# STACK EMISSIONS MONITORING REPORT

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

| Your contact at SOCOTEC LTD |
| --- |
| [redacted]th<br>[redacted] |

| Operator & Address: |
| --- |
| Derby City Council<br>Mearkeaton Lane<br>Derby<br>Derbyshire<br>DE22 4NH |

| Permit Reference: |
| --- |
| DEFRA Process Guidance Note: PG 5/2 (12) |

| Release Point: |
| --- |
| Abatement System 1 |

| Sampling Date(s): |
| --- |
| 13th April 2023 |

| | |
| --- | --- |
| SOCOTEC Job Number: | LNO 17793 |
| Report Date: | 3rd May 2023 |
| Version: | 1 |
| Report By: | [redacted] |
| MCERTS Number: | [redacted] |
| MCERTS Level: | [redacted] |
| Technical Endorsements: | 1, 2, 3 & 4 |
| Report Approved By: | [redacted] |
| MCERTS Number: | [redacted] |
| Business Title: | [redacted] |
| Technical Endorsements: | 1, 2, 3 & 4 |
| Signature: | [redacted] |

UKAS TESTING
1015

mCERTS
THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

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# EXECUTIVE SUMMARY

## MONITORING OBJECTIVES

Derby City Council operates a cremation process at Markeaton Crematorium which is subject to DEFRA Process Guidance Note PG 5/2 (12), under the Environmental Permitting Regulations 2010.

SOCOTEC LTD were commissioned by Derby City Council to carry out stack emissions monitoring to determine the release of prescribed pollutants from the following Plant under normal operating conditions.

The results of these tests shall be used to demonstrate compliance with a set of emission limit values for prescribed pollutants as specified in the Plant's DEFRA Process Guidance Note, PG 5/2 (12).

**Plant**

Abatement System 1

**Operator**

Derby City Council
Mearkeaton Lane
Derby
Derbyshire
DE22 4NH

DEFRA Process Guidance Note: PG 5/2 (12)

**Stack Emissions Monitoring Test House**

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

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.
The results of this testing relate only to the emission release point(s) listed in the report.
MCERTS accredited results will only be claimed where both the sampling and analytical stages are MCERTS accredited.

# EXECUTIVE SUMMARY

## EMISSIONS SUMMARY

| Parameter | Units | Result | Calculated Uncertainty +/- | Emission Limit Value (ELV) | Accreditation |
|---|---|---|---|---|---|
| Total Particulate Matter | mg/m³ | 1.3 | 1.4 | 20 | MCERTS |
| Particulate Emission Rate | g/hr | 1.4 | 1.4 | - | |
| Mercury | mg/m³ | 0.021 | 0.0031 | 0.5 | MCERTS |
| Mercury Emission Rate | g/hr | 0.021 | 0.0031 | - | |
| Hydrogen Chloride | mg/m³ | 0.016 | 0.011 | 30 | MCERTS |
| Hydrogen Chloride Emission Rate | g/hr | 0.016 | 0.011 | - | |
| Total Volatile Organic Compounds | mg/m³ | 1.2 | 1.3 | 20 | MCERTS |
| Total Volatile Organic Compounds Emission Rate | g/hr | 4.8 | 5.2 | - | |
| Carbon Monoxide | mg/m³ | 121 | 6.8 | 100 | MCERTS |
| Carbon Monoxide Emission Rate | g/hr | 124 | 6.9 | - | |
| Oxygen | % v/v | 15.9 | 0.051 | - | MCERTS |
| Moisture | % | 6.2 | 0.30 | - | MCERTS |
| Stack Gas Temperature | °C | 104 | - | - | MCERTS |
| Stack Gas Velocity | m/s | 7.0 | 0.17 | - | |
| Gas Volumetric Flow Rate (Actual) | m³/hr | 2951 | 166 | - | |
| Gas Volumetric Flow Rate (STP, Wet) | m³/hr | 2115 | 119 | - | |
| Gas Volumetric Flow Rate (STP, Dry) | m³/hr | 1985 | 112 | - | |
| Gas Volumetric Flow Rate at Reference Conditions | m³/hr | 1016 | 57 | - | |

ND = None Detected,

Results at or below the limit of detection are highlighted by bold italic text.

The above volumetric flow rate is an average of the data collected during the isokinetic tests. Mass emissions for non isokinetic tests are also calculated using these values.

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

# EXECUTIVE SUMMARY

| MONITORING TIMES | | | |
|---|---|---|---|
| **Parameter** | **Sampling Date(s)** | **Sampling Times** | **Sampling Duration** |
| Total Particulate Matter Run 1 | 13 April 2023 | 11:54 - 12:54 | 60 minutes |
| Total Particulate Matter Run 2 | 13 April 2023 | 13:05 - 14:05 | 60 minutes |
| Total Particulate Matter Run 3 | 13 April 2023 | 14:35 - 15:35 | 60 minutes |
| Mercury Run 1 | 13 April 2023 | 10:15 - 11:15 | 60 minutes |
| Hydrogen Chloride Run 1 | 13 April 2023 | 11:54 - 12:54 | 60 minutes |
| Hydrogen Chloride Run 2 | 13 April 2023 | 13:05 - 14:05 | 60 minutes |
| Hydrogen Chloride Run 3 | 13 April 2023 | 14:35 - 15:35 | 60 minutes |
| Total Volatile Organic Compounds Run 1 | 13 April 2023 | 10:15 - 15:35 | 320 minutes |
| Combustion Gases | 13 April 2023 | 10:10 - 11:10 | 60 minutes |
| Preliminary Stack Traverse | 13 April 2023 | 10:05 | - |

# EXECUTIVE SUMMARY

## PROCESS DETAILS

| Parameter | Process Details |
|---|---|
| Description of process | Cremation |
| Continuous or batch | Batch |
| Product Details | Cremated remains |
| Part of batch to be monitored (if applicable) | First 60 minutes minus 2 minute charging period |
| Normal load, throughput or continuous rating | Normal |
| Fuel used during monitoring | Natural Gas |
| Abatement | None |
| Plume Appearance | None visible |

| CREMATOR OPERATING INFORMATION | | | | | |
|---|---|---|---|---|---|
| Description of process | Cremation | | | | |
| Continuous or batch | Batch | | | | |
| Abatement | None | | | | |
| Plume Appearance | None visible | | | | |
| **TEST SPECIFIC DETAILS** | **Run 1** | **Run 2** | **Run 3** | **Run 4** | **Run 5** |
| Coffin Type | MDF | Straw Basket | MDF | MDF | - |
| Sex | Male | Female | Female | Female | - |
| Body Size | Large | Small | Large | Medium | - |
| Cremation Number | 197577 | 197578 | 197579 | 197580 | - |

# EXECUTIVE SUMMARY

## Monitoring Methods

The selection of standard reference / alternative methods employed by SOCOTEC is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency technical Guidance 'Monitoring stack emissions: techniques and standards for periodic monitoring'.

| MONITORING METHODS | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Species** | **Method** Standard Reference Method / Alternative Method | **SOCOTEC Technical Procedure** | **UKAS Lab Number** | **Method Accreditation** | **Limit of Detection (LOD)** | **Calculated MU +/- % Result** | **Calculated MU +/- % ELV** |
| Total Particulate Matter | SRM - BS EN 13284-1 | AE 104 | 1015 | MCERTS | 0.45 mg/m³ | 103% | 4.44% |
| Mercury | SRM - BS EN 13211 | AE 107 | 1015 | MCERTS | 0.0011 mg/m³ | 15% | 0.63% |
| Hydrogen Chloride | SRM - BS EN 1911 | AE 111 | 1015 | MCERTS | 0.003 mg/m³ | 70% | 0.03% |
| Total Volatile Organic Compounds | SRM - BS EN 12619:2013 | AE 102 | 1015 | MCERTS | 0 mg/m³ | 107% | 6.5% |
| Carbon Monoxide | SRM - BS EN 15058:2017 | AE 102 | 1015 | MCERTS | 0.54 mg/m³ | 5.6% | 3.5% |
| Oxygen | AM - BS EN 14789:2017 | AE 102 | 1015 | MCERTS | 0.01% | 0.3% | N/A - No ELV |
| Moisture | BS EN 14790 | AE 105 | 1015 | MCERTS | 0.01% | 4.9% | N/A - No ELV |
| Velocity | SRM - EN ISO 16911-1 | AE 154 | 1015 | MCERTS | 5 Pa | 2.5% | N/A - No ELV |
| Volumetric Flow Rate | SRM - EN ISO 16911-1 | AE 154 | 1015 | MCERTS | - | 5.6% | N/A - No ELV |

# EXECUTIVE SUMMARY

## Analytical Methods

The following tables list the analytical methods employed together with the custody details. Unless otherwise stated the samples are archived at the analysis lab location.

| SAMPLING METHODS WITH SUBSEQUENT ANALYSIS | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Species** | **Analytical Technique** | **Analytical Procedure** | **UKAS Lab Number** | **Analysis Accreditation** | **Analysis Lab** | **Analysis Report No. Date of Analyis** | **Archive Period** |
| Total Particulate Matter | Gravimetric | AE 106 | 1015 | MCERTS | SOCOTEC (Stockport) | N/A | 8 Weeks |
| Mercury | Inductively coupled plasma - mass specetrometry / Cold vapour - atomic fluorescence spectroscopy | ASC/SOP/112 | 1252 | MCERTS | SOCOTEC (Bretby) | ASC 57831 02 May 2023 | 8 Weeks |
| Hydrogen Chloride | Ion Chromatography | ASC/SOP/110 | 1252 | MCERTS | SOCOTEC (Bretby) | ASC 57830 | 8 Weeks |

| ON-SITE TESTING | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Species** | **Analytical Technique** | **Analytical Procedure** | **UKAS Lab Number** | **Accreditation** | **Laboratory** | **Data Archive Location** | **Archive Period** |
| Total Volatile Organic Compounds | Flame Ionisation Detection | AE 102 | 1015 | MCERTS | SOCOTEC (Stockport) | SOCOTEC (Stockport) | 5 years |
| Carbon Monoxide | Non Dispersive Infra Red | AE 102 | 1015 | MCERTS | SOCOTEC (Stockport) | SOCOTEC (Stockport) | 5 years |
| Oxygen | Zirconia Cell | AE 102 | 1015 | MCERTS | SOCOTEC (Stockport) | SOCOTEC (Stockport) | 5 years |
| Moisture | Gravimetric | AE 105 | 1015 | MCERTS | SOCOTEC (Stockport) | - | - |

# EXECUTIVE SUMMARY

| SAMPLING LOCATION | | | | | |
|---|---|---|---|---|---|
| **Sampling Plane Validation Criteria** | **Value** | **Units** | **Requirement** | **Compliant** | **Method** |
| Lowest Differential Pressure | 25 | Pa | >= 5 Pa | Yes | BS EN 15259 |
| Lowest Gas Velocity | 6.2 | m/s | - | - | - |
| Highest Gas Velocity | 6.8 | m/s | - | - | - |
| Ratio of Gas Velocities | 1.1 | : 1 | < 3 : 1 | Yes | BS EN 15259 |
| Mean Velocity | 6.5 | m/s | - | - | - |
| Maximum angle of flow with regard to duct axis | <15 | ° | < 15° | Yes | BS EN 15259 |
| No local negative flow | Yes | - | - | Yes | BS EN 15259 |

| DUCT CHARACTERISTICS | | |
|---|---|---|
| | **Value** | **Units** |
| Shape | Square | - |
| Depth | 0.34 | m |
| Width | 0.34 | m |
| Area | 0.12 | $m^2$ |
| Port Depth | 380 | mm |

| SAMPLING LINES & POINTS | | |
|---|---|---|
| | **Isokinetic** | **Non-Iso & Gases** |
| Sample port size | 4 inch BSP | 4 inch BSP |
| Number of lines used | 1 | 1 |
| Number of points / line | 4 | 1 |
| Duct orientation | Vertical | Vertical |
| Filtration | Out Stack | Out Stack |
| Filtration for TPM | Out Stack | - |

| SAMPLING PLATFORM | |
|---|---|
| **General Platform Information** | |
| Permanent / Temporary Platform / Ground level / Floor Level / Roof | Temporary - Scaffold |
| Inside / Outside | Outside |

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

**Sampling Platform Improvement Recommendations (if applicable)**

The sampling platform needs to be increased in order to meet the requirments of technical guidance note M1.

# EXECUTIVE SUMMARY

## Sampling & Analytical Method Deviations

**Sampling points**

The sampling point requirements of EN 13284-1 could not be met as there was not enough room due to the limited platform space. As a result, one point sampling was utilised.

APPENDICES

## CONTENTS

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

| MONITORING SCHEDULE | | | | | |
|---|---|---|---|---|---|
| **Species** | **Method** Standard Reference Method / Alternative Method | **SOCOTEC Technical Procedure** | **UKAS Lab Number** | **MCERTS Accredited Method** | **Number of Samples** |
| Total Particulate Matter | SRM - BS EN 13284-1 | AE 104 | 1015 | MCERTS | 3 |
| Mercury | SRM - BS EN 13211 | AE 107 | 1015 | MCERTS | 1 |
| Hydrogen Chloride | SRM - BS EN 1911 | AE 111 | 1015 | MCERTS | 3 |
| Total Volatile Organic Compounds | SRM - BS EN 12619:2013 | AE 102 | 1015 | MCERTS | 1 |
| Carbon Monoxide | SRM - BS EN 15058:2017 | AE 102 | 1015 | MCERTS | 1 |
| Oxygen | AM - BS EN 14789:2017 | AE 102 | 1015 | MCERTS | 1 |
| Moisture | BS EN 14790 | AE 105 | 1015 | MCERTS | 1 |
| Velocity | SRM - EN ISO 16911-1 | AE 154 | 1015 | MCERTS | 1 |

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

## CALIBRATEABLE EQUIPMENT CHECKLIST

| Extractive Sampling | | Instrumental Analyser/s | | Miscellaneous | |
|---|---|---|---|---|---|
| **Equipment** | **Equipment I.D.** | **Equipment** | **Equipment I.D.** | **Equipment** | **Equipment I.D.** |
| Control Box DGM | LNO 13-19 | Horiba PG - 250 Analyser | LNO 21-14 | Laboratory Balance | LNO 00-33 / 00-13 |
| Box Thermocouples | LNO 03-19 | FT-IR | - | Tape Measure | LNO 24-WR |
| Meter In Thermocouple | LNO 03-19 | FT-IR Oven Box | - | Stopwatch | - |
| Meter Out Thermocouple | LNO 03-19 | Bernath 3006 FID | - | Protractor | - |
| Control Box Timer | LNO 17-19 | Signal 3030 FID | - | Barometer | LNO 08-WR |
| Oven Box | LNO 09-68 | Servomex | - | Digital Micromanometer | LNO 01-WR |
| Probe | LNO 11-07 | JCT Heated Head Filter | - | Digital Temperature Meter | LNO 03-WR |
| Probe Thermocouple | LNO 10-07 | Thermo FID | LNO 21-55 | Stack Thermocouple | LNO 10-WR |
| Probe | - | Stackmaster | - | Mass Flow Controller | - |
| Probe Thermocouple | - | FTIR Heater Box for Heated Line | - | MFC Display module | - |
| S-Pitot | LNO 06-WR | Anemometer | - | 1m Heated Line (1) | - |
| L-Pitot | - | Ecophysics NOx Analyser | - | 1m Heated Line (2) | - |
| Site Balance | LNO 14-WR | Chiller (JCT/MAK 10) | LNO 21-101 | 1m Heated Line (3) | - |
| Last Impinger Arm | - | Heated Line Controller (1) | LNO 03-102 | 5m Heated Line (1) | - |
| Dioxins Cond. Thermocouple | - | Heated Line Controller (2) | - | 10m Heated Line (1) | - |
| Callipers | LNO 31-WR | Site temperature Logger | - | 10m Heated Line (2) | - |
| Small DGM | - | | | 15m Heated Line (1) | - |
| Heater Controller | - | | | 20m Heated Line (1) | LNO 18-83 |
| Inclinometer (Swirl Device) | LNO 23-WR | | | 20m Heated Line (2) | - |

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

## CALIBRATION GASES

| Gas (traceable to ISO 17025) | Cylinder I.D Number | Supplier | ppm | % | Analytical Tolerance +/- % |
|---|---|---|---|---|---|
| Oxygen | HPC2257 | BOC | - | 20.9 | 2.0 |
| Propane | HPC2178 | BOC | 80.7 | - | 2.0 |
| Carbon Monoxide | HPC2144 | BOC | 167.8 | - | 2.0 |

## STACK EMISSIONS MONITORING TEAM

| MONITORING TEAM | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Personnel** | **MCERTS Number** | **MCERTS** | | **TE / H&S Qualifications and Expiry Date** | | | | |
| | | **Level** | **Expiry** | **TE1** | **TE2** | **TE3** | **TE4** | **H&S** |
| [redacted] | [redacted]1 | [redacted]el | Mar-25 | Dec-28 | Jun-25 | Dec-25 | Mar-25 | Mar-27 |
| [redacted] | [redacted] | [redacted]S T[redacted] | Oct-27 | - | - | - | - | Oct-27 |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

| TOTAL PARTICULATE MATTER SUMMARY | | | | | |
|---|---|---|---|---|---|
| Parameter | Sampling Times | Concentration mg/m³ | Uncertainty mg/m³ | ELV mg/m³ | Emission Rate g/hr |
| Run 1 | 11:54 - 12:54 13 April 2023 | 2.3 | 0.91 | 20 | 2.4 |
| Run 2 | 13:05 - 14:05 13 April 2023 | 1.2 | 0.89 | 20 | 1.3 |
| Run 3 | 14:35 - 15:35 13 April 2023 | 0.43 | 0.87 | 20 | 0.43 |
| Blank | - | 0.40 | - | - | - |

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

| Acetone Blank Value mg/l | Acceptable Value mg/l |
|---|---|
| 0.3 | 10 |

## FILTER INFORMATION

| SAMPLES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Test | Filter & Probe Rinse Number | Filter Start Weight g | Filter End Weight g | Mass Gained on Filter g | Probe Rinse Start Weight g | Probe Rinse End Weight g | Mass Gained on Probe g | Combined Total Mass Gained g |
| Run 1 | Q2316 | 0.14984 | 0.14948 | -0.00036 | 60.84920 | 60.85060 | 0.00140 | 0.00104 |
| Run 2 | Q2317 | 0.14950 | 0.14906 | -0.00044 | 66.29680 | 66.29780 | 0.00100 | 0.00056 |
| Run 3 | Q2318 | 0.15054 | 0.15027 | -0.00027 | 65.86240 | 65.86210 | -0.00030 | 0.00020 |

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

| BLANKS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Test | Filter & Probe Number | Filter Start Weight g | Filter End Weight g | Mass Gained Filter g | Probe Start Weight g | Probe End Weight g | Mass Gained Probe g | Combined Total Mass Gained g |
| Run 1 | Q2265 | 0.14300 | 0.14245 | -0.00055 | 63.37310 | 63.37400 | 0.00090 | 0.00035 |

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## ISOKINETIC SAMPLING EQUATIONS - RUN 1 — TPM

| | | |
|---|---|---|
| **Absolute pressure of stack gas, $P_s$** | | |
| Barometric pressure, $P_b$ | Kpa | 100.0 |
| Stack static pressure, $P_{static}$ | pa | 6.0 |
| $P_s = P_b + P_{static}$ | Kpa | 100.0 |
| **Vol. of water vapour collected, $V_{wstd}$** | | |
| Moisture trap weight increase,Vlc | g | 45.7 |
| $V_{wstd} = (0.001246)(V_{lc})$ | $m^3$ | 0.0569422 |
| **Volume of gas metered dry, $V_{mstd}$** | | |
| Volume of gas sample through gas meter, $V_m$ | | 0.977 |
| Gas meter correction factor, $Y_d$ | | 1.011 |
| Mean dry gas meter temperature, $T_m$ | | 307 |
| Mean pressure drop across orifice, DH | $mmH_2O$ | 26.576 |
| $V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$ | $m^3$ | 0.869 |
| **Volume of gas metered wet, $V_{mstw}$** | | |
| $V_{mstw} = V_{mstd} + V_{wstd}$ | $m^3$ | 0.9256 |
| **Vol. of gas metered at $O_2$ Ref. Cond., $V_{mstd@X\%O2}$** | | |
| Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)* | | No |
| % oxygen measured in gas stream, act%$O_2$ | | 15.9 |
| % oxygen reference condition | | 11 |
| $O_2$ Reference Factor $O_2$ Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$ | | 0.51 |
| $V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$ | $m^3$ | 0.4445 |
| **Moisture content, $B_{wo}$** | | |
| $B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$ | | 0.0615 |
| | % | 6.15 |
| **Moisture by FTIR** | % | - |
| **Velocity of stack gas, $V_s$** | | |
| Velocity pressure coefficient, $C_p$ | | 0.85 |
| Mean of velocity heads, $DP_{avg}$ | Pa | 31.20 |
| Mean stack gas temperature, $T_s$ | K | 377 |
| Gas density $_{(wet,\ ambient)}$, ρ p=(Ms*Ps)/(8.314*Ts) | $kg/m^3$ | 0.908 |
| Stack Velocity, Vs $V_s = \frac{\sum_{i=1}^{n} V_i}{n}$ | m/s | 7.04 |

| | | |
|---|---|---|
| **Molecular weight of dry gas, $M_d$** | | |
| $CO_2$ | % | 2.95 |
| $O_2$ | % | 15.88 |
| Total | % | 18.83 |
| $N_2$ (100 -Total) | % | 81.17 |
| $M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$ | | 29.11 |
| **Molecular weight of wet gas, $M_s$** | | |
| $M_s = M_d(1 - B_{wo}) + 18(B_{wo})$ | g/gmol | 28.42 |
| **Actual flow of stack gas, $Q_a$** | | |
| Area of stack, $A_s$ | $m^2$ | 0.12 |
| $Q_a = (60)(A_s)(V_s)$ | $m^3$/min | 48.8 |
| **Total flow of stack gas, Q** | | |
| Conversion factor (K/mm.Hg) | | 0.3592 |
| $Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$ | Dry | 32.8 |
| $Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$ | @$O_2$ref | 16.78 |
| $Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$ | Wet | 34.94 |
| **Percent isokinetic, %I** | | |
| Nozzle diameter, $D_n$ | mm | 7.88 |
| Nozzle area, $A_n$ | $mm^2$ | 48.82 |
| Total sampling time, q | min | 60 |
| $\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ | % | 104.5 |
| Acceptable isokinetic range 95% to 115% | | Yes |
| **Particulate Concentration, C** | | |
| Mass collected on filter, $M_f$ | g | -0.00036 |
| Mass collected in probe, $M_p$ | g | 0.00140 |
| Total mass collected, $M_n$ | g | 0.00104 |
| $C_{wet} = \frac{M_n}{V_{mstw}}$ | $mg/m^3$ | 1.124 |
| $C_{dry} = \frac{M_n}{V_{mstd}}$ | $mg/m^3$ | 1.197 |
| $C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$ | $mg/m^3$ | 2.340 |
| **Particulate Emission Rates, E** | | |
| $E = [(C_{wet})(Q_{stw})(60)] / 1000$ | | 2.36 |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## ISOKINETIC SAMPLING EQUATIONS - RUN 2 — TPM

| | | | | | |
|---|---|---|---|---|---|
| **Absolute pressure of stack gas, $P_s$** | | | **Molecular weight of dry gas, $M_d$** | | |
| Barometric pressure, $P_b$ | Kpa | 100.0 | $CO_2$ | % | 2.95 |
| Stack static pressure, $P_{static}$ | pa | 6.0 | $O_2$ | % | 15.88 |
| $P_s = P_b + P_{static}$ | Kpa | 100.0 | Total | % | 18.83 |
| | | | $N_2$ (100 -Total) | % | 81.17 |
| **Vol. of water vapour collected, $V_{wstd}$** | | | $M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$ | | 29.11 |
| Moisture trap weight increase,Vlc | g | - | **Molecular weight of wet gas, $M_s$** | | |
| $V_{wstd} = (0.001246)(V_{lc})$ | $m^3$ | - | $M_s = M_d(1 - B_{wo}) + 18(B_{wo})$ | g/gmol | 28.42 |
| **Volume of gas metered dry, $V_{mstd}$** | | | **Actual flow of stack gas, $Q_a$** | | |
| Volume of gas sample through gas meter, $V_m$ | | 1.002 | Area of stack, $A_s$ | $m^2$ | 0.12 |
| Gas meter correction factor, $Y_d$ | | 1.011 | $Q_a = (60)(A_s)(V_s)$ | $m^3$/min | 50.8 |
| Mean dry gas meter temperature, $T_m$ | | 311 | **Total flow of stack gas, Q** | | |
| Mean pressure drop across orifice, DH | $mmH_2O$ | 29.370 | Conversion factor (K/mm.Hg) | | 0.3592 |
| $V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$ | $m^3$ | 0.881 | $Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$ | Dry | 34.3 |
| **Volume of gas metered wet, $V_{mstw}$** | | | $Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$ | @$O_2$ref | 17.54 |
| $V_{mstw} = V_{mstd} + V_{wstd}$ | $m^3$ | 0.9386 | $Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$ | Wet | 36.53 |
| **Vol. of gas metered at $O_2$ Ref. Cond., $V_{mstd@X\%O2}$** | | | | | |
| Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)* | | No | **Percent isokinetic, %I** | | |
| % oxygen measured in gas stream, act%$O_2$ | | 15.9 | Nozzle diameter, $D_n$ | mm | 7.88 |
| % oxygen reference condition | | 11 | Nozzle area, $A_n$ | $mm^2$ | 48.82 |
| $O_2$ Reference Factor $O_2$ Ref = $\frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$ | | 0.51 | Total sampling time, q | min | 60 |
| $V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$ | $m^3$ | 0.4507 | $\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ | % | 101.4 |
| **Moisture content, $B_{wo}$** | | | Acceptable isokinetic range 95% to 115% | | Yes |
| $B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$ | | 0.0615 | **Particulate Concentration, C** | | |
| | % | 6.15 | Mass collected on filter, $M_f$ | g | -0.00044 |
| **Moisture by FTIR** | % | - | Mass collected in probe, $M_p$ | g | 0.00100 |
| **Velocity of stack gas, $V_s$** | | | Total mass collected, $M_n$ | g | 0.00056 |
| Velocity pressure coefficient, $C_p$ | | 0.85 | $C_{wet} = \frac{M_n}{V_{mstw}}$ | $mg/m^3$ | 0.597 |
| Mean of velocity heads, $DP_{avg}$ | Pa | 33.89 | $C_{dry} = \frac{M_n}{V_{mstd}}$ | $mg/m^3$ | 0.636 |
| Mean stack gas temperature, $T_s$ | K | 374 | $C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$ | $mg/m^3$ | 1.242 |
| Gas density (wet, ambient), ρ p=(Ms*Ps)/(8.314*Ts) | $kg/m^3$ | 0.913 | | | |
| Stack Velocity, Vs $V_s = \frac{\sum_{i=1}^{n} V_i}{n}$ | m/s | 7.32 | **Particulate Emission Rates, E** | | |
| | | | $E = [(C_{wet})(Q_{stw})(60)] / 1000$ | | 1.31 |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## ISOKINETIC SAMPLING EQUATIONS - RUN 3 — TPM

| | | |
|---|---|---|
| **Absolute pressure of stack gas, $P_s$** | | |
| Barometric pressure, $P_b$ | Kpa | 100.0 |
| Stack static pressure, $P_{static}$ | pa | 6.0 |
| $P_s = P_b + P_{static}$ | Kpa | 100.0 |
| **Vol. of water vapour collected, $V_{wstd}$** | | |
| Moisture trap weight increase,Vlc | g | - |
| $V_{wstd} = (0.001246)(V_{lc})$ | $m^3$ | - |
| **Volume of gas metered dry, $V_{mstd}$** | | |
| Volume of gas sample through gas meter, $V_m$ | | 1.019 |
| Gas meter correction factor, $Y_d$ | | 1.011 |
| Mean dry gas meter temperature, $T_m$ | | 309 |
| Mean pressure drop across orifice, DH | $mmH_2O$ | 25.810 |
| $V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$ | $m^3$ | 0.900 |
| **Volume of gas metered wet, $V_{mstw}$** | | |
| $V_{mstw} = V_{mstd} + V_{wstd}$ | $m^3$ | 0.9590 |
| **Vol. of gas metered at $O_2$ Ref. Cond., $V_{mstd@X\%O2}$** | | |
| Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)* | | No |
| % oxygen measured in gas stream, act%$O_2$ | | 15.9 |
| % oxygen reference condition | | 11 |
| $O_2$ Reference Factor $O_2\ Ref = \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$ | | 0.51 |
| $V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$ | $m^3$ | 0.4605 |
| **Moisture content, $B_{wo}$** | | |
| $B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$ | | 0.0615 |
| | % | 6.15 |
| **Moisture by FTIR** | % | - |
| **Velocity of stack gas, $V_s$** | | |
| Velocity pressure coefficient, $C_p$ | | 0.85 |
| Mean of velocity heads, $DP_{avg}$ | Pa | 30.14 |
| Mean stack gas temperature, $T_s$ | K | 377 |
| Gas density $_{(wet,\ ambient)}$, p | | |
| p=(Ms*Ps)/(8.314*Ts) | $kg/m^3$ | 0.907 |
| Stack Velocity, Vs $V_s = \frac{\sum_{i=1}^{n} V_i}{n}$ | m/s | 6.91 |

| | | |
|---|---|---|
| **Molecular weight of dry gas, $M_d$** | | |
| $CO_2$ | % | 2.95 |
| $O_2$ | % | 15.88 |
| Total | % | 18.83 |
| $N_2$ (100 -Total) | % | 81.17 |
| $M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$ | | 29.11 |
| **Molecular weight of wet gas, $M_s$** | | |
| $M_s = M_d(1 - B_{wo}) + 18(B_{wo})$ | g/gmol | 28.42 |
| **Actual flow of stack gas, $Q_a$** | | |
| Area of stack, $A_s$ | $m^2$ | 0.12 |
| $Q_a = (60)(A_s)(V_s)$ | $m^3$/min | 47.9 |
| **Total flow of stack gas, Q** | | |
| Conversion factor (K/mm.Hg) | | 0.3592 |
| $Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$ | Dry | 32.2 |
| $Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$ | @$O_2$ref | 16.46 |
| $Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$ | Wet | 34.29 |
| **Percent isokinetic, %I** | | |
| Nozzle diameter, $D_n$ | mm | 7.88 |
| Nozzle area, $A_n$ | $mm^2$ | 48.82 |
| Total sampling time, q | min | 60 |
| $\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ | % | 110.4 |
| Acceptable isokinetic range 95% to 115% | | Yes |
| **Particulate Concentration, C** | | |
| Mass collected on filter, $M_f$ | g | -0.00027 |
| Mass collected in probe, $M_p$ | g | -0.00030 |
| Total mass collected, $M_n$ | g | 0.00020 |
| $C_{wet} = \frac{M_n}{V_{mstw}}$ | mg/m³ | 0.209 |
| $C_{dry} = \frac{M_n}{V_{mstd}}$ | mg/m³ | 0.222 |
| $C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$ | mg/m³ | 0.434 |
| **Particulate Emission Rates, E** | | |
| $E = [(C_{wet})(Q_{stw})(60)] / 1000$ | | 0.43 |

As the total mass gained was less than the LOD, the LOD has been reported

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## TOTAL PARTICULATE MATTER QUALITY ASSURANCE CHECKLIST

| LEAK RATE | | | | | | |
|---|---|---|---|---|---|---|
| Run | Mean Sampling Rate litre/min | Pre-sampling Leak Rate litre/min | Post-sampling Leak Rate litre/min | Maximum Vacuum mm Hg | Acceptable Leak Rate litre/min | Leak Tests Acceptable? |
| Run 1 | 16.46 | 0.20 | - | -330.2 | 0.33 | Yes |
| Run 2 | 16.88 | 0.19 | - | -355.6 | 0.34 | Yes |
| Run 3 | 17.17 | 0.18 | - | -381 | 0.34 | Yes |

In BS EN 13284-1:2017 a post sampling leak check is not required.

| ISOKINETICITY | | |
|---|---|---|
| Run | Isokinetic Variation % | Acceptable Isokineticity |
| Run 1 | 104.54 | Yes |
| Run 2 | 101.40 | Yes |
| Run 3 | 110.39 | Yes |

Acceptable isokinetic range 95% to 115%

| WEIGHING BALANCE UNCERTAINTY | | | |
|---|---|---|---|
| Run | Result $mg/m^3$ | 5% ELV $mg/m^3$ | LOD < 5% ELV |
| Run 1 | 0.45 | 1.0 | Yes |
| Run 2 | 0.44 | 1.0 | Yes |
| Run 3 | 0.43 | 1.0 | Yes |

The above is based on both the Filter and rinse uncertainty

| BLANK VALUE | | | | |
|---|---|---|---|---|
| Run | Overall Blank Value $mg/m^3$ | Daily Emission Limit Value $mg/m^3$ | Acceptable Blank Value $mg/m^3$ | Overall Blank Acceptable $mg/m^3$ |
| Blank 1 | 0.40 | 20 | 2.0 | Yes |

| FILTERS | | | | | |
|---|---|---|---|---|---|
| Run | Filter Material | Filter Size mm | Max Filtration Temperature °C | Pre-use Filter Conditioning Temperature °C | Post-use Filter Conditioning Temperature °C |
| Run 1 | Quartz Fibre | 47 | 160 | 180 | 160 |
| Run 2 | Quartz Fibre | 47 | 160 | 180 | 160 |
| Run 3 | Quartz Fibre | 47 | 160 | 180 | 160 |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## MERCURY SUMMARY - PARTICULATE & VAPOUR PHASES COMBINED

| MERCURY COMBINED | | | | | |
|---|---|---|---|---|---|
| Test | Sampling Times | Concentration mg/m³ | LOD mg/m³ | ELV mg/m³ | Emission Rate g/hr |
| Run 1 | 10:15 - 11:15<br>13 April 2023 | 0.021 | 0.0011 | 0.50 | 0.021 |
| Field Blank | - | 0.0011 | - | - | - |

| Mercury | PARTICULATE PHASE | | | VAPOUR PHASE | | |
|---|---|---|---|---|---|---|
| | Stack LOD mean mg/m³ | Lab Result ug | Concentration mg/m³ | Stack LOD mean mg/m³ | Lab Result ug | Concentration mg/m³ |
| Run 1 | 0.00108 | 0.90 | 0.0019 | 0.0000027 | 8.66 | 0.0187 |
| Volume Sampled $m^3$ | | 0.4632 | | | 0.4632 | |
| Field Blank | - | 0.50 | 0.0011 | - | 0.01 | 0.000032 |
| Volume Sampled $m^3$ | | 0.4632 | | | 0.4632 | |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## ISOKINETIC SAMPLING EQUATIONS RUN 1 — Mercury

| | | | | | |
|---|---|---|---|---|---|
| **Absolute pressure of stack gas, $P_s$** | | | **Molecular weight of dry gas, $M_d$** | | |
| Barometric pressure, $P_b$ | kPa | 99.10 | $CO_2$ | % | 2.95 |
| Stack static pressure, $P_{static}$ | Pa | 6.00 | $O_2$ | % | 15.88 |
| $P_s = P_b + (P_{static})$ | kPa | 99.11 | Total | % | 18.83 |
| | | | $N_2$ (100 -Total) | % | 81.17 |
| | | | $M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$ | | 29.11 |
| **Vol. of water vapour collected, $V_{wstd}$** | | | **Molecular weight of wet gas, $M_s$** | | |
| Moisture trap weight increase,Vlc | g | - | $M_s = M_d(1 - B_{wo}) + 18(B_{wo})$ | g/gmol | 28.42 |
| $V_{wstd} = (0.001246)(V_{lc})$ | $m^3$ | - | **Velocity of stack gas, $V_s$** | | |
| **Volume of gas metered dry, $V_{mstd}$** | | | Velocity pressure coefficient, $C_p$ | | 0.85 |
| | | | Mean of velocity heads, $DP_{avg}$ | Pa | 30.54 |
| Volume of gas sample through gas meter, $V_m$ | $m^3$ | 0.99 | Mean stack gas temperature, $T_s$ | K | 368.75 |
| Gas meter correction factor, $Y_d$ | | 1.01 | Gas density (wet, ambient), p | | |
| Mean dry gas meter temperature, $T_m$ | | 296.23 | p=(Ms*Ps)/(8.314*Ts) | $kg/m^3$ | 0.919 |
| Mean pressure drop across orifice, DH | $mmH_2O$ | 25.59 | Stack Velocity, Vs $V_s = \frac{\sum_{i=1}^{n} V_i}{n}$ | m/s | 6.92 |
| $V_{mstd} = (0.3592)(V_m)(P_b+(DH/13.6))(Y_d) / (T_m + 273)$ | $m^3$ | 0.91 | **Actual flow of stack gas, $Q_a$** | | |
| **Volume of gas metered wet, $V_{mstw}$** | | | Area of stack, $A_s$ | $m^2$ | 0.12 |
| | | | $Q_a = (60)(A_s)(V_s)$ | $m^3/min$ | 48.0 |
| $V_{mstw} = V_{mstd} + V_{wstd}$ | $m^3$ | 0.9647 | **Total flow of stack gas, Q** | | |
| **Vol. of gas metered at $O_2$ Ref. Cond., $V_{mstd@X\%O2}$** | | | Conversion factor (K/mm.Hg) | | |
| | | | $Q_{std} = (Q_a)P_s(0.3592)(1-B_{wo}) / (Ts)$ | Dry | 32.6 |
| Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)* | | No | $Q_{std02} = (Q_a)P_s(0.3592)(1-B_{wo})(O_2REF) / (Ts)$ | @O2ref | 17 |
| % oxygen measured in gas stream, act%$O_2$ | | 15.88 | $Q_{stw} = (Q_a)P_s(0.3592) / (Ts)$ | Wet | 35 |
| % oxygen reference condition | | 11 | **Percent isokinetic, %I** | | |
| $O_2$ Reference Factor $O2\ Ref = \frac{21.0 - act\%O2}{21.0 - ref\%O2}$ | | 0.51 | Nozzle diameter, $D_n$ | mm | 7.9 |
| $V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$ | $m^3$ | 0.46 | Nozzle area, $A_n$ | $mm^2$ | 48.8 |
| **Moisture content, $B_{wo}$** | | | Total sampling time, q | min | 60.0 |
| | | | $\%I = (4.6398E6)(T_s)(V_{mstd}) / (P_s)(V_s)(A_n)(q)(1-B_{wo})$ | % | 109.6 |
| $B_{wo} = V_{wstd} / (V_{mstd} + V_{wstd})$ | | 0.0615 | | | |
| | % | 6.15 | | | |
| **Moisture by FTIR** | % | - | Acceptable isokinetic range 95% to 115% | | Yes |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## MERCURY QA CHECKLIST

| Leak Test Results | Mean Sampling Rate litre/min | Pre-sampling Leak Rate litre/min | Post-sampling Leak Rate litre/min | Maximum Vacuum mm Hg | Acceptable Leak Rate litre/min | Leak Tests Acceptable litre/min |
|---|---|---|---|---|---|---|
| Run 1 | 16.7 | 0.18 | 0.10 | -304.8 | 0.33 | Yes |

| Isokinetic Criterion Compliance | Isokinetic Variation % | Acceptable Isokineticity |
|---|---|---|
| Run 1 | 109.6 | Yes |

| Filtration / Temp | Filter Material | Filter Size mm | Maximum Filtration Temperature °C | Temperature during storage / transit <25°C |
|---|---|---|---|---|
| Run 1 | Quartz Fibre | 47 | 180 | Yes |

| Mercury | Type of Absorbers - Mercury | Absorption Solutions - Mercury |
|---|---|---|
| Run 1 | PTFE | 4% Potassium Dichromate, 20% Nitric Acid |

| Parameter | | Total ug | Final Absorber ug | Absorption Efficiency | Required | Pass / Fail |
|---|---|---|---|---|---|---|
| Mercury | Run 1 | 9.56 | ND | 100 | 95 | N/A <30% ELV |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

| HYDROGEN CHLORIDE SUMMARY | | | | | |
|---|---|---|---|---|---|
| Test | Sampling Times | Concentration mg/m³ | LOD mg/m³ | ELV mg/m³ | Emission Rate g/hr |
| Run 1 | 11:54 - 12:54 13 April 2023 | 0.027 | 0.004 | 30 | 0.028 |
| Run 2 | 13:05 - 14:05 13 April 2023 | 0.012 | 0.003 | 30 | 0.013 |
| Run 3 | 14:35 - 15:35 13 April 2023 | 0.0073 | 0.003 | 30 | 0.0073 |
| Field Blank | - | 0.0052 | - | - | - |

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

## HYDROGEN CHLORIDE QUALITY ASSURANCE CHECKLIST

| | Barometric Pressure Kpa | Average Oxygen Value for Referencing % | Total Sample Volume @ ref Conditions m³ | Mean Sampling Rate l/min | Pre Sampling Leak Rate l/min | Post Sampling Leak Rate l/min | Acceptable Leak Rate l/min | Leak Tests Acceptable? |
|---|---|---|---|---|---|---|---|---|
| Run 1 | 100.0 | 15.9 | 0.444 | 16.5 | 0.20 | - | 0.33 | Yes |
| Run 2 | 100.0 | 15.9 | 0.451 | 16.9 | 0.19 | - | 0.34 | Yes |
| Run 3 | 100.0 | 15.9 | 0.461 | 17.2 | 0.18 | - | 0.34 | Yes |

| | Filter Material | Filter Size mm | Max. Filtration Temp. °C | Temperature during storage / transit <25°C | Type of Absorbers | Absorption Solutions |
|---|---|---|---|---|---|---|
| Run 1 | Quartz Fibre | 47 | 160 | N/A | Glass | HPLC Water |
| Run 2 | Quartz Fibre | 47 | 160 | N/A | Glass | HPLC Water |
| Run 3 | Quartz Fibre | 47 | 160 | N/A | Glass | HPLC Water |

## HYDROGEN CHLORIDE ABSORPTION EFFICIENCY

| Parameter | Total ug | IMP C ug | Absorption Efficiency % | Acceptable Absorption Efficiency % | Absorption Efficiency Acceptable ? |
|---|---|---|---|---|---|
| Run 1 | 12.21 | 3.18 | 74 | 95 | N/A - <30% ELV |
| Run 2 | 5.54 | 1.34 | 76 | 95 | N/A - <30% ELV |
| Run 3 | ND | 1.23 | 64 | 95 | N/A - <30% ELV |

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## ISOKINETIC SAMPLING EQUATIONS 1 — Hydrogen Chloride

| | | | | | |
|---|---|---|---|---|---|
| **Absolute pressure of stack gas, $P_s$** | | | **Velocity of stack gas, $V_s$** | | |
| Barometric pressure, $P_b$ | kPa | 100 | Velocity pressure coefficient, $C_p$ | | 0.85 |
| Stack static pressure, $P_{static}$ | Pa | 6 | Mean of velocity heads, $DP_{avg}$ | Pa | 31.20 |
| $P_s = P_b + (P_{static})$ | kPa | 100.01 | Mean stack gas temperature, $T_s$ | K | 376.58 |
| | | | Gas density $_{(wet, ambient)}$, p | | |
| **Vol. of water vapour collected, $V_{wstd}$** | | | p=(Ms*Ps)/(8.314*Ts) | kg/m$^3$ | 0.908 |
| Moisture trap weight increase,Vlc | g | - | Stack Velocity, Vs | | |
| $V_{wstd} = (0.001246)(V_{lc})$ | m$^3$ | - | $V_s = \frac{\sum_{i=1}^{n} V_i}{n}$ | m/s | 7.04 |
| **Volume of gas metered dry, $V_{mstd}$** | | | **Actual flow of stack gas, $Q_a$** | | |
| Volume of gas sample through gas meter, $V_m$ | m$^3$ | 0.9770 | Area of stack, $A_s$ | m$^2$ | 0.12 |
| Gas meter correction factor, $Y_d$ | | 1.011070729 | $Q_a = (60)(A_s)(V_s)$ | m³/min | 49 |
| Mean dry gas meter temperature, $T_m$ | K | 307.17 | **Dry total flow of stack gas, $Q_{std}$** | | |
| Mean pressure drop across orifice, DH | mm$H_2O$ | 26.58 | Conversion factor (K/mm.Hg) | | 0.3592 |
| $V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$ | m$^3$ | 0.87 | $Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$ | m³/min | 33 |
| **Volume of gas metered wet, $V_{mstw}$** | | | **Wet total flow of stack gas, $Q_{stw}$** | | |
| $V_{mstw} = V_{mstd} + V_{wstd}$ | m$^3$ | 0.9256 | $Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$ | m³/min | 35 |
| **Vol. of gas metered at $O_2$ Ref. Cond., $V_{mstd@X\%O2}$** | | | **Dry total flow of stack gas at X% $O_2$, $Q_{stdO2}$** | | |
| Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)* | | No | $Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$ | m³/min | 17 |
| % oxygen measured in gas stream, act%$O_2$ | | 15.88 | **Percent isokinetic, %I** | | |
| % oxygen reference condition | | 11 | Nozzle diameter, $D_n$ | mm | 7.88 |
| $O_2$ Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$ | | 0.51 | Nozzle area, $A_n$ | mm$^2$ | 48.82 |
| $V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$ | m$^3$ | 0.4445 | Total sampling time, q | min | 60 |
| **Moisture content, $B_{wo}$** | | | $\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ | % | 105 |
| $B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$ | | 0.0615 | | | |
| | % | 6.15 | Acceptable isokinetic range 95% to 115% | | Yes |
| **Moisture by FTIR** | % | - | **Hydrogen Chloride Concentration, C** | | |
| **Molecular weight of dry gas, $M_d$** | | | Mass collected , M | ug | 12 |
| $CO_2$ | | 2.95 | $C_{wet} = \frac{M_n}{V_{mstw}}$ | mg/m³ | 0.013 |
| $O_2$ | | 15.88 | $C_{dry} = \frac{M_n}{V_{mstd}}$ | mg/m³ | 0.014 |
| Total | | 18.83 | $C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$ | mg/m³ | 0.027 |
| $N_2$ (100 -Total) | | 81.17 | | | |
| $M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$ | | 29.11 | | | |
| **Molecular weight of wet gas, $M_s$** | | | **Hydrogen Chloride Emission Rates, E** | | |
| $M_s = M_d(1 - B_{wo}) + 18(B_{wo})$ | g/gmol | 28.4 | $E = [(C_{wet})(Q_{stw})(60)] / 1000$ | g/hr | 0.03 |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## ISOKINETIC SAMPLING EQUATIONS 2 — Hydrogen Chloride

| | | | | | |
|---|---|---|---|---|---|
| **Absolute pressure of stack gas, $P_s$** | | | **Velocity of stack gas, $V_s$** | | |
| Barometric pressure, $P_b$ | kPa | 100 | Velocity pressure coefficient, $C_p$ | | 0.85 |
| Stack static pressure, $P_{static}$ | Pa | 6 | Mean of velocity heads, $DP_{avg}$ | Pa | 33.89 |
| $P_s = P_b + (P_{static})$ | kPa | 100.01 | Mean stack gas temperature, $T_s$ | K | 374.33 |
| | | | Gas density $_{(wet, ambient)}$, p | | |
| **Vol. of water vapour collected, $V_{wstd}$** | | | p=(Ms*Ps)/(8.314*Ts) | kg/m$^3$ | 0.913 |
| Moisture trap weight increase,Vlc | g | - | Stack Velocity, Vs | | |
| $V_{wstd} = (0.001246)(V_{lc})$ | m$^3$ | - | $V_s = \frac{\sum_{i=1}^{n} V_i}{n}$ | m/s | 7.32 |
| **Volume of gas metered dry, $V_{mstd}$** | | | **Actual flow of stack gas, $Q_a$** | | |
| Volume of gas sample through gas meter, $V_m$ | m$^3$ | 1.0020 | Area of stack, $A_s$ | m$^2$ | 0.12 |
| Gas meter correction factor, $Y_d$ | | 1.011070729 | $Q_a = (60)(A_s)(V_s)$ | m³/min | 51 |
| Mean dry gas meter temperature, $T_m$ | K | 310.75 | **Dry total flow of stack gas, $Q_{std}$** | | |
| Mean pressure drop across orifice, DH | mm$H_2O$ | 29.37 | Conversion factor (K/mm.Hg) | | 0.3592 |
| $V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$ | m$^3$ | 0.88 | $Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$ | m³/min | 34 |
| **Volume of gas metered wet, $V_{mstw}$** | | | **Wet total flow of stack gas, $Q_{stw}$** | | |
| $V_{mstw} = V_{mstd} + V_{wstd}$ | m$^3$ | 0.9386 | $Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$ | m³/min | 37 |
| **Vol. of gas metered at $O_2$ Ref. Cond., $V_{mstd@X\%O2}$** | | | **Dry total flow of stack gas at X% $O_2$, $Q_{stdO2}$** | | |
| Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)* | | No | $Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$ | m³/min | 18 |
| % oxygen measured in gas stream, act%$O_2$ | | 15.88 | **Percent isokinetic, %I** | | |
| % oxygen reference condition | | 11 | Nozzle diameter, $D_n$ | mm | 7.88 |
| $O_2$ Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$ | | 0.51 | Nozzle area, $A_n$ | mm$^2$ | 48.82 |
| $V_{mstd@X\%oxygen} = (V_{mstd})\ (O_{2\ Ref})$ | m$^3$ | 0.4507 | Total sampling time, q | min | 60 |
| **Moisture content, $B_{wo}$** | | | $\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ | % | 101 |
| $B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$ | | 0.0615 | | | |
| | % | 6.15 | Acceptable isokinetic range 95% to 115% | | Yes |
| **Moisture by FTIR** | % | - | **Hydrogen Chloride Concentration, C** | | |
| **Molecular weight of dry gas, $M_d$** | | | Mass collected , M | ug | 6 |
| $CO_2$ | | 2.95 | $C_{wet} = \frac{M_n}{V_{mstw}}$ | mg/m³ | 0.006 |
| $O_2$ | | 15.88 | | | |
| Total | | 18.83 | $C_{dry} = \frac{M_n}{V_{mstd}}$ | mg/m³ | 0.006 |
| $N_2$ (100 -Total) | | 81.17 | | | |
| | | | $C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$ | mg/m³ | 0.012 |
| $M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$ | | 29.11 | | | |
| **Molecular weight of wet gas, $M_s$** | | | **Hydrogen Chloride Emission Rates, E** | | |
| $M_s = M_d(1 - B_{wo}) + 18(B_{wo})$ | g/gmol | 28.4 | $E = [(C_{wet})(Q_{stw})(60)] / 1000$ | g/hr | 0.01 |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## ISOKINETIC SAMPLING EQUATIONS 3 — Hydrogen Chloride

| | | | | | |
|---|---|---|---|---|---|
| **Absolute pressure of stack gas, $P_s$** | | | **Velocity of stack gas, $V_s$** | | |
| Barometric pressure, $P_b$ | kPa | 100 | Velocity pressure coefficient, $C_p$ | | 0.85 |
| Stack static pressure, $P_{static}$ | Pa | 6 | Mean of velocity heads, $DP_{avg}$ | Pa | 30.14 |
| $P_s = P_b + (P_{static})$ | kPa | 100.01 | Mean stack gas temperature, $T_s$ | K | 376.75 |
| | | | Gas density $_{(wet, ambient)}$, p | | |
| **Vol. of water vapour collected, $V_{wstd}$** | | | p=(Ms*Ps)/(8.314*Ts) | $kg/m^3$ | 0.907 |
| Moisture trap weight increase,Vlc | g | - | Stack Velocity, Vs | | |
| $V_{wstd} = (0.001246)(V_{lc})$ | $m^3$ | - | $V_s = \frac{\sum_{i=1}^{n} V_i}{n}$ | m/s | 6.91 |
| **Volume of gas metered dry, $V_{mstd}$** | | | **Actual flow of stack gas, $Q_a$** | | |
| Volume of gas sample through gas meter, $V_m$ | $m^3$ | 1.0190 | Area of stack, $A_s$ | $m^2$ | 0.12 |
| Gas meter correction factor, $Y_d$ | | 1.011070729 | $Q_a = (60)(A_s)(V_s)$ | $m^3/min$ | 48 |
| Mean dry gas meter temperature, $T_m$ | K | 309.17 | **Dry total flow of stack gas, $Q_{std}$** | | |
| Mean pressure drop across orifice, DH | $mmH_2O$ | 25.81 | Conversion factor (K/mm.Hg) | | 0.3592 |
| $V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m}$ | $m^3$ | 0.90 | $Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s)}$ | $m^3/min$ | 32 |
| **Volume of gas metered wet, $V_{mstw}$** | | | **Wet total flow of stack gas, $Q_{stw}$** | | |
| $V_{mstw} = V_{mstd} + V_{wstd}$ | $m^3$ | 0.9590 | $Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s)}$ | $m^3/min$ | 34 |
| **Vol. of gas metered at $O_2$ Ref. Cond., $V_{mstd@X\%O2}$** | | | **Dry total flow of stack gas at X% $O_2$, $Q_{stdO2}$** | | |
| Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)* | | No | $Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s)}$ | $m^3/min$ | 16 |
| % oxygen measured in gas stream, act%$O_2$ | | 15.88 | **Percent isokinetic, %I** | | |
| % oxygen reference condition | | 11 | Nozzle diameter, $D_n$ | mm | 7.88 |
| $O_2$ Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$ | | 0.51 | Nozzle area, $A_n$ | $mm^2$ | 48.82 |
| $V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$ | $m^3$ | 0.4605 | Total sampling time, q | min | 60 |
| **Moisture content, $B_{wo}$** | | | $\%I = \frac{(4.6398E6)(T_s)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ | % | 110 |
| $B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$ | | 0.0615 | | | |
| | % | 6.15 | Acceptable isokinetic range 95% to 115% | | Yes |
| **Moisture by FTIR** | % | - | **Hydrogen Chloride Concentration, C** | | |
| **Molecular weight of dry gas, $M_d$** | | | Mass collected , M | ug | 3 |
| $CO_2$ | | 2.95 | $C_{wet} = \frac{M_n}{V_{mstw}}$ | $mg/m^3$ | 0.004 |
| $O_2$ | | 15.88 | | | |
| Total | | 18.83 | $C_{dry} = \frac{M_n}{V_{mstd}}$ | $mg/m^3$ | 0.004 |
| $N_2$ (100 -Total) | | 81.17 | $C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$ | $mg/m^3$ | 0.007 |
| $M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$ | | 29.11 | | | |
| **Molecular weight of wet gas, $M_s$** | | | **Hydrogen Chloride Emission Rates, E** | | |
| $M_s = M_d(1 - B_{wo}) + 18(B_{wo})$ | g/gmol | 28.4 | $E = [(C_{wet})(Q_{stw})(60)] / 1000$ | g/hr | 0.01 |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## TOTAL VOLATILE ORGANIC COMPOUNDS SUMMARY

| Test | Sampling Times | Concentration mg/m³ | LOD mg/m³ | ELV mg/m³ | Emission Rate g/hr |
|---|---|---|---|---|---|
| Run 1 | 10:15 - 15:35<br>13 April 2023 | 1.2 | 0.40 | 20 | 4.8 |

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

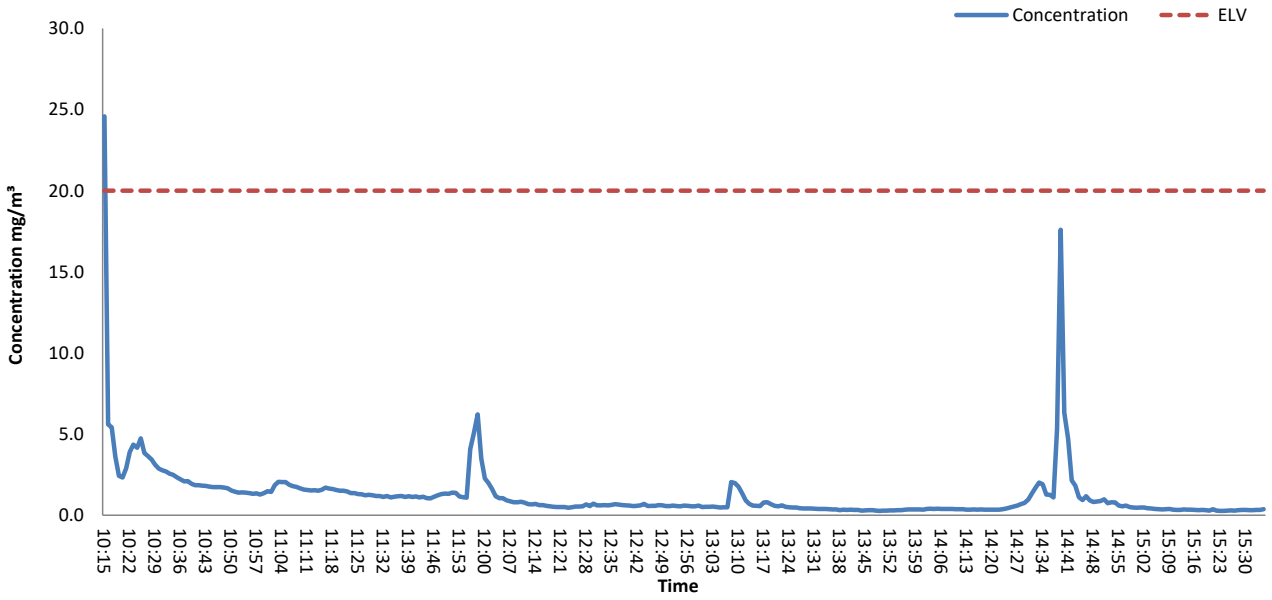
### INSTRUMENTAL SPAN & ZERO CHECKS

| PRE-SAMPLING CALIBRATION CHECKS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | 13 April 2023 | | | | | | | |
| Start Time | 09:00 | | | | | | | |
| End Time | 09:20 | | | | | | | |
| Gas | Gas Conc (ppm) | Range | Instrument Zero Reading | Instrument Span Reading | Instrument Zero Reading | Zero Down line reading | Span down line reading | Leak Rate (%) |
| Propane | 80.7 | 100 | 0.00 | 80.7 | 0.87 | 1.05 | 82.2 | -1.86 |

Zero and Span gas contained 20% Oxygen

| POST-SAMPLING CALIBRATION CHECKS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | 13 April 2023 | | | | | | | |
| Start Time | 15:40 | | | | | | | |
| End Time | 16:00 | | | | | | | |
| Gas | Mean Raw Value ppm | Zero down line reading | Span down line reading | Zero Drift (%) | Span Drift (%) | Corrected for Zero Drift | Corrected for Span Drift | Corrected Values ppm / % |
| Propane | 1.43 | 1.12 | 83.1 | 0.09 | 1.03 | × | × | N/A - not corrected |

## TOTAL VOLATILE ORGANIC COMPOUNDS EMISSIONS CHART




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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## COMBUSTION GASES SUMMARY

| Test | Sampling Time and Date | Concentration mg/m³ | LOD mg/m³ | ELV mg/m³ | Emission Rate g/hr |
|---|---|---|---|---|---|
| Carbon Monoxide | 10:10 - 11:10<br>13 April 2023 | 121.0 | 0.54 | 100 | 124 |

| Test | Sampling Time and Date | Concentration % | LOD % |
|---|---|---|---|
| Oxygen | 10:10 - 11:10<br>13 April 2023 | 15.88 | 0.01 |

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

### PRE-SAMPLING CALIBRATION DATA

| | |
|---|---|
| Date | 13 April 2023 |
| Start Time | 09:00 |
| End Time | 09:20 |

| | |
|---|---|
| Chiller Temperature (°C) | 2.4 |
| Requirement | < 4°C |
| Compliant | Yes |

| Gas | Range (ppm / %) | Zero Reading at analyser | Span Reading at analyser | Zero Check at analyser | Zero Check down line | Span Check down line | Response Time (Secs) | Leak Rate % |
|---|---|---|---|---|---|---|---|---|
| Carbon Monoxide | 200 | 0.00 | 167.8 | -0.80 | -0.20 | 166.5 | 45 | 0.77 |
| Oxygen | 25 | 0.00 | 20.90 | 0.03 | 0.08 | 20.92 | 40 | -0.10 |

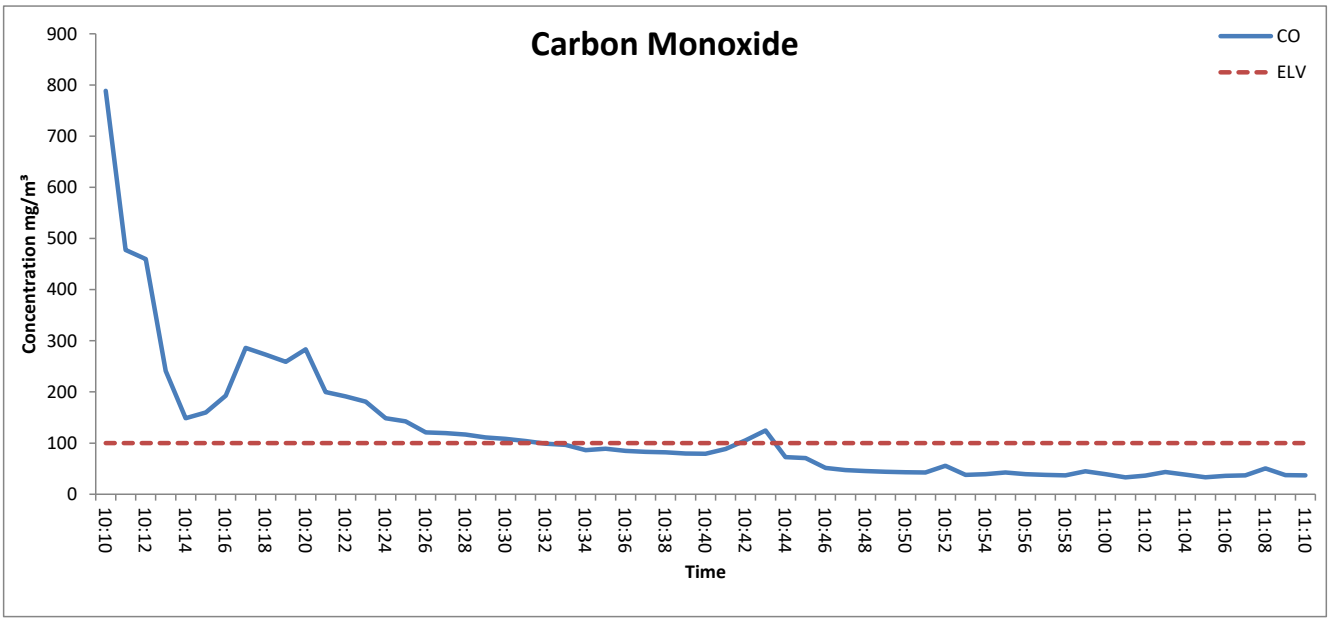
### POST-SAMPLING CALIBRATION DATA

| | |
|---|---|
| Date | 13 April 2023 |
| Start Time | 15:40 |
| End Time | 16:00 |

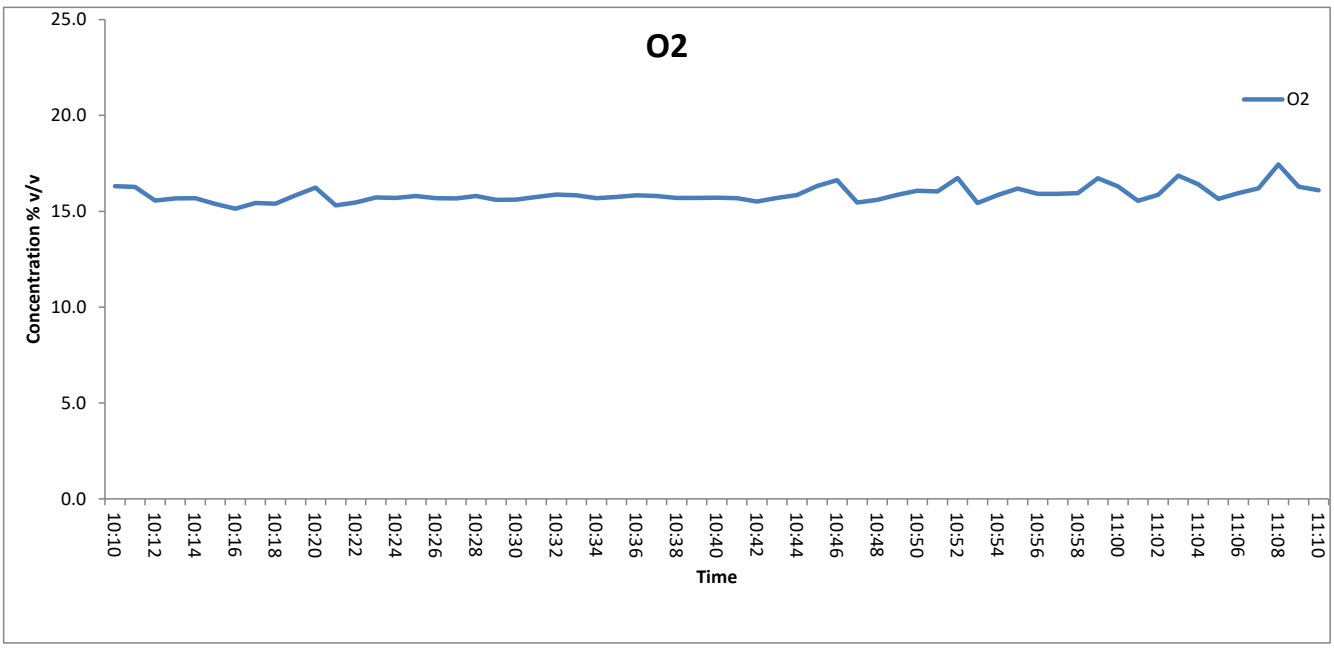
| | |
|---|---|
| Chiller Temperature (°C) | 3.1 |
| Requirement | < 4°C |
| Compliant | Yes |

| Gas | Zero Check at Analyser | Span Check at Analyser | Zero Drift (%) | Span Drift (%) | Corrected for Zero Drift | Corrected for Span Drift | Corrected Values ppm / % |
|---|---|---|---|---|---|---|---|
| Carbon Monoxide | -0.20 | 165.9 | 0.35 | -1.49 | × | × | N/A - not corrected |
| Oxygen | 0.06 | 20.94 | 0.14 | 0.05 | × | × | N/A - not corrected |

## CARBON MONOXIDE EMISSIONS CHART




## OXYGEN EMISSIONS CHART



APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## MOISTURE CALCULATIONS

| Moisture Determination - Isokinetic | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Number | Sampling Time and Date | Start Weight kg | End Weight kg | Total gain kg | Concentration % | LOD % | Uncertainty % |
| Run 1 | 11:54 - 12:54 13 April 2023 | 3.3845 | 3.4302 | 0.0457 | 6.2 | 0.01 | 4.9 |

| Moisture Quality Assurance | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Number | Sampling Duration mins | Total Volume Sampled l | Sampling Rate l/min | Start Leak Rate l/min | End Leak Rate l/min | Acceptable Leak Rate l/min | Leak Tests Acceptable? |
| Run 1 | 60 | 926 | 16.5 | 0.20 | - | 0.33 | Yes |

## PRELIMINARY STACK SURVEY

| Stack Characteristics | | |
|---|---|---|
| Stack Diameter / Depth, D | 0.34 | m |
| Stack Width, W | 0.34 | m |
| Stack Area, A | 0.12 | $m^2$ |
| Average stack gas temperature | 91 | $^oC$ |
| Stack static pressure | 0.006 | kPa |
| Barometric Pressure | 100 | kPa |

| Stack Gas Composition & Molecular Weights | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Component | Molar Mass M | Density $kg/m^3$ p | Conc Dry % Vol | Dry Volume Fraction r | Dry Conc $kg/m^3$ pi | Conc Wet % Vol | Wet Volume Fraction r | Wet Conc $kg/m^3$ pi |
| $CO_2$ | 44 | 1.963059 | 2.948332 | 0.029483 | 0.057877 | 2.766947 | 0.027669 | 0.054317 |
| $O_2$ | 32 | 1.427679 | 15.883060 | 0.158831 | 0.226759 | 14.905915 | 0.149059 | 0.212809 |
| $N_2$ | 28 | 1.249219 | 81.168608 | 0.811686 | 1.013974 | 76.175019 | 0.761750 | 0.951593 |
| $H_2O$ | 18 | 0.803070 | - | - | - | 6.152119 | 0.061521 | 0.049406 |

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

| Calculation of Stack Gas Densities | | |
|---|---|---|
| Determinand | Result | Units |
| Dry Density (STP), $P_{STD}$ | 1.2986 | $kg/m^3$ |
| Wet Density (STP), $P_{STW}$ | 1.2681 | $kg/m^3$ |
| Dry Density (Actual), $P_{Actual}$ | 0.9615 | $kg/m^3$ |
| Average Wet Density (Actual), $P_{ActualW}$ | 0.939 | $kg/m^3$ |

**Where:**

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

$P_{STW} = (P_{STD} + pi \text{ of } H_2O) / (1 + (pi \text{ of } H_2O / 0.8036))$

$P_{Actual} = P_{STD} \times (Ts / Ps) \times (Pa / Ta)$

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

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## PRELIMINARY STACK SURVEY

### TRAVERSE 1

| | |
|---|---|
| Date of Survey | 13 April 2023 |
| Time of Survey | 10:05 |
| Velocity Measurement Device: | S-Type Pitot |

**Sampling Line A**

| Traverse Point | Distance into duct (m) | DP pt Pa (average of 3 readings) | DP pt $mmH_2O$ (average of 3 readings) | Temp °C | Velocity m/s | Volumetric Flow Rate (actual) $m^3/s$ | $O_2$ % Vol | Angle of Swirl ° |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.05 | 30.1 | 3.1 | 91 | 6.8 | 0.79 | - | - |
| 2 | 0.13 | 27.8 | 2.8 | 91 | 6.5 | 0.76 | - | - |
| 3 | 0.21 | 26.1 | 2.7 | 91 | 6.3 | 0.73 | - | - |
| 4 | 0.29 | 24.8 | 2.5 | 91 | 6.2 | 0.71 | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| Mean | - | 27.2 | 2.8 | 91 | 6.5 | 0.7 | - | - |

**Sampling Line B**

| Traverse Point | Distance into duct (m) | DP pt Pa (average of 3 readings) | DP pt $mmH_2O$ (average of 3 readings) | Temp °C | Velocity m/s | Volumetric Flow Rate (actual) $m^3/s$ | $O_2$ % Vol | Angle of Swirl ° |
|---|---|---|---|---|---|---|---|---|
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - |
| Mean | - | - | - | - | - | - | - | - |

## PRELIMINARY STACK SURVEY QUALITY ASSURANCE CHECKLIST

**PITOT LEAK CHECK**

| Run | Pre Traverse Leak Rate | | | | Post Traverse Leak Rate | | | |
|---|---|---|---|---|---|---|---|---|
| | Start Value mmH2O | End Value mmH2O | Difference % | Outcome | Start Value mmH2O | End Value mmH2O | Difference % | Outcome |
| Run 1 | 104 | 102 | 1.9 | Pass | 130 | 128 | 1.5 | Pass |

To complete a compliant pitot leak check a pressure of over 80 $mmH_2O$ (or 800 Pa) is applied and the pressure drop monitored over 5 mins. A drop of less than 5% must be observed.

**S-Type Pitot Stagnation Check**

| Run | Stagnation (Pa) | Reference (Pa) | Difference (Pa) | Outcome (Permitted +/- 10 Pa) |
|---|---|---|---|---|
| Run 1 | 6 | 6 | 0.0 | Pass |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## PRELIMINARY STACK SURVEY (CONTINUED)

| Sampling Plane Validation Criteria | | | | |
|---|---|---|---|---|
| EA Technical Guidance Note (Monitoring) M1 | Result | Units | Requirement | Compliant |
| Lowest Average Differential Pressure | 25 | Pa | >= 5 Pa | Yes |
| Lowest Gas Velocity | 6.2 | m/s | - | - |
| Highest Gas Velocity | 6.8 | m/s | - | - |
| Ratio of Gas Velocities | 1.1 | - | < 3 : 1 | Yes |
| Maximum angle of flow with regard to duct axis | <15 | ° | < 15° | Yes |
| No local negative flow | Yes | - | - | Yes |

| Calculation of Stack Gas Velocity, V | | |
|---|---|---|
| Velocity at Traverse Point, V = $K_{pt}$ x (1-e) * Ô(2 * D$P_{pt}$ / $P_{ActualW}$) | | |
| **Where:**<br>$K_{pt}$ = Pitot tube calibration coefficient<br>(1-e) = Compressibility correction factor, assumed at a constant 0.998 | | |
| Average Stack Gas Velocity, Va | **6.5** | m/s |

| Calculation of Stack Gas Volumetric Flowrate, Q | | | |
|---|---|---|---|
| Duct gas flow conditions | Actual | Reference | Units |
| Temperature | 91 | 0 | °C |
| Total Pressure | 100.006 | 101.3 | kPa |
| Oxygen | 15.9 | 11 | % |
| Moisture | 6.15 | 0.00 | % |
| Pitot tube calibration coefficient, $K_{pt}$ | 0.85 | | |

| Gas Volumetric Flowrate | Result | Units |
|---|---|---|
| Average Stack Gas Velocity (Va) | 6.46 | m/s |
| Stack Area (A) | 0.12 | $m^2$ |
| Gas Volumetric Flowrate (Actual), $Q_{Actual}$ | 2690.07 | $m^3$/hr |
| Gas Volumetric Flowrate (STP, Wet), $Q_{STP}$ | 1991.78 | $m^3$/hr |
| Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$ | 1869.24 | $m^3$/hr |
| Gas Volumetric Flowrate (REF), $Q_{Ref}$ | 956.48 | $m^3$/hr |

**Where:**
$Q_{Actual}$ = Va x A x 3600
$Q_{STP}$ = Q (Actual) x (Ts / Ta) x (Pa / Ps) x 3600
$Q_{STP,Dry}$ = Q (STP) / (100 - (100 / Ma)) x 3600
$Q_{Ref}$ = Q (STP) x ((100 - Ma) / (100 - Ms)) x ((21 - $O_2$a) / (21 - $O_2$s))

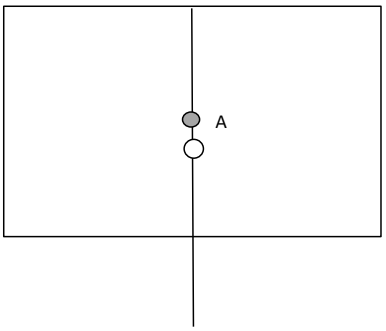
**Nomenclature:**
Ts = Absolute Temperature, Standard Conditions, 273 K
Ps = Absolute Pressure, Standard Conditions, 101.3 kPa
Ta = Absolute Temperature, Actual Conditions, K
Pa = Absolute Pressure, Actual Conditions, kPa
Ma = Water vapour, Actual Conditions, % Vol
Ms = Water vapour, Reference Conditions, % Vol
$O_2$a = Oxygen, Actual Conditions, % Vol
$O_2$s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## STACK DIAGRAM

| | Value | Units |
|---|---|---|
| Stack Depth | 0.34 | m |
| Stack Width | 0.34 | m |
| Area | 0.12 | $m^2$ |

| Non-Isokinetic/Gases Sampling | | | |
|---|---|---|---|
| Sampling Point | Distance (% of Depth) | Distance into Stack | Units |
| A | 50 | 0.17 | m |




Sampling Line

| Isokinetic Sampling | | | |
|---|---|---|---|
| Sampling Point | Distance (% of Depth) | Distance into Stack (m) | Swirl ° |
| 1 | 14.7 | 0.05 | < 15 |
| 2 | 37.5 | 0.13 | < 15 |
| 3 | 62.5 | 0.21 | < 15 |
| 4 | 85.3 | 0.29 | < 15 |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |

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

## SAMPLING LOCATION

Abatement System 1

APPENDIX 3 - Measurement Uncertainty Budget Calculations

## MEASUREMENT UNCERTAINTY BUDGET - TOTAL PARTICULATE MATTER

| Run | Sampled Volume | Sampled Gas Temp | Sampled Gas Pressure | Sampled Gas Humidity | Oxygen Content | Limit of Detection | Leak | Uncollected Mass |
|---|---|---|---|---|---|---|---|---|
| | $m^3$ | K | kPa | % by volume | % by volume | % by mass | % | mg |
| **MU required** | **≤ 2%** | **≤ 2%** | **≤ 1%** | **≤ 1%** | **≤ 10%** | **≤ 5% of ELV** | **≤ 2%** | **≤ 10% of ELV** |
| Run 1 | 0.0017 | 2.0 | 0.50 | 1.0 | 0.1 | 0.20 | - | - |
| as a % | 0.20 | 0.53 | 0.50 | 1.0 | 0.63 | 2.25 | 1.21 | 0.0018 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Run 2 | 0.0009 | 2.0 | 0.50 | 1.0 | 0.1 | 0.20 | - | - |
| as a % | 0.20 | 0.64 | 0.50 | 1.0 | 0.63 | 2.22 | 1.13 | 0.0018 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Run 3 | 0.0009 | 2.0 | 0.50 | 1.0 | 0.1 | 0.20 | - | - |
| as a % | 0.20 | 0.65 | 0.50 | 1.0 | 0.63 | 2.17 | 1.05 | 0.0018 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| Run | Volume (STP) | Mass of particulate | $O_2$ Correction | Leak | Uncollected Mass | Combined uncertainty |
|---|---|---|---|---|---|---|
| | $m^3$ | mg | - | $mg/m^3$ | mg | |
| Run 1 | 0.62 | 1.0400 | 2.0 | 0.0164 | 0.0002 | - |
| MU as $mg/m^3$ | 0.030 | 0.4500 | 0.05 | 0.0164 | 0.0005 | **0.45** |
| MU as % | 1.27 | 19.2308 | - | 0.701 | 0.0194 | - |
| Run 2 | 0.39 | 0.5600 | 2.0 | 0.0081 | 0.00020 | - |
| MU as $mg/m^3$ | 0.016 | 0.4437 | 0.02 | 0.0081 | 0.0004 | **0.44** |
| MU as % | 1.3 | 35.7143 | - | 0.650 | 0.0361 | - |
| Run 3 | 0.40 | 0.2000 | 2.0 | 0.0026 | 0.0002 | - |
| MU as $mg/m^3$ | 0.006 | 0.4343 | 0.01 | 0.0026 | 0.0004 | **0.43** |
| MU as % | 1.31 | 100.0000 | - | 0.605 | 0.1010 | - |

| | | | | | |
|---|---|---|---|---|---|
| **R1 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.91** | **mg/m³** | **38.77** | **% Result** | **4.54** | **% ELV** |
| **R2 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.89** | **mg/m³** | **71.60** | **% Result** | **4.45** | **% ELV** |
| **R3 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.87** | **mg/m³** | **200.06** | **% Result** | **4.34** | **% ELV** |

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

## MEASUREMENT UNCERTAINTY BUDGET - MERCURY

| Run | Sampled Volume<br>m³ | Sampled Gas Temp<br>K | Sampled Gas Pressure<br>kPa | Sampled Gas Humidity<br>% by volume | Oxygen Content<br>% by volume | Concentration in impinger<br>mg | Leak<br>% |
|---|---|---|---|---|---|---|---|
| **MU required** | **<=2%** | **<2.5 k** | **<=1%** | **<=1%** | **<=5%** | **<5%** | **<=2%** |
| Run 1 | 0.00093 | 2.0 | 0.50 | 1.0 | 0.10 | 0.00105 | - |
| as a % | 0.20 | 0.7 | 0.50 | 1.0 | 0.63 | 3.00 | 1.08 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| Run | Volume (STP)<br>m³ | O2 Correction<br>- | Mass of Mercury<br>mg | Leak<br>mg/m³ | Lab Uncertainty<br>mg | Combined |
|---|---|---|---|---|---|---|
| Run 1 | 0.4176 | 1.9543 | 9.5601 | 0.000128 | - | - |
| MU as mg/m$^3$ | 0.00027 | 0.00040 | 0.0011 | 0.000128 | 0.00103 | **0.0016** |
| MU as % | 1.3265 | 1.9543 | 5.2431 | 0.6223 | 5.00000 | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| **R1 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.00316** | **mg/m³** | **15.29** | **% Result** | **0.63** | **% ELV** |

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

## MEASUREMENT UNCERTAINTY BUDGET - ISOKINETIC HYDROGEN CHLORIDE

| Run | Sampled Volume<br>m³ | Sampled Gas Temp<br>K | Sampled Gas Pressure<br>kPa | Sampled Gas Humidity<br>% by volume | Oxygen Content<br>% by volume | Limit of Detection<br>% by mass | Leak<br>% |
|---|---|---|---|---|---|---|---|
| **MU required** | **<=2%** | **<2.5 k** | **<=1%** | **<=1%** | **<=5%** | **≤ 5% of ELV** | **<=2%** |
| Run 1 | 0.444 | 307 | 100.06 | 1.0 | 15.9 | 0.023 | - |
| as a % | 0.22 | 0.65 | 0.50 | 1.0 | 0.63 | 0.018 | 1.21 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Run 2 | 0.451 | 311 | 100.06 | 1.0 | 15.9 | 0.010 | - |
| as a % | 0.22 | 0.64 | 0.50 | 1.0 | 0.63 | 0.014 | 1.13 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Run 3 | 0.461 | 309 | 100.06 | 1.0 | 15.9 | 0.0068 | - |
| as a % | 0.22 | 0.65 | 0.50 | 1.0 | 0.63 | 0.01 | 1.05 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| Run | Volume (STP)<br>m³ | Mass of Hydrogen Chloride<br>mg | O2 Correction<br>- | Leak<br>mg/m³ | Lab Uncertainty<br>mg | Combined uncertainty |
|---|---|---|---|---|---|---|
| Run 1 | 0.3902 | 0.0230 | 1.9543 | 0.00019 | - | - |
| MU as mg/m$^3$ | 0.0004 | 0.0055 | 0.00054 | 0.00019 | 0.0013 | **0.0057** |
| MU as % | 1.3188 | 20.0012 | 1.9543 | 0.7014 | 4.8 | - |
| Run 2 | 0.391 | 0.010 | 1.954 | 0.000080 | - | - |
| MU as mg/m$^3$ | 0.00016 | 0.004 | 0.00024 | 0.000080 | 0.00059 | **0.004** |
| MU as % | 1.315 | 33.335 | 1.954 | 0.650 | 4.800 | - |
| Run 3 | 0.402 | 0.007 | 1.954 | 0.000044 | - | - |
| MU as mg/m$^3$ | 0.00010 | 0.004 | 0.00014 | 0.000044 | 0.00035 | **0.004** |
| MU as % | 1.315 | 50.001 | 1.954 | 0.605 | 4.800 | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| **R1 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.011** | **mg/m³** | **41.43** | **% Result** | **0.038** | **% ELV** |
| **R2 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.0083** | **mg/m³** | **67.53** | **% Result** | **0.028** | **% ELV** |
| **R3 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.0074** | **mg/m³** | **100.58** | **% Result** | **0.025** | **% ELV** |

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

## MEASUREMENT UNCERTAINTY BUDGET - MOISTURE

| Run | Sampled Volume $m^3$ | Sampled Gas Temp K | Sampled Gas Pressure kPa | Sampled Gas Humidity % by volume | Oxygen Content % by volume | Leak % |
|---|---|---|---|---|---|---|
| **MU required** | **≤ 2%** | **≤ 2%** | **≤ 1%** | **≤ 1%** | **≤ 10%** | **≤ 2%** |
| Run 1 | 0.0017 | 2.0 | 0.50 | 1.0 | 0.1 | - |
| as a % | 0.20 | 0.53 | 0.50 | 1.0 | 0.63 | 1.21 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| Run | Volume (STP) $m^3$ | Mass Gained mg | $O_2$ Correction - | Leak $mg/m^3$ | Uncollected Mass mg | Combined uncertainty |
|---|---|---|---|---|---|---|
| Run 1 | 0.62 | 45700 | 2.0 | 369.00 | 58 | - |
| MU as % v/v | 0.084 | 0.01 | 0.13 | 0.05 | 0.008 | **0.16** |
| MU as % | 1.27 | 0.22 | 1.95 | 0.70 | 0.13 | - |

| | | | | |
|---|---|---|---|---|
| **R1 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.32** | **% v/v** | **4.89** | **%** |

APPENDIX 3 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - VOLATILE ORGANIC COMPOUNDS RUN 1**

| | | |
|---|---|---|
| Measured Concentration | 1.2 | $mg/m^3$ |
| Limit | 20 | $mg/m^3$ |
| Calibration Gas Concentration | 129.12 | $mg/m^3$ |
| Range | 160 | $mg/m^3$ |

| Performance characteristics | Value | Units | specification | MU Met? |
|---|---|---|---|---|
| Response time | 35 | seconds | <180 | Yes |
| Logger sampling interval | 60 | seconds | - | - |
| Measurement period | 320 | minutes | - | - |
| Number of readings in measurement | 320 | - | - | - |
| Repeatability at zero | 0.25 | % full scale | <1 % range | Yes |
| Repeatability at span level | 0.15 | % full scale | <2 % range | Yes |
| Deviation from linearity | 0.70 | % of value | <2 % range | Yes |
| Zero drift | 0.09 | % full scale | <5% range / 24hr | Yes |
| Span drift | 1.03 | % full scale | <5% range / 24hr | Yes |
| volume or pressure flow dependence | 0.02 | % of full scale/3 kPa | <2 % / 3 kPa | Yes |
| atmospheric pressure dependence | 0.80 | % of full scale/2 kPa | <3% / 2 kPa | Yes |
| ambient temperature dependence | 0.01 | % full scale/10K | <3% range / 10 K | Yes |
| dependence on voltage | 0.10 | % full scale/10V | < 0.1%vol /10 volt | Yes |
| losses in the line (leak) | -1.86 | % of value | < 2% of span gas value | Yes |
| Uncertainty of calibration gas | 1.0 | % of value | < 2% of value | Yes |

| Performance characteristic | Uncertainty | Value of uncertainty quantity |
|---|---|---|
| Standard deviation of repeatability at zero | ur0 | 0.01 |
| Standard deviation of repeatability at span level | urs | 0.01 |
| Lack of fit | ufit | 0.65 |
| Drift | u0dr | 0.06 |
| volume or pressure flow dependence | uspres | 0.00 |
| atmopsheric pressure dependence | uapres | 0.04 |
| ambient temperature dependence | utemp | 0.00 |
| Dependence on voltage | uvolt | 0.14 |
| losses in the line (leak) | uleak | -0.01 |
| Uncertainty of calibration gas | ucalib | 0.01 |
| Uncertainty in factor | uf | 0.01 |

| | | |
|---|---|---|
| Measurement uncertainty Measured Concentration | 1.22 | $mg/m^3$ |
| Combined uncertainty | 0.66 | $mg/m^3$ |
| Expanded uncertainty | 1.30 | $mg/m^3$ |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **6.52** | **% ELV** |
| | | |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **1.30** | **$mg/m^3$** |
| | | |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **106.92** | **% value** |

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - CARBON MONOXIDE**

| | | |
|---|---|---|
| Limit value | 100 | $mg/m^3$ |
| Concentration @ Ref conditions | 121.0 | $mg/m^3$ |
| Cal gas conc | 209.8 | $mg/m^3$ |
| Analyser Full Scale | 250 | $mg/m^3$ |

| Performance characteristics | Value | Units | specification | MU Met? |
|---|---|---|---|---|
| Response time | 45 | seconds | 180 | Yes |
| Logger sampling interval | 60 | seconds | - | - |
| Measurement period | 60 | minutes | - | - |
| Number of readings in measurement | 60 | - | - | - |
| Repeatability at zero | 0.1 | % full scale | <1 % range | Yes |
| Repeatability at span level | 0.2 | % full scale | <2 % range | Yes |
| Deviation from linearity | 0.61 | % of value | <2 % range | Yes |
| Zero drift | 0.35 | % full scale | <5% range / 24hr | Yes |
| Span drift | -1.49 | % full scale | <5% range / 24hr | Yes |
| volume or pressure flow dependence | 0.2 | % of full scale/3 kPa | <2 % / 3 kPa | Yes |
| atmospheric pressure dependence | 0.44 | % of full scale/2 kPa | <3% / 2 kPa | Yes |
| ambient temperature dependence zero / span | 1 | % full scale/10K | <3% range / 10 K | Yes |
| Combined interference | 0.03 | % of Range | <4% of Range | Yes |
| dependence on voltage | -0.06 | % full scale/10V | < 0.1%vol /10 volt | Yes |
| Influence of Vibration | N/A | % of upper limit of Cal range | <2% | N/A |
| losses in the line (leak) | 0.01 | % of value | < 2% of value | Yes |
| Uncertainty of calibration gas | 1.00 | % of value | < 2% of value | Yes |

N/A - Horiba's are not effected by Vibration

| Performance characteristic | Uncertainty | Value of uncertainty quantity |
|---|---|---|
| repeatability | $U_r = S_r$ | 0.003 |
| lack of fit | $U_{lof}$ | 0.12 |
| short term zero drift | $U_{d,z}$ | 0.35 |
| short term span drift | $U_{d,s}$ | 0.20 |
| influence of Ambient Temp zero | $U_{t,z}$ | -0.04 |
| influence of Ambient Temp span | $U_{t,s}$ | 0.07 |
| influence of sample gas pressure | $U_p$ | 0.00 |
| influence of sample gas flow | $U_{fit}$ | 0.14 |
| influence of supply voltage | $U_v$ | -0.09 |
| Combined Interfence | $U_i$ | 1.51 |
| Uncertainty of Cal gas | $U_{adj}$ | 0.84 |

| | | |
|---|---|---|
| Measurement uncertainty (Concentration Measured) | 62.5 | $mg/m^3$ |
| Combined uncertainty | 1.8 | $mg/m^3$ |
| Expanded uncertainty | 3.5 | $mg/m^3$ |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **3.5** | **% ELV** |
| | | |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **3.5** | **$mg/m^3$** |
| | | |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **5.6** | **% value** |

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - OXYGEN**

| | | |
|---|---|---|
| Reference | 11 | %vol |
| Reported Concentration | 15.88 | %vol |
| Calibration gas | 20.9 | %vol |
| Analyser Full Scale | 25 | %vol |

| | Value | Units | specification | MU Met? |
|---|---|---|---|---|
| Response time | 40 | seconds | 180 | Yes |
| Logger sampling interval | 60 | seconds | - | - |
| Measurement period | 60 | minutes | - | - |
| Number of readings in measurement | 60 | - | - | - |
| Repeatability at zero | 0.25 | % full scale | <1 % range | Yes |
| Repeatability at span level | 0.15 | % full scale | <2 % range | Yes |
| Deviation from linearity | 0.13 | % of value | <2 % range | Yes |
| Zero drift | 0.14 | % full scale | <5% range / 24hr | Yes |
| Span drift | 0.05 | % full scale | <5% range / 24hr | Yes |
| volume or pressure flow dependence | 0.03 | % of full scale/3 kPa | <2 % / 3 kPa | Yes |
| atmospheric pressure dependence | 0.05 | % of full scale/2 kPa | <3% / 2 kPa | Yes |
| ambient temperature dependence | -0.08 | % full scale/10K | <3% range / 10 K | Yes |
| Combined interference | 0.14 | % range | <4% of Range | Yes |
| dependence on voltage | 0.00 | % full scale/10V | < 0.1%vol /10 volt | Yes |
| losses in the line (leak) | 0.14 | % of value | < 2% of value | Yes |
| Uncertainty of calibration gas | 0.1 | % of value | < 2% of value | Yes |

| Performance characteristic | Uncertainty | Value of uncertainty quantity |
|---|---|---|
| repeatability | $U_r = S_r$ | 0.0083 |
| lack of fit | $U_{lof}$ | 0.0751 |
| short term zero drift | $U_{d,z}$ | 0.0829 |
| short term span drift | $U_{d,s}$ | 0.0276 |
| influence of Ambient Temp at Zero | $U_{t,z}$ | -0.0003 |
| influence of Ambient Temp at Span | $U_{t,s}$ | -0.0018 |
| influence of sample gas pressure | $U_p$ | 0.0000 |
| influence of sample gas flow | $U_{fit}$ | 0.0173 |
| influence of supply voltage | $U_v$ | 0.0001 |
| Combined Interfence | $U_i$ | 0.0485 |
| Uncertainty of Cal gas | $U_{adj}$ | 0.1045 |

| | | |
|---|---|---|
| Measurement uncertainty (Concentration Measured) | 15.88 | % |
| Combined uncertainty | 0.16 | % |
| Expanded uncertainty | 0.32 | % |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **0.32** | **%** |
| **Expanded uncertainty expressed with a level of confidence of 95%** | **2.02** | **% vol** |

## MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

| | | |
|---|---|---|
| Measured Velocity at Actual Conditions | 6.5 | m/s |
| Measured Volumetric Flow rate at Actual Conditions | 2690 | m³/hr |

| Performance Characteristics & Source of Value | Units | Values | Requirement | Compliant |
|---|---|---|---|---|
| Uncertainty of Local Gas Velocity Determination | | | | |
| Uncertainty of pitot tube coefficient | - | 0.010 | | |
| Uncertainty of mean local dynamic pressures | - | 0.44 | | |
| Factor loading, function of the number of measurements. | 3 readings | 0.591 | minimum 3 | Yes |
| Range of measurment device | pa | 1000 | | |
| Resolution | pa | 1.00 | | |
| Calibration uncertainty | pa | 5.88 | <1% of Value or 20 Pa whichever is greater | Yes |
| Drift | % range | 0.10 | | |
| Linearity | % range | 0.06 | <2% of value | Yes |
| Uncertainty of gas density determination | | | | |
| Uncertainty of molar mass determination | kg/mol | 0.00051 | | |
| Uncertainty of temperature measurement | K | 1.86 | <1% of value | Yes |
| Uncertainty of absolute pressure in the duct | pa | 510 | | |
| Uncertainty associated with the calculation of density | kg/m3 | 0.008 | | |
| Uncertainty associated with the measurement of local velocity | - | 0.0001 | | |
| Uncertainty associated with the measurement of mean velocity | - | 0.0002 | | |

| Measurement Uncertainty - Velocity | m/s |
|---|---|
| **Combined uncertainty** | 0.08 |
| **Expanded uncertainty at a 95% Confidence Interval** | 0.16 |

*Note - The expanded uncertainty uses a coverage factor of k = 2.*

| Expanded Measurement Uncertainty of Velocity at a 95% Confidence Interval | % |
|---|---|
| **Expressed as a % of the Measured Velocity** | 1.3 |
| **Expanded uncertainty at a 95% Confidence Interval** | 2.5 |

| Measurement Uncertainty Volumetric Flow Rate | m³/hr |
|---|---|
| **Combined uncertainty** | 77 |
| **Expanded uncertainty at a 95% Confidence Interval** | 151 |

*Note - The expanded uncertainty uses a coverage factor of k = 2.*

| Expanded Measurement Uncertainty of Volumetric Flow Rate at a 95% Confidence Interval | % |
|---|---|
| **Expressed as a % of the Measured Volumetric Flow Rate** | 2.9 |
| **Expanded uncertainty at a 95% Confidence Interval** | 5.6 |

Reference – SOCOTEC Technical Procedure AE150 Estimation of Uncertainty of Measurement

## END OF REPORT

*Thank you for choosing SOCOTEC for your environmental monitoring needs. We hope our services have met your requirements and that you are fully satisfied with your experience of working with us, we really do value your custom and would welcome your feedback. We would appreciate it if you could take a moment to complete a short online questionnaire so that we can improve our operations and address any areas that have not met with your expectations, by clicking on the following*

https://www.surveymonkey.co.uk/r/CAE_customer_feedback_weblink