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Stack Emissions Testing Report Commissioned by
Enviro Solution

Installation Name & Address
Rapid Precision Engineering Ltd
Unit 16 Brickfields
Wilson Road
Huyton Business Park
Liverpool
L36 6HY

PPC Permit: None

Stack Reference
Passivation Stack

Dates of the Monitoring Campaign
17th February 2017

Job Reference Number
CAT-3250

Report Written by
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Report Date
16th March 2017

Version
Version 1

Signature of Report Approver

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Executive Summary

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MONITORING OBJECTIVES

Rapid Precision Engineering Ltd, Liverpool
Passivation Stack
17th February 2017

Overall Aim of the Monitoring Campaign

Exova Catalyst were commissioned by Enviro Solution to carry out stack emissions testing for Rapid Precision Engineering Ltd on the Passivation Stack at Liverpool.

The aim of the monitoring campaign was to perform testing, as requested by the customer, for a number of prescribed pollutants. There are no emission limits set for any of the pollutants at this time.

Special Requirements

There were no special requirements.

Target Parameters

Chromium, Hexavalent Chromium (Cr^{+6}) in Fine Particulate Matter, Total Oxides of Nitrogen

Executive Summary

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MONITORING RESULTS

Rapid Precision Engineering Ltd, Liverpool
 Passivation Stack
 17th February 2017

where MU = Measurement Uncertainty associated with the Result

Parameter	Concentration				Mass Emission			
	Units	Result	MU +/-	Limit	Units	Result	MU +/-	Limit
Chromium ¹	mg/m ³	0.03	0.004	-	g/hr	0.05	0.01	-
Hexavalent Chromium (Cr ⁺⁶) in Fine Particulate Matter	mg/m ³	< 0.00016	0.00002	-	g/hr	< 0.0003	0.00005	-
Total Oxides of Nitrogen	mg/m ³	< 6.0	0.74	-	g/hr	< 10.7	1.5	-
Water Vapour	% v/v	1.5	0.58					
Stack Gas Temperature	°C	16.6						
Stack Gas Velocity	m/s	3.7	0.16					
Volumetric Flow Rate (ACTUAL)	m ³ /hr	1918	121					
Volumetric Flow Rate (REF)	m ³ /hr	1791	113					

NOTE: VOLUMETRIC FLOW RATE & VELOCITY DATA TAKEN FROM AN AVERAGE OF ALL OF THE ISOKINETIC RUNS.

¹ Reference Conditions (REF) are: 273K, 101.3kPa, without correction for water vapour content.

Executive Summary

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MONITORING DATE(S) & TIMES

Rapid Precision Engineering Ltd, Liverpool
 Passivation Stack
 17th February 2017

Parameter	Units	Concentration	Units	Mass Emission	Sampling Date(s)	Sampling Times	Duration mins
Chromium	R1 mg/m ³	0.03	g/hr	0.05	17/02/2017	10:27 - 10:57, 10:59 - 11:29	60
Hexavalent Chromium (Cr ⁺⁶) in Fine Particulate Matter	R1 mg/m ³	< 0.0002	g/hr	< 0.0003	17/02/2017	12:38 - 13:38	60
Total Oxides of Nitrogen	R1 mg/m ³	< 6.0	g/hr	< 10.7	17/02/2017	11:32 - 12:32	60
Velocity & Volumetric Flow Rate	R1				17/02/2017	10:05 - 10:21	

All results are expressed at the respective reference conditions.

Executive Summary

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PROCESS DETAILS

Rapid Precision Engineering Ltd, Liverpool
Passivation Stack
17th February 2017

Standard Operating Conditions

Parameter	Value
Process Status	Normal Operation
Capacity (of 100%) and Tonnes / Hour	Full Capacity
Continuous or Batch Process	Continuous Batch
Feedstock (if applicable)	Plane Parts
Abatement System	Bag Filter
Abatement System Running Status	On
Fuel	N/A
Plume Appearance	None Visible

Executive Summary

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MONITORING & ANALYTICAL METHODS

Rapid Precision Engineering Ltd, Liverpool

Passivation Stack

17th February 2017

Parameter	Monitoring				Analysis				MCERTS Testing	LOD (Average)
	Standard	Technical Procedure	ISO 17025 Testing	Testing Lab	Analytical Procedure	Analytical Technique	ISO 17025 Analysis	Analysis Lab		
Chromium	EN 14385	CAT-TP-06	Yes	CAT	M31-BS EN14385	ICP-MS	Yes	RPS	Yes	0.0004 mg/m ³
Hexavalent Chromium (Cr ⁺⁶) in Fine Particulate Matter	Based on EN ISO 23210	CAT-TP-18	Yes	CAT	CAT-AP-06	UV-VIS	No	CAT	No	0.00016 mg/m ³
Total Oxides of Nitrogen	US EPA M7D	CAT-TP-35	Yes	CAT	C27	IC	Yes	RPS	Yes	5.957 mg/m ³
Water Vapour	EN 14790	CAT-TP-05	Yes	CAT	CAT-TP-05	Gravimetric	Yes	CAT	Yes	0.10 % v/v
Velocity & Vol. Flow Rate	EN 16911-1 (MID)	CAT-TP-41	Yes	CAT	Pitot Tube and Thermocouple				Yes	1.2 m/s

ANALYSIS LABORATORIES

(with short name reference as appears in the table above)

Exova Catalyst (CAT)	ISO 17025 Accreditation Number: 4279
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SUMMARY OF SAMPLING DEVIATIONS

Parameter	Run	Deviation
All Parameters	All	There are no deviations associated with the sampling employed.

Executive Summary

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SUITABILITY OF SAMPLING LOCATION

Duct Characteristics

Parameter	Units	Value
Type	-	Circular
Depth	m	0.43
Width	m	-
Area	m ²	0.15
Port Depth	cm	9
Orientation of Duct	-	Vertical
Sample Port Size	-	4" BSP

Location of Sampling Platform

General Platform Information	Value
Permanent / Temporary Platform	Temporary
Inside / Outside	Inside

Platform Details

EA Technical Guidance Note M1 / EN 15259 Platform Requirements	Value
Sufficient working area to manipulate probe and operate the measuring instruments	Yes
Platform has 2 levels of handrails (approx. 0.5m & 1.0m high)	Yes
Platform has vertical base boards (approx. 0.25m high)	Yes
Platform has chains / self closing gates at top of ladders	Yes
There are no obstructions present which hamper insertion of sampling equipment	Yes
Safe Access Available	Yes
Easy Access Available	Yes

Sampling Location / Platform Improvement Recommendations

All platforms should be designed in accordance with the requirements in the Environment Agency's Technical Guidance Note M1 and EN 15259.

EN 15259 Homogeneity Test Requirements

There is no requirement to perform a EN 15259 Homogeneity Test on this Stack.

Sampling Plane Validation Criteria (from EN 15259)

Criteria in EN 15259	Units	Traverse 1	Required	Compliant
Lowest Differential Pressure	Pa	14.0	> 5 Pa	Yes
Mean Velocity	m/s	13.43	-	-
Lowest Gas Velocity	m/s	12.57	-	-
Highest Gas Velocity	m/s	14.26	-	-
Ratio of Above	: 1	1.13	< 3 : 1	Yes
Maximum Angle of Swirl	°	0	< 15°	Yes
No Local Negative Flow	-	Yes	-	Yes

Executive Summary

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PLANT PHOTOS

Photo 1



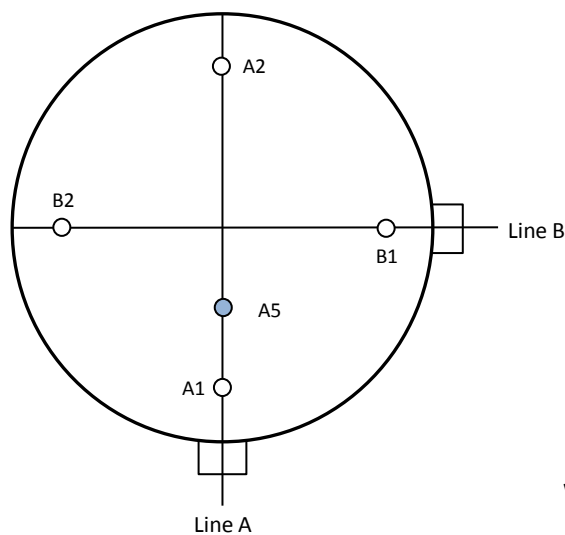
Photo 2



Photo 3



SAMPLE POINTS



- where
- = isokinetic point sampled at
 - = isokinetic point not sampled at
 - = combustion gases sample point
 - = non-isokinetic sample point



APPENDICES

APPENDIX CONTENTS

APPENDIX 1 - Stack Emissions Monitoring Personnel, List of Equipment & Methods and Technical Procedures Used

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK EMISSIONS MONITORING PERSONNEL

Position	Name	MCERTS Accreditation	MCERTS Number	Technical Endorsements
Team Leader	Danny Pryke	MCERTS Level 2	MM 03 163	TE1 TE2 TE3 TE4
Technician	Craig Macdonald	MCERTS Level 1	MM 11 1130	None

LIST OF EQUIPMENT

Extractive Sampling		Instrumental Analysers		Miscellaneous Items	
Equipment Type	Equipment I.D.	Equipment Type	Equipment I.D.	Equipment Type	Equipment I.D.
Control Box DGM (1)	CAT 7.62	Horiba PG-250	-	Digital Manometer (1)	CAT 3.25
Control Box DGM (2)	-	Horiba PG-250	-	Digital Manometer (2)	-
Box Thermocouples (1)	-	Servomex 4900	-	Digital Temperature Meter	CAT 3.25
Box Thermocouples (2)	-	Eco Physics CLD 822Mh	-	Stopwatch	CAT 14.72
Umbilical (1)	CAT 7.62	ABB AO2020-URAS26	-	Barometer	CAT 13.38
Umbilical (2)	-	Servomex 5200MP	-	Stack Thermocouple (1)	-
Oven Box (1)	CAT DP	JCT JCC P1 Cooler	-	Stack Thermocouple (2)	-
Oven Box (2)	-	Gasmet DX4000	-	Stack Thermocouple (3)	-
Heated Probe (1)	CAT 5.12	Gasmet Sampling System	-	1m Heated Line (1)	-
Heated Probe (2)	-	Bernath 3006 FID	CAT 8.61	1m Heated Line (2)	-
Heated Probe (3)	-	M&C PSS	-	1m Heated Line (3)	-
S-Pitot (1)	-	Mass Flow Controller (1)	CAT 6.48	10m Heated Line (1)	CAT 20.69
S-Pitot (2)	-	Mass Flow Controller (2)	CAT 6.49	15m Heated Line (1)	-
L-Pitot	-	Mass View (1)	CAT 25.46	20m Heated Line (1)	-
Site Balance	CAT 17.26	Mass View (2)	CAT 25.47	20m Heated Line (2)	-
500g / 1Kg Check Weights	CAT 17.26	Easylogger EN-EL-12 Bit	-	Dual Channel Heater Controller	-
Last Impinger Arm	-	Easylogger EN-EL-12 Bit	-	Single Channel Heater Controller	-
Callipers	CAT 23.27	Bioaerosols Temperature Logger	-	Laboratory Balance	-
Tubes Kit Thermocouple	-	Electronic Refrigerator	-	Tape Measure	CAT 16.31

METHODS & TECHNICAL PROCEDURES USED

Parameter	Standard	Technical Procedure
Chromium	EN 14385	CAT-TP-06
Hexavalent Chromium (Cr ⁺⁶) in Fine Particulate Matter	Based on EN ISO 23210	CAT-TP-18
Total Oxides of Nitrogen	US EPA M7D	CAT-TP-35
Water Vapour	EN 14790	CAT-TP-05
Velocity & Vol. Flow Rate	EN 16911-1 (MID)	CAT-TP-41

PRELIMINARY STACK SURVEY: CALCULATIONS

General Stack Details

Stack Details (from Traverse)	Units	Value
Stack Diameter / Depth, D	m	0.43
Stack Width, W	m	-
Stack Area, A	m ²	0.15
Average Stack Gas Temperature, T _a	°C	15.8
Average Stack Gas Pressure	Pa	16.0
Average Stack Static Pressure, P _{static}	kPa	0.013
Average Barometric Pressure, P _b	kPa	10.4
Average Pitot Tube Calibration Coefficient, C _p	-	0.84

Stack Gas Composition & Molecular Weights

Component	Conc ppm	Conc Dry % v/v	Conc Wet % v/v	Volume Fraction r	Molar Mass M	Density kg/m ³ p	Conc kg/m ³ p _i
CO ₂ (Estimated)	-	0.06	0.06	0.0006	44.01	1.9635	0.00118
O ₂ (Estimated)	-	20.80	20.48	0.2080	32.00	1.4277	0.29696
N ₂	-	79.14	77.93	0.7914	28.01	1.2498	0.98913
Moisture (H ₂ O)	-	-	1.53	0.0153	18.02	0.8037	0.01227

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

Calculation of Stack Gas Densities

Determinand	Units	Result
Dry Density (STP), P _{STD}	kg/m ³	1.287
Wet Density (STP), P _{STW}	kg/m ³	1.280
Dry Density (Actual), P _{Actual}	kg/m ³	0.125
Average Wet Density (Actual), P _{ActualW}	kg/m ³	0.124

Where: P_{STD} = sum of component concentrations, kg/m³ (not including water vapour)
P_{STW} = sum of all wet concentrations / 100 x density, kg/m³ (including water vapour)
 $P_{Actual} = P_{STD} \times (T_{STP} / (P_{STP})) \times ((P_{static} + P_b) / T_a)$
 $P_{ActualW} \text{ (at each sampling point)} = P_{STW} \times (T_s / P_s) \times (P_a / T_a)$

Calculation of Stack Gas Volumetric Flowrate, Q

Duct gas flow conditions	Units	Actual	REF ¹
Temperature	°C	15.8	0.0
Total Pressure	kPa	10.4	101.3
Moisture	%	1.53	1.53

Gas Volumetric Flowrate (from Traverse)	Units	Result
Gas Volumetric Flowrate (Actual)	m ³ /hr	7022
Gas Volumetric Flowrate (STP, Wet)	m ³ /hr	682
Gas Volumetric Flowrate (STP, Dry)	m ³ /hr	672
Gas Volumetric Flowrate REF ¹	m ³ /hr	682

PRELIMINARY STACK SURVEY: VELOCITY TRAVERSE TO EN 16911-1 (MID)

(1 of 1)

Parameter	Units	Value
Date of Survey	-	17/02/2017
Time of Survey	-	10:05 - 10:21
Atmospheric Pressure	kPa	10.4
Average Stack Static Pressure	Pa	13
Result of Pitot Stagnation Test	-	Pass
Are Water Droplets Present?	-	No
Device Used	S-Type Pitot with KIMO MP 200 (500Pa)	

Parameter	Units	Value
Initial Pitot Leak Check	-	Pass
Final Pitot Leak Check	-	Pass
Orientation of Duct	-	Vertical
Pitot Tube, C _p	-	0.84
Number of Lines Available	-	2
Number of Lines Used	-	2

Traverse Point	Depth m	Sampling Line A					Sampling Line B				
		ΔP Pa	Temp °C	Wet Density kg/m ³	Velocity m/s	Swirl °	ΔP Pa	Temp °C	Wet Density kg/m ³	Velocity m/s	Swirl °
<i>STATIC (Units: Pa)</i>		14.0					12.0				
Mean		17.5	15.9	0.124	14.06		14.5	15.7	0.124	12.80	
1	0.06	18.0	15.8	0.124	14.26	0.0	14.0	15.6	0.124	12.57	0.0
2	0.37	17.0	16.0	0.124	13.87	0.0	15.0	15.8	0.124	13.02	0.0

PRELIMINARY STACK SURVEY: VELOCITY TRAVERSE TO EN 16911-1 (MID) - MEASUREMENT UNCERTAINTY

(1 of 1)

Performance characteristics (Uncertainty Components)	Uncertainty	Value	Units
Standard Uncertainty on the coefficient of the Pitot Tube	$u(k)$	0.005	-
Standard Uncertainty associated with the mean local dynamic pressures	$u(\Delta p_i)$	1.073	Pa
- Resolution	$u(res)$	0.00087	
- Calibration	$u(cal)$	0.027	
- Drift	$u(drift)$	0.083	
- Lack of Fit	$u(fit)$	0.040	
- Overall corrections to dynamic measurements	$u(C_f)$	0.151	
Standard uncertainty associated with the molar mass of the gas	$u(M)$	0.00003	-
- $\varphi_{O_2,w}$	-	20.482	
- $\varphi_{CO_2,w}$	-	0.059	
- Oxygen, dry	$u(\phi_{O_2,d})$	0.637	
- Carbon Dioxide, dry	$u(\phi_{CO_2,d})$	0.002	
- Water Vapour	$u(\phi_{H_2O})$	0.078	
- Oxygen, wet	$u(\phi_{O_2,w})$	0.627	
- Carbon Dioxide, wet	$u(\phi_{CO_2,w})$	0.002	
Standard uncertainty associated with the stack temperature	$u(T_c)$	1.473	K
Standard uncertainty associated with the absolute pressure in the duct	$u(p_c)$	175.694	Pa
- Atmospheric Pressure	$u(p_{atm})$	175.692	
- Static Pressure	$u(p_{stat})$	0.759	
Standard uncertainty associated with the density in the duct	$u(\rho)$	0.00219	-
Standard uncertainty associated with the local velocities	$u(v_i)$	0.495	Pa
Standard uncertainty associated with the mean velocity	$u(\underline{v})$	0.301	m/s
Standard uncertainty associated with the mean velocity (95% Confidence)	$U_c(v)$	0.590	m/s
Standard uncertainty associated with the mean velocity (95% Confidence), relative	$U_{c,rel}(v)$	4.40	%
Standard uncertainty associated with the volume flow rate (95% Confidence)	$U_c(qV,w)$	443.1	m ³ /hr
- $u^2(a)/a^2$	-	0.00053	
- $u^2(qV,w)/q^2V,w$	-	0.00104	
- $u^2(qV,w)$	-	51107	
- $u(qV,w)$	-	226.1	
Standard uncertainty associated with the volume flow rate (95% Confidence), relative	$U_{c,rel}(qV,w)$	6.31	%

CHROMIUM: RESULTS SUMMARY

Rapid Precision Engineering Ltd, Liverpool
Passivation Stack

Sample Runs

Parameter	Units	Run 1	Mean
Concentration	mg/m ³	0.03	0.03
Uncertainty	±mg/m ³	0.004	0.004
Mass Emission	g/hr	0.05	0.05
Uncertainty	±g/hr	0.01	0.01

Parameter	Units	Run 1	Mean
Water Vapour	% v/v	0.93	0.93
Uncertainty	±% v/v	0.06	0.06

Blank Runs

Parameter	Units	Blank 1	Maximum
Concentration	mg/m ³	0.02	0.02

General Sampling Information

Parameter	Value
Standard	EN 14385
Technical Procedure	CAT-TP-06
Name of Analytical Laboratory	RPS
Analytical Laboratory's Procedure	M31-BS EN14385
ISO 17025 Accredited Analysis?	Yes
Date of Sample Analysis	24/02/2017
Probe Material	Titanium
Filter Housing Material	Titanium
Impinger Material	Borosilicate Glass
Absorption Solution	Potassium Dichromate
Positioning of Filter	Out Stack
Filter Size and Material	47mm Quartz Fibre
Number of Sampling Lines Used	2 / 2
Number of Sampling Points Used	4 / 4
Sample Point I.D.'s	A1, A2, B1 & B2

FORMAT: Number Used / Number Required

FORMAT: Number Used / Number Required

Reference Conditions

Reference Conditions are: 273K, 101.3kPa, without correction for water vapour content.

CHROMIUM: ISOKINETIC SAMPLING CALCULATIONS

Test	Units	Run 1	
Absolute pressure of stack gas, P_s			
Barometric pressure, P _b	mmHg	753.0	
Stack static pressure, P _{static}	mmH ₂ O	1.4	
P _s = (P _b + (P _{static} / 13.6))	mmHg	753.1	
Volume of water vapour collected, V_{wstd}			
Total mass collected in impingers (liquid trap)	g	2.3	
Total mass collected in impingers (silica trap)	g	8.3	
Total mass of liquid collected, V _{lc}	g	10.6	
V _{wstd} = (0.001246)(V _{lc})	m ³	0.0132	
Volume of gas metered dry, V_{mstd}			
Volume of gas sample through gas meter, V _m	m ³	1.4860	
Gas meter correction factor, Y _d	-	1.0090	
Average dry gas meter temperature, T _m	°C	16.3	
Average pressure drop across orifice, ΔH	mmH ₂ O	70.0	
V _{mstd} = ((0.3592)(V _m)(P _b + (ΔH/13.6))(Y _d)) / (T _m + 273)	m ³	1.4113	
Moisture content, B_{w0} & R_{wv}			
B _{w0} = V _{wstd} / (V _{mstd} + V _{wstd})	m ³	0.0093	
B _{w0} as a percentage	% v/v	0.93	
Reported Water Vapour, checked with Tables in EN 14790, R _{wv}	% v/v	0.93	
Volume of gas metered wet, V_{mstw}			
V _{mstw} = (V _{mstd})(100/(100 - R _{wv}))	m ³	1.4245	
Volume of gas metered at Oxygen Reference Conditions, V_{mstd@X%O₂} & V_{mstw@X%O₂}			
IED & Incinerates Hazardous Material? (Yes = no positive O ₂ correction)	-	No	
% wet oxygen measured in gas stream, ACT%O _{2w}	% v/v	N/A	
% dry oxygen measured in gas stream, ACT%O _{2d}	% v/v	N/A	
% oxygen reference condition, REF%O ₂	% v/v	N/A	
O ₂ Reference Factor wet (O _{2REFw}) = (21 - REF%O ₂) / (21 - ACT%O _{2w})	-	N/A	
O ₂ Reference Factor dry (O _{2REFd}) = (21 - REF%O ₂) / (21 - ACT%O _{2d})	-	N/A	
V _{mstw@X%oxygen} = (V _{mstw}) / (O _{2REFw})	m ³	N/A	
V _{mstd@X%oxygen} = (V _{mstd}) / (O _{2REFd})	m ³	N/A	
Molecular weight of dry gas stream, M_d			
CO ₂ (Estimated)	% v/v	0.06	
O ₂ (Estimated)	% v/v	20.80	
Total	% v/v	20.86	
N ₂	% v/v	79.14	
M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)	g/gmol	28.84	
Molecular weight of stack gas (wet), M_s			
M _s = M _d (1 - (R _{wv} /100)) + 18(R _{wv} /100)	g/gmol	28.74	
Velocity of stack gas, V_s			
Pitot tube velocity constant, K _p	-	34.97	
Velocity pressure coefficient, C _p	-	0.84	
Average of velocity heads, ΔP _{avg}	mmH ₂ O	1.18	
Average square root of velocity heads, √ΔP	√mmH ₂ O	1.08	
Average stack gas temperature, T _s	°C	16.3	
V _s = ((K _p)(C _p)(√ΔP)(√T _s + 273)) / (√(M _s)(P _s))	m/s	3.68	
Total flow of stack gas: Actual (Q_a), Wet (Q_{stw}), Dry (Q_{std}), Wet@O_{2REF} (Q_{stwO₂}), Dry@O_{2REF} (Q_{stdO₂})			
Area of stack, A _s	m ²	0.15	
Q _a = (60)(A _s)(V _s)	m ³ /min	32.1	
Conversion factor (K/mm.Hg), C _f	-	0.3592	
Q _{stw} = ((Q _a)(P _s)(C _f)) / ((T _s + 273)	m ³ /min	30.0	
Q _{std} = ((Q _a)(P _s)(C _f)(1 - (R _{wv} /100))) / ((T _s + 273)	m ³ /min	29.7	
Q _{stwO₂} = ((Q _a)(P _s)(C _f)) / ((T _s + 273) / (O _{2REFw}))	m ³ /min	N/A	
Q _{stdO₂} = ((Q _a)(P _s)(C _f)(1 - (R _{wv} /100))) / ((T _s + 273) / (O _{2REFd}))	m ³ /min	N/A	
Percent isokinetic, %I			
Nozzle diameter, D _n	mm	11.98	
Nozzle area, A _n	mm ²	112.80	
Total sampling time, q	min	60	
%I = (4.6398E ⁶)(T _s +273)(V _{mstd}) / (P _s)(V _s)(A _n)(q)(1 - (R _{wv} /100))	%	101.9	

CHROMIUM: SAMPLING DETAILS

Sample Runs

Parameter	Units	Run 1	
Sampling Times	-	10:27 - 10:57, 10:59 - 11:29	
Sampling Dates	-	17/02/2017	
Sampling Device	-	ISO	
Volume Sampled (REF)	m ³	1.4245	
Mass on Filter / in Rinse	µg	13.00	
Mass in Front Impingers	µg	27.68	
Mass in Back Impinger	µg	0.14	
Total Mass Collected	µg	40.82	
Calculated Concentration	mg/m ³	0.0287	
Reported Concentration	mg/m ³	0.0287	

Where: ISO stands for Manual Isokinetic Sampling Train

Blank Runs

Parameter	Units	Blank 1	
Blank Dates	-	17/02/2017	
Average Volume Sampled (REF)	m ³	1.4245	
Mass on Filter / in Rinse	µg	22.00	
Mass in Front Impingers	µg	0.42	
Mass in Back Impinger	µg	< 0.01	
Total Mass Collected	µg	22.43	
Calculated Concentration	mg/m ³	0.0157	
Reported Concentration	mg/m ³	0.0157	

CHROMIUM: QUALITY ASSURANCE

(PAGE 1 OF 2)

Sample Runs

Leak Test Results	Units	Run 1	
Mean Sampling Rate	l/min	24.99	
Pre-Sampling Leak Rate	l/min	0.13	
Post-Sampling Leak Rate	l/min	0.13	
Allowable Leak Rate	l/min	0.50	
Leak Test Acceptable	-	Yes	
Absorption Efficiency	Units	Run 1	
Absorption Efficiency	%	99.7	
Allowable Absorption Efficiency	%	90	
Absorption Efficiency Acceptable	-	Yes	
Detection Limit	Units	Run 1	
Detection Limit	µg/m ³	0.4	
Allowable Detection Limit	µg/m ³	5	
Detection Limit Acceptable	-	Yes	
Water Droplets	Units	Run 1	
Are Water Droplets Present	-	No	
MU (Concurrent Water Vapour)	Units	Run 1	
Measurement Uncertainty (MU)	%	6.0	
Allowable MU	%	20	
MU Acceptable	%	Yes	
Silica Gel (Concurrent Water Vapour)	Units	Run 1	
Less than 50% Faded	%	Yes	
Isokinetic Criterion Compliance	Units	Run 1	
Isokinetic Variation	%	101.9	
Allowable Isokinetic Range	%	95 - 115	
Isokineticity Acceptable	-	Yes	
Filter Temperatures	Units	Run 1	
Maximum Filter Temperature	°C	180	
Impingers Exit Temperature	Units	Run 1	
Maximum Temperature Recorded	°C	7	
Maximum Allowable Temperature	°C	30	
Exit Temperature Acceptable	-	Yes	
Test Conditions	Units	Run 1	
Ambient Temperature Recorded?	-	Yes	

CHROMIUM: QUALITY ASSURANCE

(PAGE 2 OF 2)

Blank Runs

Leak Test Results	Units	Blank 1	
Expected Sampling Rate	l/min	20.00	
Pre-Sampling Leak Rate	l/min	0.11	
Post-Sampling Leak Rate	l/min	0.12	
Allowable Leak Rate	l/min	0.40	
Leak Test Acceptable	-	Yes	

Validity of Blank vs ELV	Units	Blank 1	
Allowable Blank	mg/m ³	N/A	
Blank Acceptable	-	N/A	

Method Deviations

Nature of Deviation	Run Number
(x = deviation applies to the associated run, wx = deviation also applies to the concurrent water vapour run)	1
There are no deviations associated with the sampling employed.	wx

CHROMIUM: MEASUREMENT UNCERTAINTY CALCULATIONS

Measured Quantities	Value			Standard uncertainty			
	Symbol	Run 1		Symbol	Units	Run 1	
Sampled Volume (Actual)	V _m	1.4860		uV _m	m ³	0.0297	
Sampled Gas Temperature	T _m	289.3		uT _m	K	2.0	
Sampled Gas Pressure	p _m	100.4		up _m	kPa	0.5	
Sampled Gas Humidity	H _m	0.0		uH _m	% v/v	1.0	
Leak	L	0.52		uL	%	-	
Laboratory Result	L _r	6.00		uL _r	%	-	

Measured Quantities	Uncertainty as a Percentage			Requirement of Standard
	Units	Run 1		
Sampled Volume (Actual)	%	2.00		≤2%
Sampled Gas Temperature	%	0.69		≤1%
Sampled Gas Pressure	%	0.50		≤1%
Sampled Gas Humidity	%	1.00		≤1%
Leak	%	0.52		≤2%
Laboratory Result	%	6.00		No Requirement

Measured Quantities	Uncertainty in Measurement Units				Sensitivity Coefficient	
	Symbol	Units	Run 1		Run 1	
Sampled Volume (STP)	V _m	m ³	1.4113		0.02	
Leak	L	mg/m ³	0.0001		1.00	
Laboratory Result	L _r	mg/m ³	0.0017		1.00	

Measured Quantities	Uncertainty in Result		
	Units	Run 1	
Sampled Volume (STP)	mg/m ³	0.0007	
Leak	mg/m ³	0.0001	
Laboratory Result	mg/m ³	0.0017	

Measured Quantities	Oxygen Correction Part of MU Budget		
	Units	Run 1	
O ₂ Correction Factor	-	N/A	
Stack Gas O ₂ Content	% v/v	N/A	
MU for O ₂ Correction	%	N/A	
Overall MU For O ₂ Measurement	%	N/A	

Parameter	Units	Run 1	
Combined uncertainty	mg/m ³	0.0019	
Expanded uncertainty (95% confidence), without Oxygen Correction	mg/m ³	0.0037	
Expanded uncertainty (95% confidence), with Oxygen Correction	mg/m ³	N/A	
Expanded uncertainty (95% confidence), estimated with Method Deviations	mg/m ³	0.0037	
Reported Uncertainty	mg/m ³	0.0037	
Expanded uncertainty (95% confidence), without Oxygen Correction	%	12.7	
Expanded uncertainty (95% confidence), with Oxygen Correction	%	N/A	
Expanded uncertainty (95% confidence), estimated with Method Deviations	%	12.7	
Reported Uncertainty	%	12.7	

HEXAVALENT CHROMIUM (Cr⁶⁺) IN FINE PARTICULATE MATTER: RESULTS SUMMARY

Rapid Precision Engineering Ltd, Liverpool
Passivation Stack

Sample Runs

Parameter	Units	Run 1	Mean
Concentration	mg/m ³	< 0.0002	< 0.0002
Uncertainty	±mg/m ³	0.00002	0.00002
Mass Emission	g/hr	< 0.0003	< 0.0003
Uncertainty	±g/hr	0.00005	0.00005

Parameter	Units	Run 1	Mean
Water Vapour	% v/v	1.8	1.8
Uncertainty	±% v/v	0.10	0.10

Blank Runs

Parameter	Units	Blank 1	Maximum
Concentration	mg/m ³	< 0.0002	< 0.0002

General Sampling Information

Parameter	Value
Standard	Based on EN ISO 23210
Technical Procedure	CAT-TP-18
Sizing Device	TCR Tecora MSS1 3-Stage Cascade Impactor
Sizing Device Material	Titanium
Positioning of Filter	In Stack
Filter Size and Material	1.0M NaOH treated 47mm Quartz Fibre
Number of Sampling Lines Used	1 / 1
Number of Sampling Points Used	1 //1
Sample Point I.D.'s	A5

FORMAT: Number Used / Number Required

Reference Conditions

Reference Conditions are: 273K, 101.3kPa, without correction for water vapour content.

HEXAVALENT CHROMIUM (Cr⁺⁶) IN FINE PARTICULATE MATTER: ISOKINETIC SAMPLING CALCULATIONS

Test	Units	Run 1	
Absolute pressure of stack gas, P_s			
Barometric pressure, P _b	mmHg	752.3	
Stack static pressure, P _{static}	mmH ₂ O	1.4	
P _s = (P _b + (P _{static} / 13.6))	mmHg	752.4	
Volume of water vapour collected, V_{wstd}			
Total mass collected in impingers (liquid trap)	g	23.8	
Total mass collected in impingers (silica trap)	g	3.7	
Total mass of liquid collected, V _{lc}	g	27.5	
V _{wstd} = (0.001246)(V _{lc})	m ³	0.0343	
Volume of gas metered dry, V_{mstd}			
Volume of gas sample through gas meter, V _m	m ³	1.9020	
Gas meter correction factor, Y _d	-	1.0090	
Average dry gas meter temperature, T _m	°C	16.3	
Average pressure drop across orifice, ΔH	mmH ₂ O	200.4	
V _{mstd} = ((0.3592)(V _m)(P _b + (ΔH/13.6))(Y _d)) / (T _m + 273)	m ³	1.8274	
Moisture content, B_{wv} & R_{wv}			
B _{wv} = V _{wstd} / (V _{mstd} + V _{wstd})	m ³	0.0184	
B _{wv} as a percentage	% v/v	1.84	
Reported Water Vapour, checked with Tables in EN 14790, R _{wv}	% v/v	1.84	
Volume of gas metered wet, V_{mstw}			
V _{mstw} = (V _{mstd})(100/(100 - R _{wv}))	m ³	1.8617	
Volume of gas metered at Oxygen Reference Conditions, V_{mstd@X%O₂} & V_{mstw@X%O₂}			
IED & Incinerates Hazardous Material? (Yes = no positive O ₂ correction)	-	No	
% wet oxygen measured in gas stream, ACT%O _{2w}	% v/v	N/A	
% dry oxygen measured in gas stream, ACT%O _{2d}	% v/v	N/A	
% oxygen reference condition, REF%O ₂	% v/v	N/A	
O ₂ Reference Factor wet (O _{2REFw}) = (21 - REF%O ₂) / (21 - ACT%O _{2w})	-	N/A	
O ₂ Reference Factor dry (O _{2REFd}) = (21 - REF%O ₂) / (21 - ACT%O _{2d})	-	N/A	
V _{mstw@X%oxygen} = (V _{mstw}) / (O _{2REFw})	m ³	N/A	
V _{mstd@X%oxygen} = (V _{mstd}) / (O _{2REFd})	m ³	N/A	
Molecular weight of dry gas stream, M_d			
CO ₂ (Estimated)	% v/v	0.06	
O ₂ (Estimated)	% v/v	20.80	
Total	% v/v	20.86	
N ₂	% v/v	79.14	
M _d = 0.44(%CO ₂)+0.32(%O ₂)+0.28(%N ₂)	g/gmol	28.84	
Molecular weight of stack gas (wet), M_s			
M _s = M _d (1 - (R _{wv} /100)) + 18(R _{wv} /100)	g/gmol	28.64	
Velocity of stack gas, V_{spt}			
Velocity pressure coefficient, C _p	-	0.84	
Average stack gas temperature, T _s	°C	16.9	
Velocity of stack gas (pre-test from traverse), V _{spt}	m/s	3.65	
Total flow of stack gas: Actual (Q_a), Wet (Q_{stw}), Dry (Q_{std}), Wet@O_{2REF} (Q_{stwO₂}), Dry@O_{2REF} (Q_{stdO₂})			
Area of stack, A _s	m ²	0.15	
Q _a = (60)(A _s)(V _s)	m ³ /min	31.8	
Conversion factor (K/mm.Hg), C _f	-	0.3592	
Q _{stw} = ((Q _a)(P _s)(C _f)) / ((T _s) + 273)	m ³ /min	29.7	
Q _{std} = ((Q _a)(P _s)(C _f)(1 - (R _{wv} /100))) / ((T _s) + 273)	m ³ /min	29.1	
Q _{stwO₂} = ((Q _a)(P _s)(C _f)) / ((T _s) + 273) / (O _{2REFw})	m ³ /min	N/A	
Q _{stdO₂} = ((Q _a)(P _s)(C _f)(1 - (R _{wv} /100))) / ((T _s) + 273) / (O _{2REFd})	m ³ /min	N/A	
Percent isokinetic, %I			
Nozzle diameter, D _n	mm	13.96	
Nozzle area, A _n	mm ²	153.15	
Total sampling time, q	min	60	
Velocity at nozzle, V _n	m/s	3.62	
%I = V _n / V _{spt} x 100	%	99.1	

HEXAVALENT CHROMIUM (Cr⁶⁺) IN FINE PARTICULATE MATTER: SAMPLING DETAILS

Sample Runs

Parameter	Units	Run 1	
Sampling Times	-	12:38 - 13:38	
Sampling Dates	-	17/02/2017	
Sampling Device	-	ISO	
Volume Sampled (REF)	m ³	1.8617	
PM ₁₀ phase Cr ⁶⁺ Result from Lab	µg	< 0.30	
Calculated Concentration	mg/m ³	< 0.00016	

Where: ISO stands for Manual Isokinetic Sampling Train

Blank Runs

Parameter	Units	Blank 1	
Blank Dates	-	17/02/2017	
Average Volume Sampled (REF)	m ³	1.8617	
PM ₁₀ phase Cr ⁶⁺ Result from Lab	µg	< 0.30	
Calculated Concentration	mg/m ³	< 0.00016	

HEXAVALENT CHROMIUM (Cr⁺⁶) IN FINE PARTICULATE MATTER: QUALITY ASSURANCE

(PAGE 1 OF 2)

Sample Runs

Leak Test Results	Units	Run 1	
Expected Sampling Rate	l/min	20.00	
Pre-Sampling Leak Rate	l/min	0.19	
Allowable Leak Rate	l/min	0.40	
Leak Test Acceptable	-	Yes	

Water Droplets	Units	Run 1	
Are Water Droplets Present	-	No	

MU (Concurrent Water Vapour)	Units	Run 1	
Measurement Uncertainty (MU)	%	5.2	
Allowable MU	%	20	
MU Acceptable	%	Yes	

Silica Gel (Concurrent Water Vapour)	Units	Run 1	
Less than 50% Faded	%	Yes	

Isokinetic Criterion Compliance	Units	Run 1	
Isokinetic Variation	%	99.1	
Allowable Isokinetic Range	%	90 - 130	
Isokineticity Acceptable	-	Yes	

Test Conditions	Units	Run 1	
Ambient Temperature Recorded?	-	Yes	

Cut Size (PM₁₀ Part)	Units	Run 1	
D ₅₀ Cut Size	µm	9.99	
Allowable D ₅₀ Cut Size	µm	9 - 11	
D ₅₀ Cut Size Acceptable	-	Yes	

Cut Size (PM_{2.5} Part)	Units	Run 1	
D ₅₀ Cut Size	µm	2.52	
Allowable D ₅₀ Cut Size	µm	2.25 - 2.75	
D ₅₀ Cut Size Acceptable	-	Yes	

HEXAVALENT CHROMIUM (Cr⁺⁶) IN FINE PARTICULATE MATTER: QUALITY ASSURANCE

(PAGE 2 OF 2)

Blank Runs

Leak Test Results	Units	Blank 1	
Expected Sampling Rate	l/min	20.00	
Pre-Sampling Leak Rate	l/min	0.12	
Allowable Leak Rate	l/min	0.40	
Leak Test Acceptable	-	Yes	

Validity of Blank vs ELV	Units	Blank 1	
Allowable Blank	mg/m ³	N/A	
Blank Acceptable	-	N/A	

Method Deviations

Nature of Deviation	Run Number
(x = deviation applies to the associated run, wx = deviation also applies to the concurrent water vapour run)	1
There are no deviations associated with the sampling employed.	wx

HEXAVALENT CHROMIUM (Cr⁺⁶) IN FINE PARTICULATE MATTER: MEASUREMENT UNCERTAINTY CALCULATIONS

Measured Quantities	Value			Standard uncertainty			
	Symbol	Run 1		Symbol	Units	Run 1	
Sampled Volume (Actual)	V _m	1.9020		uV _m	m ³	0.0380	
Sampled Gas Temperature	T _m	289.3		uT _m	K	2.0	
Sampled Gas Pressure	ρ _m	100.3		uρ _m	kPa	0.5	
Sampled Gas Humidity	H _m	0.0		uH _m	% v/v	1.0	
Leak	L	0.95		uL	%	-	
Laboratory Result	L _r	7.50		uL _r	μg	-	

Uncertainty as a Percentage				
Measured Quantities	Units	Run 1		Requirement of Standard
Sampled Volume (Actual)	%	2.0000		≤2%
Sampled Gas Temperature	%	0.7		≤1%
Sampled Gas Pressure	%	0.5		≤1%
Sampled Gas Humidity	%	1.0		≤1%
Leak	%	0.95		≤2%
Laboratory Result	%	7.50		-

Uncertainty in Measurement Units				Sensitivity Coefficient	
Measured Quantities	Symbol	Units	Run 1	Run 1	
Sampled Volume (STP)	V _m	m ³	1.8274	0.00	
Leak	L	mg/m ³	0.000001	1.00	
Laboratory Result	L _r	mg/m ³	0.000012	1.00	

Uncertainty in Result		
Measured Quantities	Units	Run 1
Sampled Volume (STP)	mg/m ³	0.000004
Leak	mg/m ³	0.000001
Laboratory Result	mg/m ³	0.000012

Oxygen Correction Part of MU Budget		
Measured Quantities	Units	Run 1
O ₂ Correction Factor	-	N/A
Stack Gas O ₂ Content	% v/v	N/A
MU for O ₂ Correction	-	N/A
Overall MU For O ₂ Measurement	%	N/A

Parameter	Units	Run 1
Combined uncertainty	mg/m ³	0.00001
Expanded uncertainty (95% confidence), without Oxygen Correction	mg/m ³	0.00002
Expanded uncertainty (95% confidence), with Oxygen Correction	mg/m ³	N/A
Expanded uncertainty (95% confidence), estimated with Method Deviations	mg/m ³	0.00002
Reported Uncertainty	mg/m ³	0.00002
Expanded uncertainty (95% confidence), without Oxygen Correction	%	15.5
Expanded uncertainty (95% confidence), with Oxygen Correction	%	N/A
Expanded uncertainty (95% confidence), estimated with Method Deviations	%	15.5
Reported Uncertainty	%	15.5

TOTAL OXIDES OF NITROGEN: RESULTS SUMMARY

Rapid Precision Engineering Ltd, Liverpool
Passivation Stack

Sample Runs

Parameter	Units	Run 1	Mean
Concentration	mg/m ³	< 6.0	< 6.0
Uncertainty	±mg/m ³	0.74	0.74
Mass Emission	g/hr	< 10.7	< 10.7
Uncertainty	±g/hr	1.5	1.5

Parameter	Units	Run 1	Mean
Water Vapour	% v/v	1.8	1.8
Uncertainty	±% v/v	1.6	1.6

Blank Runs

Parameter	Units	Blank 1	Maximum
Concentration	mg/m ³	< 5.1	< 5.1

General Sampling Information

Parameter	Value
Standard	US EPA M7D
Technical Procedure	CAT-TP-35
Name of Analytical Laboratory	RPS
Analytical Laboratory's Procedure	C27
ISO 17025 Accredited Analysis?	Yes
Date of Sample Analysis	23/02/2017
Probe Material	Stainless Steel
Filter Housing Material	Borosilicate Glass
Impinger Material	Borosilicate Glass
Absorption Solution	Potassium Permanganate Solution
Positioning of Filter	Out Stack
Filter Size and Material	47mm Quartz Fibre
Number of Sampling Lines Used	2 / 2
Number of Sampling Points Used	4 / 4
Sample Point I.D.'s	A1, A2, B1 & B2

FORMAT: Number Used / Number Required
FORMAT: Number Used / Number Required

Reference Conditions

Reference Conditions are: 273K, 101.3kPa, without correction for water vapour content.

TOTAL OXIDES OF NITROGEN: SAMPLING DETAILS

Sample Runs

Parameter	Units	Run 1	
Sampling Times	-	11:32 - 12:32	
Sampling Dates	-	17/02/2017	
Sampling Device	-	MFC / MV	
Duration	mins	60	
Volume Sampled (STP, Dry)	m ³	0.0270	
Volume Sampled (STP, Wet)	m ³	0.0275	
Volume Sampled (REF)	m ³	0.0275	
Sample Flow Rate	l/min	0.45	
Laboratory Result for Front Impingers	µg/ml	< 0.25	
Laboratory Result for Back Impinger	µg/ml	< 0.25	
Volume in Front Impingers	ml	408.9	
Volume in Back Impinger	ml	246.1	
Mass in Front Impingers	µg	< 102.2	
Mass in Back Impinger	µg	< 61.5	
Total Mass Collected	µg	< 163.8	
Calculated Concentration	mg/m ³	< 5.96	
Liquid Trap Start Mass	g	2121.5	
Liquid Trap End Mass	g	2121.9	
Silica Trap Start Mass	g	773.1	
Silica Trap End Mass	g	773.1	
Total Mass Of Water Vapour	g	0.4	
Calculated Water Vapour	% v/v	1.81	

Where: MFC stands for Mass Flow Controller, MV stands for Mass View Flowmeter

Blank Runs

Parameter	Units	Blank 1	
Blank Dates	-	17/02/2017	
Average Volume Sampled (REF)	m ³	0.0275	
Laboratory Result for Impingers	µg/ml	< 0.25	
Volume in Impingers	ml	559.3	
Total Mass Collected	µg	< 139.8	
Calculated Concentration	mg/m ³	< 5.09	

TOTAL OXIDES OF NITROGEN: QUALITY ASSURANCE

Sample Runs

Leak Test Results	Units	Run 1	
Mean Sampling Rate	l/min	0.45	
Pre-Sampling Leak Rate	l/min	0.005	
Post-Sampling Leak Rate	l/min	0.005	
Allowable Leak Rate	l/min	0.009	
Leak Test Acceptable	-	Yes	

Absorption Efficiency	Units	Run 1	
Absorption Efficiency	%	100.0	
Allowable Absorption Efficiency	%	N/A	
Absorption Efficiency Acceptable	-	N/A	

Water Droplets	Units	Run 1	
Are Water Droplets Present	-	No	

Silica Gel (Concurrent Water Vapour)	Units	Run 1	
Less than 50% Faded	%	Yes	

Test Conditions	Units	Run 1	
Ambient Temperature Recorded?	-	Yes	

Blank Runs

Leak Test Results	Units	Blank 1	
Expected Sampling Rate	l/min	0.50	
Pre-Sampling Leak Rate	l/min	0.002	
Post-Sampling Leak Rate	l/min	0.002	
Allowable Leak Rate	l/min	0.010	
Leak Test Acceptable	-	Yes	

Validity of Blank vs ELV	Units	Blank 1	
Allowable Blank	mg/m ³	N/A	
Blank Acceptable	-	N/A	

Method Deviations

Nature of Deviation	Run Number
(x = deviation applies to the associated run, wx = deviation also applies to the concurrent water vapour run)	1
There are no deviations associated with the sampling employed.	wx

TOTAL OXIDES OF NITROGEN: MEASUREMENT UNCERTAINTY CALCULATIONS

Measured Quantities	Value			Standard uncertainty			
	Symbol	Run 1		Symbol	Units	Run 1	
Sampled Volume (STP)	V _m	0.0270		uV _m	m ³	0.0005	
Leak	L	1.11		uL	%	-	
Laboratory Result	L _r	6.00		uL _r	%	-	

Measured Quantities	Uncertainty as a Percentage			Requirement of Standard
	Units	Run 1		
Sampled Volume (STP)	%	2.00		≤2%
Leak	%	1.11		≤2%
Laboratory Result	%	6.00		No Requirement

Measured Quantities	Uncertainty in Measurement Units				Sensitivity Coefficient	
	Symbol	Units	Run 1		Run 1	
Sampled Volume (STP)	V _m	m ³	0.0270		220.72	
Leak	L	mg/m ³	0.038		1.00	
Laboratory Result	L _r	mg/m ³	0.357		1.00	

Measured Quantities	Uncertainty in Result		
	Units	Run 1	
Sampled Volume (STP)	mg/m ³	0.1191	
Leak	mg/m ³	0.0382	
Laboratory Result	mg/m ³	0.3574	

Measured Quantities	Oxygen Correction Part of MU Budget		
	Units	Run 1	
O ₂ Correction Factor	-	N/A	
Stack Gas O ₂ Content	% v/v	N/A	
MU for O ₂ Correction	-	N/A	
Overall MU For O ₂ Measurement	%	N/A	

Parameter	Units	Run 1	
Combined uncertainty	mg/m ³	0.38	
Expanded uncertainty (95% confidence), without Oxygen Correction	mg/m ³	0.74	
Expanded uncertainty (95% confidence), with Oxygen Correction	mg/m ³	N/A	
Expanded uncertainty (95% confidence), estimated with Method Deviations	mg/m ³	0.74	
Reported Uncertainty	mg/m ³	0.74	
Expanded uncertainty (95% confidence), without Oxygen Correction	%	12.5	
Expanded uncertainty (95% confidence), with Oxygen Correction	%	N/A	
Expanded uncertainty (95% confidence), estimated with Method Deviations	%	12.5	
Reported Uncertainty	%	12.5	