# STACK EMISSIONS MONITORING REPORT

SOCOTEC

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| --- |
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| Operator & Address: |
| --- |
| RWE Generation Ltd<br>Aberthaw Power Station<br>The Leys<br>Nr Barry<br>CF62 4ZW |

| Permit Reference: |
| --- |
| EPR Permit: RP3133LD/V012 |

| Release Point: |
| --- |
| Unit 8 |

| Sampling Date(s): |
| --- |
| 12th February 2019 |

| | |
| --- | --- |
| SOCOTEC UK Job Number: | LSO 181001 |
| Report Date: | 13th March 2019 |
| Version: | 1 |
| Report By: | Jonathan Ward |
| MCERTS Number: | MM 02 080 |
| MCERTS Level: | MCERTS Level 2 - Team Leader |
| Technical Endorsements: | 1, 2, 3 & 4 |
| Report Approved By: | David May |
| MCERTS Number: | MM 07 862 |
| Business Title: | MCERTS Level 2 - Operations Manager (LSO) |
| Technical Endorsements: | 1, 2, 3 & 4 |
| Signature: | |

UKAS TESTING 1015

MCERTS

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# EXECUTIVE SUMMARY

## MONITORING OBJECTIVES

RWE Generation Ltd operates a coal fired steam turbine process at Aberthaw which is subject to EPR Permit RP3133LD/V012, under the Environmental Permitting Regulations 2010.

SOCOTEC UK LTD were commissioned by RWE Generation Ltd 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 EPR Permit, RP3133LD/V012.

**Plant**

Unit 8

**Operator**

RWE Generation Ltd
Aberthaw Power Station
The Leys
Nr Barry
CF62 4ZW

EPR Permit: RP3133LD/V012

**Stack Emissions Monitoring Test House**

SOCOTEC UK - Cirencester Laboratory
Units C & D
Bankside Trade Park
Cirencester
GL7 1YT
UKAS and MCERTS Accreditation Number: 1015

Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.
MCERTS accredited results will only be claimed where both the sampling and analytical stages are UKAS accredited.

# EXECUTIVE SUMMARY

| EMISSIONS SUMMARY | | | | | |
|---|---|---|---|---|---|
| Parameter | Units | Result | Calculated Uncertainty +/- | Limit | MCERTS accredited result |
| Mercury | mg/m³ | 0.0006 | 0.0009 | 0.005 | ✓ |
| Mercury Emission Rate | g/hr | 0.7230 | 1.0281 | - | |
| Oxygen | % v/v | 10.0 | 1.0 | - | ✓ |
| Moisture | % | 2.2 | 0.08 | - | ✓ |
| Stack Gas Temperature | °C | 62 | - | - | ✓ |
| Stack Gas Velocity | m/s | 18.8 | 0.46 | - | |
| Gas Volumetric Flow Rate (Actual) | m³/hr | 2043817 | 105079 | - | |
| Gas Volumetric Flow Rate (STP, Wet) | m³/hr | 1649441 | 84803 | - | |
| Gas Volumetric Flow Rate (STP, Dry) | m³/hr | 1612639 | 82911 | - | |
| Gas Volumetric Flow Rate at Reference Conditions | m³/hr | 1182167 | 60779 | - | |

ND = None Detected,

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

The above volumetric flow rate is calculated using data from the preliminary survey. Mass emissions for non isokinetic tests are calculated using these values. For all isokinetic testing the mass emission is calculated using test specific flow data and not the above values.

Reference conditions are 273K, 101.3kPa, dry gas 6% Oxygen.

# EXECUTIVE SUMMARY

| MONITORING TIMES | | | |
|---|---|---|---|
| **Parameter** | **Sampling Date(s)** | **Sampling Times** | **Sampling Duration** |
| Mercury Run 1 | 12 February 2019 | 18:40 - 19:40 | 60 minutes |
| Mercury Run 2 | 12 February 2019 | 19:50 - 20:50 | 60 minutes |
| Mercury Run 3 | 12 February 2019 | 20:58 - 21:58 | 60 minutes |
| Preliminary Stack Traverse | 12 February 2019 | 10:30 | - |

# EXECUTIVE SUMMARY

## PROCESS DETAILS

| Parameter | Process Details |
|---|---|
| Description of process | Coal fired steam turbine |
| Continuous or batch | Continuous |
| Product Details | Energy |
| Part of batch to be monitored (if applicable) | N/A |
| Normal load, throughput or continuous rating | 439 MW |
| Fuel used during monitoring | Coal |
| Abatement | None |
| Plume Appearance | Slight Plume Visible |

# EXECUTIVE SUMMARY

## Monitoring Methods

The selection of standard reference / alternative methods employed by SOCOTEC UK is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency Technical Guidance Note (Monitoring) M2.

| MONITORING METHODS | | | | | | |
|---|---|---|---|---|---|---|
| Species | Method Standard Reference Method / Alternative Method | SOCOTEC UK Technical Procedure | UKAS Lab Number | MCERTS Accredited Method | Limit of Detection (LOD) | Calculated MU +/- % |
| Mercury | SRM - BS EN 13211 / MID 14385 | AE 107/AE 108 | 1252 | Yes | 0.0005 mg/m³ | 142.2% |
| $H_2O$ | SRM - BS EN 14790 | AE 063 | 1015 | Yes | 0.01% | 3.72% |
| Velocity | SRM - BS EN ISO 16911-1 | AE 154 | 1015 | Yes | 5 Pa | 2.4% |
| Volumetric Flow Rate | SRM - BS EN ISO 16911-1 | AE 154 | 1015 | Yes | - | 5.1% |

BS EN 14790 has been validated over a range of 4 - 40%. It is however the prefered method of the Environment Agency for concentrations below 4%

The measurement of Moisture is covered by UKAS under the conditions of ESG's flexible scope.

# EXECUTIVE SUMMARY

## Analytical Methods

The following tables list the analytical methods employed together with the custody and archiving details:

| SAMPLING METHODS WITH SUBSEQUENT ANALYSIS | | | | | | | |
|---|---|---|---|---|---|---|---|
| Species | Analytical Technique | Analytical Procedure | UKAS Lab Number | UKAS Accredited Lab Analysis | Analysis Lab | Sample Archive Location | Archive Period |
| Mercury | Inductively coupled Plasma - Mass Spectrometry | ASC/SOP/117 | 1252 | Yes | SOCOTEC UK (Bretby) | SOCOTEC UK (Bretby) | 8 Weeks |

| ON-SITE TESTING | | | | | | | |
|---|---|---|---|---|---|---|---|
| Species | Analytical Technique | Analytical Procedure | UKAS Lab Number | MCERTS Accredited Analysis | Laboratory | Data Archive Location | Archive Period |
| $O_2$ | Paramagnetism | AE 102 | 1015 | Yes | SOCOTEC UK - (Cirencester) | SOCOTEC UK - (Cirencester) | 5 years |
| $H_2O$ | Gravimetric | AE 105 | 1015 | Yes | SOCOTEC UK - (Cirencester) | - | - |

# EXECUTIVE SUMMARY

| SAMPLING LOCATION | | | | | |
|---|---|---|---|---|---|
| **Sampling Plane Validation Criteria** | **Value** | **Units** | **Requirement** | **Compliant** | **Method** |
| Lowest Differential Pressure | 265 | Pa | >= 5 Pa | Yes | BS EN 15259 |
| Lowest Gas Velocity | 18.5 | m/s | - | - | - |
| Highest Gas Velocity | 19.2 | m/s | - | - | - |
| Ratio of Gas Velocities | 1.0 | : 1 | < 3 : 1 | Yes | BS EN 15259 |
| Mean Velocity | 18.8 | m/s | - | - | - |
| Maximum angle of flow with regard to duct axis | <15 | $^{o}$ | < 15$^{o}$ | Yes | BS EN 15259 |
| No local negative flow | Yes | - | - | Yes | BS EN 15259 |

| DUCT CHARACTERISTICS | | |
|---|---|---|
| | **Value** | **Units** |
| Shape | Circular | - |
| Depth | 6.20 | m |
| Width | - | m |
| Area | 30.19 | $m^2$ |
| Port Depth | 300 | mm |

| SAMPLING LINES & POINTS | | |
|---|---|---|
| | **Isokinetic** | **Non-Iso & Gases** |
| Sample port size | 4" BSP | 4" BSP |
| Number of lines used | 1 | 1 |
| Number of points / line | 1 | 1 |
| Duct orientation | Vertical | Vertical |

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

| **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) | N/A |
| 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)**

No Improvements Possible

# EXECUTIVE SUMMARY

## Sampling & Analytical Method Deviations

**Sample Points**

One Point per port available to test due to platform restrictions behind ports

**Sample Ports**

One Port used due to platform restrictions and safety issues

APPENDICES

## CONTENTS

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

| MONITORING SCHEDULE | | | | | |
|---|---|---|---|---|---|
| Species | Method<br>Standard Reference Method / Alternative Method | SOCOTEC UK Technical Procedure | UKAS Lab Number | MCERTS Accredited Method | Number of Samples |
| Mercury | SRM - BS EN 13211 / MID 14385 | AE 107/AE 108 | 1252 | Yes | 3 |
| Moisture | AM - M22/FTIR | AE 063 | 1015 | Yes | 1 |
| $H_2O$ | SRM - BS EN 14790 | AE 063 | 1015 | Yes | 1 |
| Velocity | SRM - BS EN ISO 16911-1 | AE 154 | 1015 | Yes | 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 | P2023 | Horiba PG-250 Analyser | - | Laboratory Balance | P66 |
| Box Thermocouples | P2023 | FT-IR Protea | LNO 5858 | Tape Measure | P1256 |
| Meter In Thermocouple | P2023 | FT-IR Oven Box | - | Stopwatch | P2674 |
| Meter Out Thermocouple | P2023 | Bernath 3006 FID | - | Protractor | - |
| Control Box Timer | P2023 | Signal 3030 FID | - | Barometer | P1313 |
| Oven Box | P1870 | Servomex | - | Digital Micromanometer | P2868 |
| Probe | P1972 | JCT Heated Head Filter | - | Digital Temperature Meter | P1475 |
| Probe Thermocouple | P2137 | Thermo FID | - | Stack Thermocouple | P2707 |
| Probe | - | Stackmaster | Appliance ID 8600 | Mass Flow Controller | - |
| Probe Thermocouple | - | FTIR Heater Box for Heated Line | - | MFC Display module | - |
| S-Pitot | P2174 | Anemometer | - | 1m Heated Line (1) | - |
| L-Pitot | - | Ecophysics NOx Analyser | - | 1m Heated Line (2) | - |
| Site Balance | - | Chiller (JCT/MAK 10) | - | 1m Heated Line (3) | - |
| Last Impinger Arm | P1033 | Heated Line Controller (1) | P1897 | 5m Heated Line (1) | - |
| Dioxins Cond. Thermocouple | - | Heated Line Controller (2) | - | 10m Heated Line (1) | P2404 |
| Callipers | - | Site temperature Logger | P2873 | 10m Heated Line (2) | - |
| Small DGM | - | | - | 15m Heated Line (1) | - |
| Heater Controller | - | | - | 20m Heated Line (1) | - |
| Inclinometer (Swirl Device) | P2191 | | - | 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 / CHECK GASES

| Gas (traceable to ISO 17025) | Cylinder I.D Number | Supplier | ppm | % | Analytical Tolerance +/- % |
|---|---|---|---|---|---|
| Oxygen | CD 4 | BOC | - | 10.15 | 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 |
| David May | MM 02 080 | MCERTS Level 2 | Nov-22 | Dec-19 | Sep-20 | Mar-20 | Sep-24 | Nov-22 |
| Stephen Huntley | MM 02 081 | MCERTS Level 2 | Mar-23 | Mar-22 | Mar-22 | Mar-22 | Nov-23 | Sep-17 |

## MERCURY SUMMARY - PARTICULATE & VAPOUR PHASES COMBINED

| Test | Sampling Times | Concentration mg/m³ | LOD mg/m³ | Limit mg/m³ | Emission Rate g/hr |
|---|---|---|---|---|---|
| Run 1 | 18:40 - 19:40 12 February 2019 | 0.0006 | 0.0005 | 0.005 | 0.650 |
| Run 2 | 19:50 - 20:50 12 February 2019 | 0.0008 | 0.0005 | 0.005 | 0.933 |
| Run 3 | 20:58 - 21:58 12 February 2019 | 0.0005 | 0.0005 | 0.005 | 0.587 |
| Field Blank | - | 0.0006 | - | - | - |

| 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 | 0.00048 | 0.50 | 0.00048 | 0.0000 | 0.09 | 0.000 |
| Volume Sampled $m^3$ | | 1.0459 | | | 1.0459 | |
| Run 2 | 0.00 | 0.70 | 0.00 | 0.0000 | 0.16 | 0.000 |
| Volume Sampled $m^3$ | | 1.11 | | | 1.1118 | |
| Run 3 | 0.00 | 0.50 | 0.00 | 0.0000 | 0.07 | 0.000 |
| Volume Sampled $m^3$ | | 1.12 | | | 1.1186 | |
| Field Blank | - | 0.50 | 0.00046 | - | 0.14 | 0.0001 |
| Volume Sampled $m^3$ | | 1.0921 | | | 1.0459 | |

Reference conditions are 273K, 101.3kPa, dry gas 6% Oxygen.

## ISOKINETIC SAMPLING EQUATIONS RUN 1 — Mercury

| | | |
|---|---|---|
| **Absolute pressure of stack gas, $P_s$** | | |
| Barometric pressure, $P_b$ | mm Hg | 750.0 |
| Stack static pressure, $P_{static}$ | mm $H_2O$ | -12.2 |
| $P_s = \frac{P_b + (P_{static})}{13.6}$ | mm Hg | 749.1 |
| **Vol. of water vapour collected, $V_{wstd}$** | | |
| Moisture trap weight increase,Vlc | g | $H_2O$ by Non Iso |
| $V_{wstd} = (0.001246)(V_{lc})$ | m3 | - |
| **Volume of gas metered dry, $V_{mstd}$** | | |
| Volume of gas sample through gas meter, $V_m$ | | 1.6 |
| Gas meter correction factor, $Y_d$ | | 0.974 |
| Mean dry gas meter temperature, $T_m$ | | 23.50 |
| Mean pressure drop across orifice, DH | mmH | 73.44 |
| $V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$ | | 1.43 |
| **Volume of gas metered wet, $V_{mstw}$** | | |
| $V_{mstw} = V_{mstd} + V_{wstd}$ | $m^3$ | 1.4587 |
| **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%$O_2$ | | 10.0 |
| % oxygen reference condition | | 6 |
| $O_2$ Reference Factor: $O2\ Ref = \frac{21.0 - act\%O2}{21.0 - ref\%O2}$ | | 0.73 |
| $V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$ | $m^3$ | 1.046 |
| **Moisture content, $B_{wo}$** | | |
| $B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$ | | 0.0223 |
| | % | 2.23 |
| **Moisture by FTIR** | % | - |

| | | |
|---|---|---|
| **Molecular weight of dry gas, $M_d$** | | |
| $CO_2$ | % | 12.67 |
| $O_2$ | % | 10.00 |
| Total | % | 22.67 |
| $N_2$ (100 -Total) | % | 77.33 |
| $M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$ | | 30.43 |
| **Molecular weight of wet gas, $M_s$** | | |
| $M_s = M_d(1 - B_{wo}) + 18(B_{wo})$ | g/gmol | 30.15 |
| **Velocity of stack gas, $V_s$** | | |
| Pitot tube velocity constant, $K_p$ | | 34.97 |
| Velocity pressure coefficient, $C_p$ | | 0.84 |
| Mean of velocity heads, $DP_{avg}$ | mm $H_2O$ | 27.00 |
| Mean square root of velocity heads, ÖDP | | 5.20 |
| Mean stack gas temperature, $T_s$ | °C | 65 |
| $V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$ | m/s | 18.67 |
| **Actual flow of stack gas, $Q_a$** | | |
| Area of stack, $A_s$ | $m^2$ | 30.19 |
| $Q_a = (60)(A_s)(V_s)$ | m³/min | 33828.6 |
| **Total flow of stack gas, Q** | | |
| Conversion factor (K/mm.Hg) | | 0.3592 |
| $Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$ | Dry | 26329.9 |
| $Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$ | @O2ref | 19308.6 |
| $Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$ | Wet | 26930.7 |
| **Percent isokinetic, %I** | | |
| Nozzle diameter, $D_n$ | mm | 6.01 |
| Nozzle area, $A_n$ | $mm^2$ | 28.37 |
| Total sampling time, q | min | 60 |
| $\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ | % | 96.1 |
| Acceptable isokinetic range 95% to 115% | | Yes |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## ISOKINETIC SAMPLING EQUATIONS RUN 2 — Mercury

| | | | | | |
|---|---|---|---|---|---|
| **Absolute pressure of stack gas, $P_s$** | | | **Molecular weight of dry gas, $M_d$** | | |
| Barometric pressure, $P_b$ | mm Hg | 750.0 | $CO_2$ | % | 12.67 |
| Stack static pressure, $P_{static}$ | mm $H_2O$ | -12.2 | $O_2$ | % | 10.00 |
| $P_s = P_b + (P_{static}) / 13.6$ | mm Hg | 749.1 | Total | % | 22.67 |
| | | | $N_2$ (100 -Total) | % | 77.33 |
| | | | $M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$ | | 30.43 |
| **Vol. of water vapour collected, $V_{wstd}$** | | | **Molecular weight of wet gas, $M_s$** | | |
| Moisture trap weight increase,Vlc | g | H₂0 by Non Iso | $M_s = M_d(1 - B_{wo}) + 18(B_{wo})$ | g/gmol | 30.15 |
| $V_{wstd} = (0.001246)(V_{lc})$ | m3 | - | **Velocity of stack gas, $V_s$** | | |
| **Volume of gas metered dry, $V_{mstd}$** | | | Pitot tube velocity constant, $K_p$ | | 34.97 |
| | | | Velocity pressure coefficient, $C_p$ | | 0.84 |
| Volume of gas sample through gas meter, $V_m$ | | 1.7 | Mean of velocity heads, $DP_{avg}$ | mm $H_2O$ | 29.00 |
| Gas meter correction factor, $Y_d$ | | 0.974 | Mean square root of velocity heads, ÖDP | | 5.39 |
| Mean dry gas meter temperature, $T_m$ | | 23.50 | Mean stack gas temperature, $T_s$ | °C | 65 |
| Mean pressure drop across orifice, DH | mmH | 78.87 | $V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$ | m/s | 19.35 |
| $V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$ | | 1.52 | **Actual flow of stack gas, $Q_a$** | | |
| | | | Area of stack, $A_s$ | $m^2$ | 30.19 |
| **Volume of gas metered wet, $V_{mstw}$** | | | $Q_a = (60)(A_s)(V_s)$ | m³/min | 35059.2 |
| | | | **Total flow of stack gas, Q** | | |
| $V_{mstw} = V_{mstd} + V_{wstd}$ | $m^3$ | 1.5507 | Conversion factor (K/mm.Hg) | | 0.3592 |
| **Vol. of gas metered at $O_2$ Ref. Cond., $V_{mstd@X\%O2}$** | | | $Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$ | Dry | 27287.6 |
| Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)* | | No | $Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$ | @O2ref | 20010.9 |
| % oxygen measured in gas stream, act%$O_2$ | | 10.0 | $Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$ | Wet | 27910.4 |
| % oxygen reference condition | | 6 | | | |
| $O_2$ Reference Factor $= \frac{21.0 - act\%O2}{21.0 - ref\%O2}$ | | 0.73 | **Percent isokinetic, %I** | | |
| | | | Nozzle diameter, $D_n$ | mm | 6.0 |
| $V_{mstd@X\%oxygen} = (V_{mstd}) (O_{2\ Ref})$ | $m^3$ | 1.112 | Nozzle area, $A_n$ | $mm^2$ | 28.4 |
| **Moisture content, $B_{wo}$** | | | Total sampling time, q | min | 60 |
| $B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$ | | 0.0223 | $\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ | % | 98.5 |
| | % | 2.23 | | | |
| **Moisture by FTIR** | % | - | Acceptable isokinetic range 95% to 115% | | Yes |

## ISOKINETIC SAMPLING EQUATIONS RUN 3 — Mercury

| | | | | | |
|---|---|---|---|---|---|
| **Absolute pressure of stack gas, $P_s$** | | | **Molecular weight of dry gas, $M_d$** | | |
| Barometric pressure, $P_b$ | mm Hg | 741.8 | $CO_2$ | % | 12.67 |
| Stack static pressure, $P_{static}$ | mm $H_2O$ | -12.2 | $O_2$ | % | 10.00 |
| $P_s = \frac{P_b + (P_{static})}{13.6}$ | mm Hg | 740.9 | Total | % | 22.67 |
| | | | $N_2$ (100 -Total) | % | 77.33 |
| | | | $M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$ | | 30.43 |
| **Vol. of water vapour collected, $V_{wstd}$** | | | **Molecular weight of wet gas, $M_s$** | | |
| Moisture trap weight increase,Vlc | g | H₂0 by Non Iso | $M_s = M_d(1 - B_{wo}) + 18(B_{wo})$ | g/gmol | 30.15 |
| $V_{wstd} = (0.001246)(V_{lc})$ | m3 | - | **Velocity of stack gas, $V_s$** | | |
| **Volume of gas metered dry, $V_{mstd}$** | | | Pitot tube velocity constant, $K_p$ | | 34.97 |
| | | | Velocity pressure coefficient, $C_p$ | | 0.84 |
| Volume of gas sample through gas meter, $V_m$ | | 1.73 | Mean of velocity heads, $DP_{avg}$ | mm $H_2O$ | 27.33 |
| Gas meter correction factor, $Y_d$ | | 0.9740 | Mean square root of velocity heads, ÖDP | | 5.23 |
| Mean dry gas meter temperature, $T_m$ | | 23.50 | Mean stack gas temperature, $T_s$ | °C | 65 |
| Mean pressure drop across orifice, DH | mmH | 74.36 | $V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$ | m/s | 18.89 |
| $V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$ | | 1.525 | **Actual flow of stack gas, $Q_a$** | | |
| | | | Area of stack, $A_s$ | $m^2$ | 30.19 |
| **Volume of gas metered wet, $V_{mstw}$** | | | $Q_a = (60)(A_s)(V_s)$ | m³/min | 34225.80 |
| | | | **Total flow of stack gas, Q** | | |
| $V_{mstw} = V_{mstd} + V_{wstd}$ | $m^3$ | 1.5602 | Conversion factor (K/mm.Hg) | | 0.3592 |
| **Vol. of gas metered at $O_2$ Ref. Cond., $V_{mstd@X\%O2}$** | | | $Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$ | Dry | 26345.63 |
| Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)* | | No | $Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$ | @O2ref | 19320.13 |
| % oxygen measured in gas stream, act%$O_2$ | | 10.0 | $Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$ | Wet | 26946.8 |
| % oxygen reference condition | | 6 | | | |
| $O_2$ Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$ | | 0.73 | **Percent isokinetic, %I** | | |
| | | | Nozzle diameter, $D_n$ | mm | 6.01 |
| $V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$ | $m^3$ | 1.119 | Nozzle area, $A_n$ | $mm^2$ | 28.37 |
| **Moisture content, $B_{wo}$** | | | Total sampling time, q | min | 60 |
| | | | $\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$ | % | 102.7 |
| $B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$ | | 0.0223 | | | |
| | % | 2.23 | | | |
| **Moisture by FTIR** | % | - | Acceptable isokinetic range 95% to 115% | | Yes |

## HEAVY METALS 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 | 26.0 | 0.30 | 0.30 | -381 | 0.52 | Yes |
| Run 2 | 27.6 | 0.30 | 0.30 | -381 | 0.55 | Yes |
| Run 3 | 28.1 | 0.30 | 0.30 | -381 | 0.56 | Yes |

| Isokinetic Criterion Compliance | Isokinetic Variation % | Acceptable Isokineticity |
|---|---|---|
| Run 1 | 96.1 | Yes |
| Run 2 | 98.5 | Yes |
| Run 3 | 102.7 | Yes |

| Filtration / Temp | Filter Material | Filter Size mm | Maximum Filtration Temperature °C | Maximum storage / transit Temperature °C |
|---|---|---|---|---|
| Run 1 | Quartz Fibre | 90 | 181 | 7 |
| Run 2 | Quartz Fibre | 90 | 181 | 7 |
| Run 3 | Quartz Fibre | 90 | 181 | 7 |

| Mercury | Type of Absorbers - Mercury | Absorption Solutions - Mercury |
|---|---|---|
| Run 1 | Glass | 4% Potassium Dichromate, 20% Nitric Acid |
| Run 2 | Glass | 4% Potassium Dichromate, 20% Nitric Acid |
| Run 3 | Glass | 4% Potassium Dichromate, 20% Nitric Acid |

## HEAVY METALS ABSORBTION EFFICIENCY

| Parameter | | Total ug | 5th Absorber ug | Absorption Efficiency | Required | Pass / Fail |
|---|---|---|---|---|---|---|
| Mercury | Run 1 | 0.59 | ND | 100 | 95 | N/A <30% ELV |
| | Run 2 | 0.86 | 0.03 | 97 | 95 | N/A <30% ELV |
| | Run 3 | 0.57 | 0.03 | 94 | 95 | N/A <30% ELV |

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## DAILY OXYGEN SUMMARY

| Sampling Times | Concentration % | LOD % |
|---|---|---|
| 11:00 - 16:28<br>12 February 2019 | 10.00 | 0.01 |

| PRE SAMPLING CALIBRATION DATA | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Time of Analyser Checks | Range (%) | Zero Reading at analyser | Span Reading at analyser | Zero Check at analyser | Zero Check down line | Span Check down line | Leak Rate % |
| 12 February 2019 | 10:30 - 10:50 | 25 | 0.00 | 10.15 | 0.13 | 0.18 | 10.28 | 1.26 |

| POST SAMPLING CALIBRATION DATA | | | | | |
|---|---|---|---|---|---|
| Date | Time of Analyser Checks | Zero Check down line | Span Check down line | Zero Drift (%) | Span Drift (%) |
| 13 February 2019 | 08:00 - 08:30 | 0.13 | 10.31 | -0.20 | 0.32 |

## MOISTURE CALCULATIONS

| Moisture Determination - Non Isokinetic | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Number | Sampling Time and Date | Start Weight kg | End Weight kg | Total gain kg | Concentration % | LOD % | Uncertainty % |
| Run 1 | 18:40 - 19:40 12 February 2019 | 1.0000 | 1.0220 | 0.0220 | 2.2 | 0.01 | 3.7 |

| 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 | 1201 | 20.0 | 0.30 | 0.30 | 0.40 | Yes |

## PRELIMINARY STACK SURVEY

| Stack Characteristics | | |
|---|---|---|
| Stack Diameter / Depth, D | 6.20 | m |
| Stack Width, W | - | m |
| Stack Area, A | 30.19 | $m^2$ |
| Average stack gas temperature | 62 | °C |
| Stack static pressure | -0.13 | kPa |
| Barometric Pressure | 100.3 | 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 | 12.666667 | 0.126667 | 0.248654 | 12.384056 | 0.123841 | 0.243106 |
| $O_2$ | 32 | 1.427679 | 10.004048 | 0.100040 | 0.142826 | 9.780844 | 0.097808 | 0.139639 |
| $N_2$ | 28 | 1.249219 | 77.329286 | 0.773293 | 0.966012 | 75.603964 | 0.756040 | 0.944459 |
| $H_2O$ | 18 | 0.803070 | - | - | - | 2.231136 | 0.022311 | 0.017918 |

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

| Calculation of Stack Gas Densities | | |
|---|---|---|
| Determinand | Result | Units |
| Dry Density (STP), $P_{STD}$ | 1.3575 | $kg/m^3$ |
| Wet Density (STP), $P_{STW}$ | 1.3451 | $kg/m^3$ |
| Dry Density (Actual), $P_{Actual}$ | 1.0955 | $kg/m^3$ |
| Average Wet Density (Actual), $P_{ActualW}$ | 1.086 | $kg/m^3$ |

**Where:**

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

$P_{STW}$ = ($P_{STD}$ + p*i* of $H_2O$) / (1 + (p*i* of $H_2O$ / 0.8036))

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

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

## PRELIMINARY STACK SURVEY

### TRAVERSE 1

| | |
|---|---|
| Date of Survey | 12 February 2019 |
| Time of Survey | 10:30 |
| Velocity Measurement Device: | S-Type Pitot |

**Sampling Line A**

| Traverse Point | Distance into duct (m) | DP pt $mmH_2O$ (average of 3 readings) | DP pt Pa (average of 3 readings) | Temp °C | Velocity m/s | Volumetric Flow Rate (actual) m³/s | $O_2$ % Vol | Angle of Swirl ° |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.30 | 27.0 | 265 | 61 | 18.5 | 557.1 | - | <15 |
| Mean | - | 27.0 | 265 | 61 | 18.5 | 557.1 | - | - |

**Sampling Line B**

| Traverse Point | Distance into duct (m) | DP pt $mmH_2O$ (average of 3 readings) | DP pt Pa (average of 3 readings) | Temp °C | Velocity m/s | Volumetric Flow Rate (actual) m³/s | $O_2$ % Vol | Angle of Swirl ° |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.30 | 29.0 | 284 | 62 | 19.2 | 578.2 | - | <15 |
| Mean | - | 29.0 | 284 | 62 | 19.2 | 578.2 | - | - |

**Sampling Line C**

| Traverse Point | Distance into duct (m) | DP pt $mmH_2O$ (average of 3 readings) | DP pt Pa (average of 3 readings) | Temp °C | Velocity m/s | Volumetric Flow Rate (actual) m³/s | $O_2$ % Vol | Angle of Swirl ° |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.30 | 28.00 | 274 | 61.00 | 18.8 | 567.3 | - | <15 |
| Mean | - | 28.00 | 274 | 61.00 | 18.8 | 567.3 | - | - |

**Sampling Line D**

| Traverse Point | Distance into duct (m) | DP pt $mmH_2O$ (average of 3 readings) | DP pt Pa (average of 3 readings) | Temp °C | Velocity m/s | Volumetric Flow Rate (actual) m³/s | $O_2$ % Vol | Angle of Swirl ° |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.30 | 28.00 | 274 | 62.00 | 18.8 | 568.2 | - | <15 |
| Mean | - | 28.00 | 274 | 62.00 | 18.8 | 568.2 | - | - |

## PRELIMINARY STACK SURVEY QUALITY ASSURANCE CHECKLIST

**PITOT LEAK CHECK**

| Run | Pre Traverse Leak Rate | | | | Post Traverse Leak Rate | | | |
|---|---|---|---|---|---|---|---|---|
| | Start Value Pa | End Value Pa | Difference % | Outcome | Start Value Pa | End Value Pa | Difference % | Outcome |
| Run 1 | 87 | 88 | -1.1 | Pass | 88 | 87 | 1.1 | 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 | -150 | -150 | 0.0 | Pass |

## PRELIMINARY STACK SURVEY (CONTINUED)

| Sampling Plane Validation Criteria | | | | |
|---|---|---|---|---|
| EA Technical Guidance Note (Monitoring) M1 | Result | Units | Requirement | Compliant |
| Lowest Differential Pressure | 265 | Pa | >= 5 Pa | Yes |
| Lowest Gas Velocity | 18.5 | m/s | - | - |
| Highest Gas Velocity | 19.2 | m/s | - | - |
| Ratio of Gas Velocities | 1.0 | - | < 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, $V = K_{pt} \times (1-e) * \sqrt{(2 * DP_{pt} / P_{ActualW})}$

**Where:**

$K_{pt}$ = Pitot tube calibration coefficient

(1-e) = Compressibility correction factor, assumed at a constant 0.998

| Average Stack Gas Velocity, Va | 18.8 | m/s |
|---|---|---|

| Calculation of Stack Gas Volumetric Flowrate, Q | | | |
|---|---|---|---|
| Duct gas flow conditions | Actual | Reference | Units |
| Temperature | 62 | 0 | °C |
| Total Pressure | 100.17 | 101.3 | kPa |
| Oxygen | 10.0 | 6 | % |
| Moisture | 2.23 | 0.00 | % |
| Pitot tube calibration coefficient, $K_{pt}$ | 0.84 | | |

| Gas Volumetric Flowrate | Result | Units |
|---|---|---|
| Average Stack Gas Velocity (Va) | 18.80 | m/s |
| Stack Area (A) | 30.19 | $m^2$ |
| Gas Volumetric Flowrate (Actual), $Q_{Actual}$ | 2043817 | $m^3$/hr |
| Gas Volumetric Flowrate (STP, Wet), $Q_{STP}$ | 1649441 | $m^3$/hr |
| Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$ | 1612639 | $m^3$/hr |
| Gas Volumetric Flowrate (REF), $Q_{Ref}$ | 1182167 | $m^3$/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 ((20.9 - $O_2$a) / (20.9 - $O_2$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

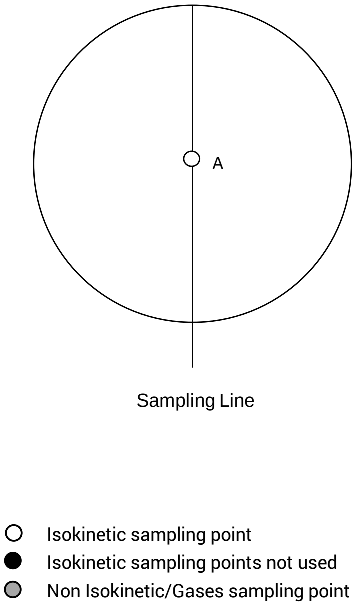
$O_2$s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

## STACK DIAGRAM

| | Value | Units |
|---|---|---|
| Stack Depth | 6.20 | m |
| Stack Width | - | m |
| Area | 30.19 | $m^2$ |

| Non-Isokinetic/Gases Sampling | | | |
|---|---|---|---|
| Sampling Point | Distance (% of Depth) | Distance into Stack | Units |
| A | 30 | 1.86 | m |




| Isokinetic Sampling | | | |
|---|---|---|---|
| Sampling Point | Distance (% of Depth) | Distance into Stack (m) | Swirl ° |
| 1 | 50.0 | 3.10 | < 15 |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |
| - | - | - | - |

APPENDIX 3 - Measurement Uncertainty Budget Calculations

## MEASUREMENT UNCERTAINTY BUDGET - MERCURY

| Run | Sampled Volume m³ | Sampled Gas Temp K | Sampled Gas Pressure kPa | Sampled Gas Humidity % by volume | Oxygen Content % by volume | Concentration in impinger mg | Leak % |
|---|---|---|---|---|---|---|---|
| **MU required** | **<=2%** | **<2.5 k** | **<=1%** | **<=1%** | **<=5%** | **<5%** | **<=2%** |
| Run 1 | 0.001 | 2.0 | 0.50 | 1.0 | 0.10 | 5.15308E-06 | - |
| as a % | 0.07 | 0.7 | 0.51 | 1.0 | 1.00 | 3.00 | 1.16 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Run 2 | 0.0 | 2.0 | 0.50 | 1.0 | 0.10 | 1.03235E-05 | - |
| as a % | 0.09 | 0.7 | 0.51 | 1.0 | 1.00 | 3.00 | 1.09 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Run 3 | 0.0 | 2.0 | 0.50 | 1.0 | 0.10 | 3.9502E-06 | - |
| as a % | 0.09 | 0.7 | 0.51 | 1.0 | 1.00 | 3.00 | 1.07 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| Run | Volume (STP) m³ | O2 Correction - | Mass of Mercury mg | Leak mg/m³ | Lab Uncertainty mg | Combined |
|---|---|---|---|---|---|---|
| Run 1 | 1.2807 | 1.3636 | 0.5864 | 0.0000 | - | - |
| MU as mg/m³ | 0.0000 | 0.0000 | 0.0005 | 0.0000 | 0.00003 | **0.0005** |
| MU as % | 1.3104 | 0.9091 | 85.2831 | 0.6669 | 5.00000 | - |
| Run 2 | 0.998 | 1.364 | 1.281 | 0.000 | - | - |
| MU as mg/m³ | 0.000 | 0.000 | 0.000 | 0.000 | 0.00004 | **0.000** |
| MU as % | 1.312 | 0.909 | 39.048 | 0.628 | 5.00000 | - |
| Run 3 | 0.993 | 1.364 | 0.566 | 0.000 | - | - |
| MU as mg/m³ | 0.000 | 0.000 | 0.000 | 0.000 | 0.00003 | **0.000** |
| MU as % | 1.314 | 0.909 | 88.341 | 0.617 | 5.00000 | - |

| | | | | |
|---|---|---|---|---|
| **R1 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.0010** | **mg/m³** | **170.89** | **%** |
| **R2 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.0006** | **mg/m³** | **78.81** | **%** |
| **R3 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.0009** | **mg/m³** | **177.00** | **%** |

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

APPENDIX 3 - Measurement Uncertainty Budget Calculations

## MEASUREMENT UNCERTAINTY BUDGET - MOISTURE

| 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 | Leak<br>% |
|---|---|---|---|---|---|---|
| **MU required** | **≤ 2%** | **≤ 2%** | **≤ 1%** | **≤ 1%** | **≤ 10%** | **≤ 2%** |
| Run 1 | 0.000 | 2.0 | 0.50 | 1.0 | 0.1 | - |
| as a % | 0.03 | 0.60 | 0.50 | 1.0 | 1.00 | 1.50 |
| **compliant?** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

| Run | Volume (STP)<br>m³ | Mass Gained<br>mg | O2 Correction<br>- | Leak<br>mg/m³ | Uncollected Mass<br>mg | Combined uncertainty |
|---|---|---|---|---|---|---|
| Run 1 | 1.0 | 22000 | 1.4 | 158.5 | 58 | - |
| MU as % v/v | 0.03 | 0.01 | 0.00 | 0.02 | 0.01 | **0.04** |
| MU as % | 1.3 | 0.5 | 0.91 | 0.9 | 0.3 | - |

| | | | | |
|---|---|---|---|---|
| **R1 - Uncertainty expressed at a 95% confidence level (where k = 2)** | **0.07** | **% v/v** | **3.72** | **%** |

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

APPENDIX 3 - Measurement Uncertainty Budget Calculations

**MEASUREMENT UNCERTAINTY BUDGET - OXYGEN**

DAY 1 - 12 February 2019

| | | |
|---|---|---|
| Reference | 6 | %vol |
| Measured concentration | 10.00 | %vol |
| Calibration gas | 10.15 | %vol |
| Analyser Full Scale | 25 | %vol |

| | Value | Units | specification | MU Met? |
|---|---|---|---|---|
| Response time | 24 | seconds | 180 | Yes |
| Logger sampling interval | 60 | seconds | - | - |
| Measurement period | 328 | minutes | - | - |
| Number of readings in measurement | 328 | - | - | - |
| Repeatability at zero | 0.25 | % full scale | <1 % range | No |
| Repeatability at span level | 0.15 | % full scale | <2 % range | Yes |
| Deviation from linearity | 0.1 | % of value | <2 % range | Yes |
| Zero drift | -0.20 | % full scale | <2% range / 24hr | Yes |
| Span drift | 0.32 | % full scale | <2% range/24hr | Yes |
| volume or pressure flow dependence | -0.0425 | % of full scale/3 kPa | <2 % / 3 kPa | Yes |
| atmospheric pressure dependence | 0.0475 | % of full scale/2 kPa | <3% / 2 kPa | Yes |
| ambient temperature dependence | 0.0025 | % full scale/10K | <3% range / 10 K | Yes |
| Combined interference | 0.00 | % range | <4% of Range | Yes |
| dependence on voltage | 0.18 | % full scale/10V | < 0.1%vol /10 volt | No |
| losses in the line (leak) | 1.26 | % of value | < 2% of value | Yes |
| Uncertainty of calibration gas | 1.00 | % of value | < 2% of value | Yes |

| losses in the line (leak) | Uncertainty | < 2% of value |
|---|---|---|
| repeatability | $U_r = S_r$ | 0.0083 |
| lack of fit | $U_{lof}$ | 0.0577 |
| short term zero drift | $U_{d,z}$ | -0.12 |
| short term span drift | $U_{d,s}$ | 0.18 |
| influence of Ambient Temp at Zero | $U_{t,z}$ | 2.19493E-05 |
| influence of Ambient Temp at Span | $U_{t,s}$ | 5.26783E-05 |
| influence of sample gas pressure | $U_p$ | 0 |
| influence of sample gas flow | $U_{fit}$ | -0.029444864 |
| influence of supply voltage | $U_v$ | 0.010255184 |
| Combined Interference | $U_i$ | 0.00 |
| Uncertainty of Cal gas | $U_{adj}$ | 0.05075 |

| | | |
|---|---|---|
| Measurement uncertainty (Concentration Measured) | 10.00 | % |
| Combined Interfence | 0.23 | % |
| Uncertainty of Cal gas | 2.33 | % |

| | | |
|---|---|---|
| **Expanded uncertainty expressed with a level of confidence of 95%** | **2.33** | **%** |

| | | |
|---|---|---|
| **Expanded uncertainty as percentage of the result** | **0.23** | **% vol** |

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

**MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE**

| | | |
|---|---|---|
| Measured Velocity at Actual Conditions | 18.8 | m/s |
| Measured Volumetric Flow rate at Actual Conditions | 2043817 | 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 | 5.99 | <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 | 0.00006 | | |
| **Uncertainty of temperature measurement** | K | 1.71 | <1% of value | Yes |
| **Uncertainty of absolute pressure in the duct** | pa | 511 | | |
| **Uncertainty associated with the estimate of density** | - | 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** | 0.23 |
| **Expanded uncertainty at a 95% Confidence Interval** | 0.46 |

*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** | 1.2 |
| **Expanded uncertainty at a 95% Confidence Interval** | 2.4 |

| Measurement Uncertainty Volumetric Flow Rate | m³/hr |
|---|---|
| **Combined uncertainty** | 53612 |
| **Expanded uncertainty at a 95% Confidence Interval** | 105079 |

*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** | 2.6 |
| **Expanded uncertainty at a 95% Confidence Interval** | 5.1 |

Reference – SOCOTEC UK Technical Procedure AE150 Estimation of Uncertainty of Measurement

**END OF REPORT**

*Thank you for choosing SOCOTEC UK 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