equation

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

Limit value	50	**mg.m^{-3}**	O2 Ref	21	%
Measured conc.	29.73	**mg.m^{-3}**			

Measured Quantities	**Symbol**	**Value**	**Standard uncertaint**		**Units**	**Uncertainty %**		**Requirement of std**
Sampled Volume	V_m	0.7595	uV_m	0.001	**m^3**	0.13		<=2%
Sampled gas Tem	T_m	287.0	uTm	2	k	0.70		<=1%
Sampled gas Pressure	ρ_m	99.9	$u\rho_m$	0.5	**kPa**	0.50		<=1%
Sampled gas Humidity	H_m	2.56	uH_m	0.5	**% by vol**	0.20		<=1%
Oxygen content	$O_{2,m}$	17	$uO_{2,m}$	0.1	**% by vol**	0.59		<=5%
Mass particulate	m	19.92	um	0.01	**mg**	0	0.03	<5% of limit val
Note - Sampled gas humidity, temperature and pressure are values at the gas meter								
Leak	L	0.33			**%**	0.33		<=2%
Uncollected Mass (Instack filter - no rinse)	UCM	0.08			**mg**	0.40		<=10%

Intermediate calculations

Factor for std conds	fs	0.88					
uncertainty components	symbol	**sensitivity coeff**		**u (in units of fs)**			
	ρ_m	0.009		0.004		$f_s = \frac{(100 - H_m)}{100} \frac{273}{T_m} \frac{\rho_m}{101.3}$	
	H_m	0.009		0.005			
	T_m	0.003		0.006			
	ufs			0.009			1.00
Corrected volume	V	0.67	uV	0.007	m^3	$V = V_m f_s$	1.01
Factor for O2 correction	fc	1.00					
uncertainty components	symbol	**sensitivity coeff**		**u**		$f_c = \frac{21 - O_{2,ref}}{21 - O_{2,m}}$	
	$O_{2,m}$	0.25		0.025			
Factor for O2 Corr	ufc	1.00		0.025			1.00

Parameter	**Uncertainty**	**Value**	**Units**	**ens coeff**	**Uncertainty in Resul**		**Uncertainty as %**	
Volume(stp)	V	0.67	m^3	44.37	0.30	mg.m^{-3}	1.01	%
Mass	m	19.92	mg	1.49	0.01	mg.m^{-3}	0.05	
Factor for O2 Correction	fc	1.00		0.00	0.00	mg.m^{-3}	0.00	%
Leak	L	0.06	mg.m^{-3}	1.00	0.06	mg.m^{-3}		
Uncollected mass	UCM	0.05	mg	1.49	0.07	mg.m^{-3}		
Combined uncertainty					**0.31**	mg.m^{-3}		

Expanded uncertainty expressed with a level of confidence of 95% **2.11 %**

Expanded uncertainty expressed with a level of confidence of 95% **0.63 mg.m^{-3}**

6. Uncertainty calculation for EN 13284-1:2017

Sample Run No. 2

Measurement Equation

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

Limit value	50	**mg.m^{-3}**	O2 Ref	21	%
Measured conc.	33.30	**mg.m^{-3}**			

Measured Quantities	**Symbol**	**Value**	**Standard uncertaint**		**Units**	**Uncertainty %**		**Requirement of std**
Sampled Volume	V_m	0.7877	uV_m	0.001	**m^3**	0.13		<=2%
Sampled gas Tem	T_m	288.0	uTm	2	k	0.69		<=1%
Sampled gas Pressure	ρ_m	99.9	$u\rho_m$	0.5	**kPa**	0.50		<=1%
Sampled gas Humidity	H_m	2.58	uH_m	0.5	**% by vol**	0.19		<=1%
Oxygen content	$O_{2,m}$	17.0	$uO_{2,m}$	0.1	**% by vol**	0.59		<=5%
Mass particulate	m	23.06	um	0.01	**mg**	0	0.03	<5% of limit val
Note - Sampled gas humidity, temperature and pressure are values at the gas meter								
Leak	L	0.27			**%**	0.27		<=2%
Uncollected Mass (Instack filter - no rinse)	UCM	0.08			**mg**	0.35		<=10%

Intermediate calculations

Factor for std conds	fs	0.88					
uncertainty components	symbol	**sensitivity coeff**		**u (in units of fs)**			
	ρ_m	0.009		0.004		$f_s = \frac{(100-H_m)}{100}\frac{273}{T_m}\frac{\rho_m}{101.3}$	
	H_m	0.009		0.005			
	T_m	0.003		0.006			
	ufs			0.009			1.00
Corrected volume	V	0.69	uV	0.007	**m^3**	$V = V_m f_s$	1.01
Factor for O2 correction	fc	1.00					
uncertainty components	symbol	**sensitivity coeff**		**u**		$f_c = \frac{21 - O_{2,ref}}{21 - O_{2,m}}$	
	$O_{2,m}$	0.25		0.025			
Factor for O2 Corr	ufc	1.00		0.025			1.00

Parameter	**Uncertainty**	**Value**	**Units**	**ens coeff**	**Uncertainty in Resul**		**Uncertainty as %**	
Volume(stp)	V	0.69	m^3	48.08	0.34	mg.m^{-3}	1.01	%
Mass	m	23.06	mg	1.44	0.01	mg.m^{-3}	0.04	
Factor for O2 Correction	fc	1.00		0.00	0.00	mg.m^{-3}	0.00	%
Leak	L	0.05	mg.m^{-3}	1.00	0.05	mg.m^{-3}		
Uncollected mass	UCM	0.00	mg	1.44	0.00	mg.m^{-3}		
Combined uncertainty					**0.34**	mg.m^{-3}		

Expanded uncertainty expressed with a level of confidence of 95% **2.04 %**

Expanded uncertainty expressed with a level of confidence of 95% **0.68 mg.m^{-3}**