REC
Resource & Environmental Consultants Ltd

*Client* **Linx Printing Technologies Limited**
**Linx House**
**33 Edison Road**
**St Ives**
**Cambridgeshire**
**PE27 3LF**

**Part 1: Executive Summary**

# Report for the Periodic Monitoring of Emissions to Air.

| | |
|---|---|
| *Site* | **St Ives** |
| *Plant* | **Ink Manufacturing Plant** |
| *Sampling Date* | **3rd November 2015** |
| *Report Date* | **7th December 2015** |
| *Job Number* | **EM-2112** |
| *Permit Number* | **B04/94** |

| | | | |
|---|---|---|---|
| **Report Prepared by:** | *Print* | **Harpreet Badwal** | |
| | *MCERTS No.* | **MM03 149** | **Level 2 TE: 1,2,3,4** |
| **Report Approved by:** | *Sign* | D. L. Myers | |
| | *Print* | **Derek Myers** | |
| | *MCERTS No.* | **MM02 115** | **Level 2 TE: 1,2,3,4** |

**REC Ltd Environmental Monitoring**
Unit 19
Bordesley Green Trading Estate
Bordesley Green Road
Birmingham
B8 1BZ

Tel: 0845 676 9303
Company Registration No 03133832

MCERTS THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME
ilac-MRA
UKAS TESTING
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# Contents

# Monitoring Objectives

The monitoring was undertaken to check compliance with authorised emission limits.

All monitoring procedures were carried out to the MCERTS requirements under the REC Environmental Monitoring quality system to ISO 17025: 2005.

Monitoring was undertaken for the listed emissions from the following sampling positions:

| Sampling Location | Emission |
|---|---|
| Ink Manufacturing Plant | Particulates<br>Total organic carbon |

# Special Monitoring Requirements

There were no special requirements for this monitoring campaign.

# Summary of Methods

| Emission | Method number | Method standard |
|---|---|---|
| Particulate | TPM/04 | BS EN 13284-1 : 2002 |
| Gas velocity and volume flow | TPM/01A | BS EN ISO 16911-1:2013 |
| Water vapour | TPM/37 | BS EN 14790 : 2005 |
| TOC | TPM/13 | BS EN 12619 : 2013 |

# Summary Of Results

The table presents the atmospheric emissions from the tests undertaken on behalf of **Linx Printing Technologies Limited**
The results were measured from the sample positions downstream of the arrestment plant.

| Emission at St Ives Ink Manufacturing Plant | Sampling Time | | | Emission Result | Authorised Limit | Uncertainty +/- | Detection Limit | Mass Emission |
|---|---|---|---|---|---|---|---|---|
| | Date | Start | End | mg/m$^{3}$* | mg/m$^{3}$* | mg/m$^{3}$* | mg/m$^{3}$* | g/h |
| TOC | 03/11/15 | 12:45 | 16:45 | 309.4 | 150 | 6.3 | 0.2 | 822.3 |
| s Particulate | 03/11/15 | 11:49 | 19:49 | ND | 20 | - | 0.05 | 0.15 |

| * at reference conditions | Stack Gas Weight | 0 °C | Without correction for moisture |
|---|---|---|---|
| | 29.00 Kg/kmol | 101.3 kPa | Oxygen No Correction % |

**Where applicable**
Oxides of nitrogen results are expressed as nitrogen dioxide
TOC results are expressed as total carbon

**Throughout Report:**

| | | |
|---|---|---|
| * | Reference conditions (see above) | Nm³ 273 K, 101.3 kPa |
| ** | Analysis not required | # - UKAS accredited only |
| ND | Non detectable | ## - Not Accredited |
| s - Subcontracted laboratory analysis | | N/A Not applicable |

**The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a 95% confidence level. The uncertainty evaluation has been carried out in accordance with UKAS requirements.**

# Summary Of Results, Exhaust Gases

The table presents the atmospheric emissions from the tests undertaken on behalf of **Linx Printing Technologies Limited**
The results were measured from the sample positions downstream of the arrestment plant.

| Emission at St Ives | | Sampling Time | | | Emission Result | Authorised Limit | Uncertainty +/- | Detection Limit | Mass Emission |
|---|---|---|---|---|---|---|---|---|---|
| Ink Manufacturing Plant | | Date | Start | End | mg/m$^{3}$* | mg/m$^{3}$* | mg/m$^{3}$* | mg/m$^{3}$* | g/h |
| TOC | Test 1 | 03/11/15 | 12:45 | 13:15 | 355.4 | 150 | 7.2 | 0.2 | 944.7 |
| TOC | Test 2 | 03/11/15 | 13:15 | 13:45 | 359.4 | 150 | 7.3 | 0.2 | 955.2 |
| TOC | Test 3 | 03/11/15 | 13:45 | 14:15 | 275.8 | 150 | 5.6 | 0.2 | 733.2 |
| TOC | Test 4 | 03/11/15 | 14:15 | 14:45 | 233.0 | 150 | 4.8 | 0.2 | 619.5 |
| TOC | Test 5 | 03/11/15 | 14:45 | 15:15 | 189.3 | 150 | 4.0 | 0.2 | 503.2 |
| TOC | Test 6 | 03/11/15 | 15:15 | 15:45 | 205.1 | 150 | 4.3 | 0.2 | 545.1 |
| TOC | Test 7 | 03/11/15 | 15:45 | 16:15 | 551.2 | 150 | 11.1 | 0.2 | 1465.1 |
| TOC | Test 8 | 03/11/15 | 16:15 | 16:45 | 305.8 | 150 | 6.2 | 0.2 | 812.7 |

| | | | |
|---|---|---|---|
| * at ref | Stack Gas Weight | 0 °C | Without correction for moisture |
| Conditions | 29.00 Kg/kmol | 101.3 kPa | Oxygen No Correction % |

**Where applicable**

Oxides of nitrogen results are expressed as nitrogen dioxide
TOC results are expressed as total carbon

**Throughout Report:**

| | |
|---|---|
| * Reference conditions (see above) | Nm³ 273 K, 101.3 kPa |
| ** Analysis not required | # - UKAS accredited only |
| ND Non detectable | ## - Not Accredited |
| s - Subcontracted laboratory analysis | N/A Not applicable |

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a 95% confidence level. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

All tests included in this report are accredited under UKAS and MCERTS accreditation schemes unless otherwise stated. Opinions and interpretations expressed herein are outside the scope of MCERTS and UKAS accreditation.

# Operating Information

The table below shows details of the operating information on each sampling date for: **Ink Manufacturing Plant**

| Date | Process type | Process duration | Fuel | Feedstock | Abatement | Load |
|---|---|---|---|---|---|---|
| 03/11/2015 | Ink Manufacturing Plant | Continuous | N/A | Methyl Ethyl Ketone<br>Acetone<br>Ethyl Lactate<br>Diethyl Ketone | None | Normal Operation |

There are no CEM's available on this process.

# Comments & Monitoring Deviations

A waste gas homogeneity test to BS EN 15259:2007 (MID) is not required:-
The homogeneity test is not applicable to non-combustion processes.
The homogeneity test is not applicable to duct areas less than 1m$^2$.

All monitoring was performed in accordance with the relevant procedures.

The sampling location is a vertical duct.

Due to the positioning of the scaffolding erected, sampling can only be undertaken from one sample port.

The particulate monitoring was within the required 95 to 115 % isokinetic rate as stated in BS EN 13284-1: 2002

The velocity and temperature profile at the sampling location met the requirements of BS EN 13284-1: 2002.

The calculated particulate emission level was greater than the control blank.

When the results are expressed as non-detected the mass emissions are calculated from the detection limit and therefore they are worst case results.

REC
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**Part 2: Supporting Information**

## Report for the Periodic Monitoring of Emissions to Air.

| | |
|---|---|
| *Client* | **Linx Printing Technologies Limited** |
| *Site* | **St Ives** |
| *Plant* | **Ink Manufacturing Plant** |
| *Sampling Date* | **3rd November 2015** |
| *Report Date* | **7th December 2015** |
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# APPENDIX 1

# Emission Monitoring Procedures And Instrumentation

## Gas velocity and temperature

Documented in-house procedure TPM01/A to the main procedural requirements of BS EN ISO 16911-1:2013

Velocity and temperature measurements are performed using a calibrated Pitot tube, a calibrated pressure differential reading device and a calibrated thermocouple. Velocity and possible flow deviation measurements are carried out at selected, representative points in the gas stream.

## Water vapour

Documented in-house procedure TPM/37 to the main procedural requirements of BS EN 14790:2005.

A measured volume of gas is extracted from the gas stream through a moisture trapping unit. The mass gain of moisture trapped is divided by the volume of gas sampled to determine the mass concentration of water vapour. For water saturated stacks the temperature of the gas stream is measured and the water vapour concentration is determined using liquid-gas equilibrium tables. Sampling points are selected in accordance with the findings of any BS EN 15259 assessment.

## Total particulate matter

Documented in-house procedure TPM/04 to the main procedural requirements of BS EN 13284-1:2002.

Stack gases are extracted from representative sampling points at isokinetic flow rates through a sharp-edged nozzle. Particulate matter is collected on a pre-weighed filter conditioned at 180$^{o}$C. Deposits upstream of the filter are also recovered and weighed. The increase of mass of the filter and mass collected upstream of the filter is divided by the volume sampled to determine the mass concentration.

## Total organic carbon

Documented in-house procedure TPM/13 to the main procedural requirements of BS EN 12619:2013.

Continuous analysis using probe, sample line and multi range Flame Ionisation Detector (FID) analyser. The analyser is calibrated before and during the tests using certified gas mixtures of nitrogen, oxygen and propane. Sampling points are selected in accordance with the findings of any BS EN 15259 assessment.

# Sampling Project Personnel Competency And Expiry Dates

| | | MCERTS No | Level 1 | Level 2 | TE1 | TE2 | TE3 | TE4 |
|---|---|---|---|---|---|---|---|---|
| Report prepared by: | Harpreet Badwal | MM03 149 | - | 30/09/2018 | 30/09/2018 | 30/04/2019 | 31/10/2019 | 31/10/2019 |
| Report authorised by: | Derek Myers | MM02 115 | - | 30/09/2017 | 31/05/2018 | 30/11/2018 | 30/11/2018 | 30/11/2018 |
| Team leader: | Harpreet Badwal | MM03 149 | - | 30/09/2018 | 30/09/2018 | 30/04/2019 | 31/10/2019 | 31/10/2019 |
| Team leader: | Aidan Wrynne | MM08 921 | - | 31/05/2017 | 31/05/2017 | 31/11/2018 | 30/11/2017 | 30/06/2018 |

# Equipment References

| Equipment | Reference Number |
|---|---|
| FID | AQ271 |
| Heated Line | HL40 |
| Heated Filter | Sintered |
| Probe | AQ187 |
| Control Box | CU16 |
| Timer / Stopwatch | CU16/7 & ST41 |
| Barometer | WS03 |
| Pitot | PT116 & PT97 |
| Callipers | CV15 |
| Hot Box | HB19 |
| Impinger Thermocouple | TV24 |
| Sample Rate Calculation Equipment | Laptop |
| Thermometer | CU16/3 & TK28 |
| Manometer | CU16/1 & PI03 |
| Balance | BL21 |
| Weights | W17 & W18 |

# Subcontracted Analysis

REC Environmental Monitoring has, with your approval, used the following sub-contracted laboratories for the laboratory analyses referenced below:

| | |
|---|---|
| Laboratory: | **Scientific Analysis Laboratories** |
| Parameters: | Particulates - Internal method, Gravimetric |
| Accreditation: | UKAS Accredited testing laboratory number 1549 |

# APPENDIX 2

| | | |
|---|---|---|
| Date | 03/11/2015 | |
| Time | 11:30 | |
| Pitot Cp | 0.79 | |

| | | |
|---|---|---|
| Barometric pressure | 101.3 | kPa |
| Duct static pressure | -0.01 | kPa |
| Stack Area | 0.196 | m$^2$ |

| | | |
|---|---|---|
| Stack Diameter (circular) | 0.50 | m |

| Traverse | Traverse | Depth | ΔP | T | Angle | velocity | Traverse | Depth | ΔP | T | Angle | velocity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Line | cm | mmH$_2$O | °C | ° | m/s | Line | cm | mmH$_2$O | °C | ° | m/s |
| 1 | A | 5.0 | 3.7 | 20 | <15 | 6.1 | B | 5.0 | 2.0 | 20 | <15 | 4.6 |
| 2 | A | 5.0 | 3.4 | 20 | <15 | 5.8 | B | 5.0 | 1.5 | 20 | <15 | 3.9 |
| 3 | A | 5.9 | 3.1 | 20 | <15 | 5.6 | B | 5.9 | 1.4 | 20 | <15 | 3.8 |
| 4 | A | 8.9 | 2.8 | 20 | <15 | 5.3 | B | 8.9 | 1.2 | 20 | <15 | 3.5 |
| 5 | A | 12.5 | 2.7 | 20 | <15 | 5.2 | B | 12.5 | 1.1 | 20 | <15 | 3.4 |
| 6 | A | 17.8 | 1.7 | 20 | <15 | 4.2 | B | 17.8 | 1.3 | 20 | <15 | 3.7 |
| 7 | A | 32.2 | 0.8 | 20 | <15 | 2.9 | B | 32.2 | 1.5 | 20 | <15 | 3.9 |
| 8 | A | 37.5 | 0.4 | 20 | <15 | 2.0 | B | 37.5 | 1.7 | 20 | <15 | 4.2 |
| 9 | A | 41.2 | 0.8 | 20 | <15 | 2.9 | B | 41.2 | 1.5 | 20 | <15 | 3.9 |
| 10 | A | 44.1 | 0.8 | 20 | <15 | 2.9 | B | 44.1 | 1.9 | 20 | <15 | 4.4 |
| 11 | A | 45.0 | 0.4 | 20 | <15 | 2.0 | B | 45.0 | 2.4 | 20 | <15 | 5.0 |
| 12 | A | 45.0 | 0.7 | 20 | <15 | 2.7 | B | 45.0 | 2.3 | 20 | <15 | 4.9 |

| | | |
|---|---|---|
| Average Pitot DP | 1.60 | mmH$_2$O |
| Average Temperature | 293.2 | K |
| Average Velocity | 4.0 | m/s |
| Average volumetric flow rate | 0.79 | m$^3$/s at stack conditions |
| Average volumetric flow rate | 0.74 | m$^3$/s (wet STP) |

**Sampling plane requirements Re: BS EN 13284-1:2001 5.2**

| | | | |
|---|---|---|---|
| a | Angel of gas flow less than 15° with regard to duct axis | | YES |
| b | No local negative flow | | YES |
| c | Minimum pitot greater than 5Pa | | NO |
| d | Ratio of highest to lowest local gas velocity less than 3:1 | | YES |
| | Minimum local gas velocity | 2.0 | |
| | Maximum local gas velocity | 6.1 | |
| | Ratio of highest to lowest local gas velocity | 3.00 | |

**Moisture Determination BS EN 14790:2005**

| | Volume | Temp | Pressure |
|---|---|---|---|
| | m$^3$ | °C | mbar |
| Meter start | 3.095 | 13 | 1013 |
| Meter end | 13.668 | 25 | 1013 |
| Meter Yd | 1.052 | | |
| Gas volume | 10.399 | | |

| Impinger | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Mass start (g) | 763.5 | 716.6 | 607.4 | 897.2 |
| Mass End (g) | 773.2 | 722.2 | 613.8 | 926.5 |
| Total Mass collected (g) | | 51.0 | | |
| Water vapour content (% v/v) | | 0.6 | | |

**If water droplets are present in the gas, the water vapour content is calculated using BS EN 14790 Annex A** N/A % v/v

## Preliminary Velocity Traverse & Moisture Data

Date 03/11/2015

From 12:45 to 13:15 30 minute mean

| | | | | |
|---|---|---|---|---|
| Volatile organic compounds | vppm, wet | 221.13 | mg/m$^3$* | 355.39 |

From 13:15 to 13:45 30 minute mean

| | | | | |
|---|---|---|---|---|
| Volatile organic compounds | vppm, wet | 223.60 | mg/m$^3$* | 359.35 |

.

From 13:45 to 14:15 30 minute mean

| | | | | |
|---|---|---|---|---|
| Volatile organic compounds | vppm, wet | 171.64 | mg/m$^3$* | 275.84 |

From 14:15 to 14:45 30 minute mean

| | | | | |
|---|---|---|---|---|
| Volatile organic compounds | vppm, wet | 145.00 | mg/m$^3$* | 233.04 |

Sampling Detection Limits

| | | | | |
|---|---|---|---|---|
| Volatile organic compounds | vppm | 0.10 | mg/m$^3$* | 0.16 |

Reference Gas Details

| Species | Units | Value | Cylinder Reference | Analyser Range | Uncertainity $k$ = 2 |
|---|---|---|---|---|---|
| Nitrogen | % | 99.999 | VCK01959 | - | ± 2 |
| Volatile organic compounds | vppm | 74.7 | VC59841 | 10 | ± 2 |

Zero And Span Gas Details

| Species | units | Initial Time | 12:30 | Final Time | 17:00 |
|---|---|---|---|---|---|
| | | Initial Zero | Initial Span | Final Zero | Final Span |
| Volatile organic compounds | vppm | 0.00 | 74.70 | 0.31 | 75.02 |

## Exhaust Gases Continuous Analysis Data

Date 03/11/2015

From 14:45 to 15:15 30 minute mean

| | | | | |
|---|---|---|---|---|
| Volatile organic compounds | vppm, wet | 117.79 | mg/m³* | 189.30 |

From 15:15 to 15:45 30 minute mean

| | | | | |
|---|---|---|---|---|
| Volatile organic compounds | vppm, wet | 127.61 | mg/m³* | 205.08 |

From 15:45 to 16:15 30 minute mean

| | | | | |
|---|---|---|---|---|
| Volatile organic compounds | vppm, wet | 342.95 | mg/m³* | 551.17 |

From 16:15 to 16:45 30 minute mean

| | | | | |
|---|---|---|---|---|
| Volatile organic compounds | vppm, wet | 190.25 | mg/m³* | 305.76 |

Sampling Detection Limits

| | | | | |
|---|---|---|---|---|
| Volatile organic compounds | vppm | 0.10 | mg/m³* | 0.16 |

Reference Gas Details

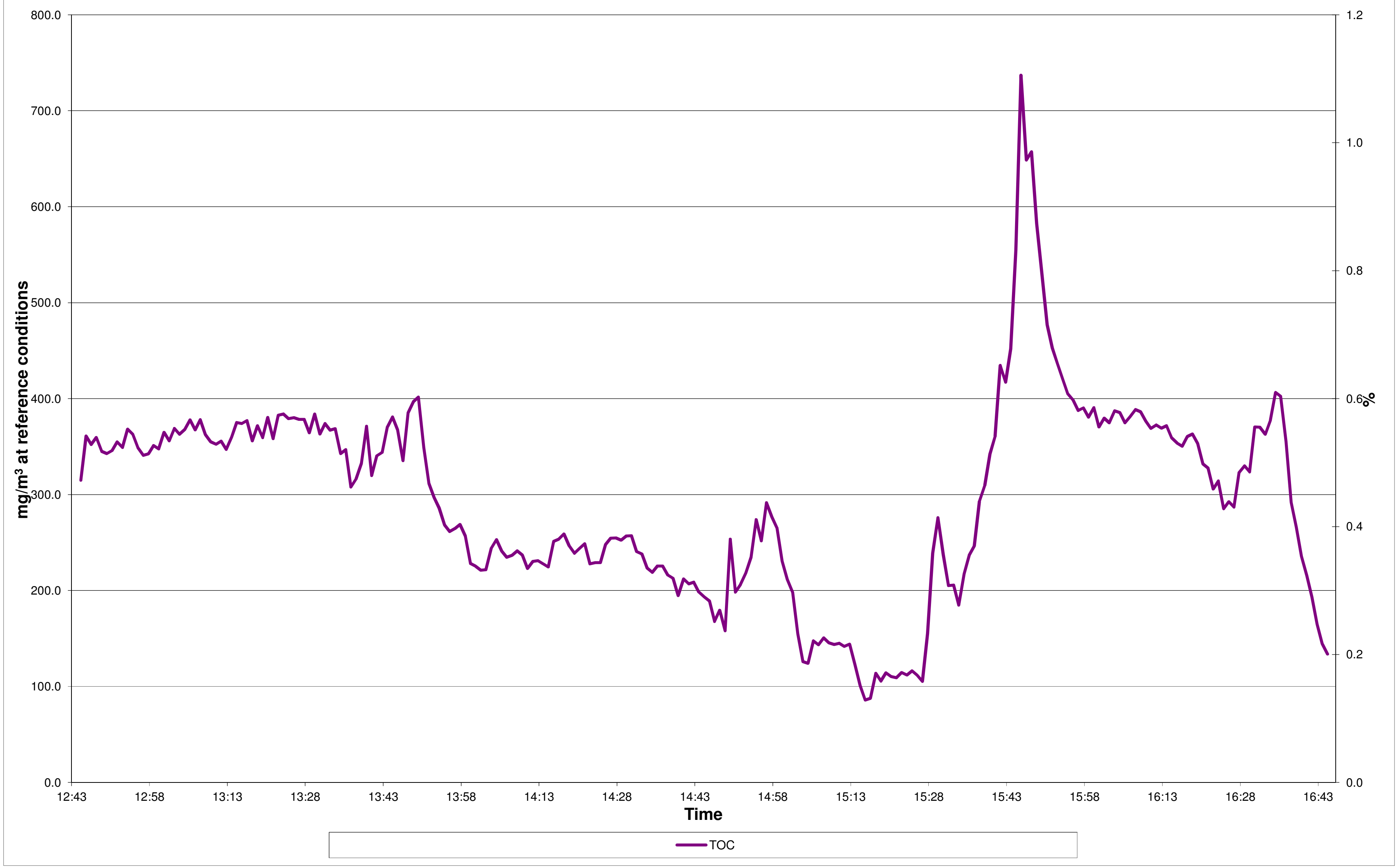
| Species | Units | Value | Cylinder Reference | Analyser Range | Uncertainity $k = 2$ |
|---|---|---|---|---|---|
| Nitrogen | % | 99.999 | VCK01959 | - | ± 2 |
| Volatile organic compounds | vppm | 74.7 | VC59841 | 10 | ± 2 |

Zero And Span Gas Details

| Species | units | Initial Time | 12:30 | Final Time | 17:00 |
|---|---|---|---|---|---|
| | | Initial Zero | Initial Span | Final Zero | Final Span |
| Volatile organic compounds | vppm | 0.00 | 74.70 | 0.31 | 75.02 |

## Exhaust Gases - Continuous Analysis Data, Continued

## Chart 1 - VOC Emissions Data - Ink Manufacturing Plant, 03/11/2015



| | | | | | |
|---|---|---|---|---|---|
| Probe/Pitot ID No | | AQ187/PT116 | Nozzle Diameter (d) | mm | 9.99 |
| Pitot Calibration Factor (Cp) | | 0.84 | In-stack Filtration | Y/N | N |
| Gas Calibration Factor (Y) | | 1.052 | Leak check OK | Y/N | Y |
| Barometric Pressure | kPa | 101.3 | Meter ID No | | CU16/2 |
| Duct static Pressure | kPa | -0.01 | Initial Gas Meter Reading | m³ | 3.095 |
| Date | | 03/11/2015 | Final Gas Meter Reading | m³ | 13.668 |
| Start Time | hh:min | 11:49 | Sampled Vol, Dry at Meter | m³ | 10.573 |
| End Time | hh:min | 19:49 | Sampled Vol, Dry STP | Nm³ | 10.298 |
| Sampling Duration | hh:min | 08:00 | Moisture content of stack gas | % v/v | 0.6 |
| | | | Isokinetic | % | 102.2 |

| Impinger | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Initial mass (g) | 763.5 | 716.6 | 607.4 | 897.2 |
| Final mass (g) | 773.2 | 722.2 | 613.8 | 926.5 |

| Sample Point Number | Line | Sampling Time | Pitot Reading (h) | Temperatures | | | Orifice Pressure (Dh) |
|---|---|---|---|---|---|---|---|
| | | | | Sample Gas Temperature (Ts) | Filter Temperature | Meter Temperature (Tm) | |
| | | hh:min | mm w.g | ℃ | ℃ | ℃ | mm w.g |
| 1 | A | 00:00 | 2.6 | 20 | 160 | 13 | 65.3 |
| | | 00:05 | 2.6 | 20 | 160 | 14 | 65.3 |
| | | 00:10 | 2.6 | 20 | 160 | 15 | 65.3 |
| | | 00:15 | 2.6 | 20 | 160 | 16 | 65.3 |
| | | 00:20 | 2.6 | 20 | 160 | 17 | 65.3 |
| | | 00:25 | 2.6 | 20 | 160 | 18 | 65.3 |
| | | 00:30 | 2.6 | 20 | 160 | 19 | 65.3 |
| | | 00:35 | 2.6 | 20 | 160 | 20 | 65.3 |
| | | 00:40 | 2.6 | 20 | 160 | 20 | 65.3 |
| | | 00:45 | 2.6 | 20 | 160 | 21 | 65.3 |
| | | 00:50 | 2.6 | 20 | 160 | 22 | 65.3 |
| | | 00:55 | 2.6 | 20 | 160 | 22 | 65.3 |
| | | 01:00 | 2.6 | 20 | 160 | 23 | 65.3 |
| | | 01:05 | 2.6 | 20 | 160 | 23 | 65.3 |
| | | 01:10 | 2.6 | 20 | 160 | 23 | 65.3 |
| | | 01:15 | 2.6 | 20 | 160 | 23 | 65.3 |
| | | 01:20 | 2.6 | 20 | 160 | 24 | 65.3 |
| | | 01:25 | 2.6 | 20 | 160 | 24 | 65.3 |
| | | 01:30 | 2.6 | 20 | 160 | 24 | 65.3 |
| | | 01:35 | 2.6 | 20 | 160 | 24 | 65.3 |
| | | 01:40 | 2.6 | 20 | 160 | 24 | 65.3 |
| | | 01:45 | 2.6 | 20 | 160 | 24 | 65.3 |
| | | 01:50 | 2.6 | 20 | 160 | 24 | 65.3 |
| | | 01:55 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 02:00 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 02:05 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 02:10 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 02:15 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 02:20 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 02:25 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 02:30 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 02:35 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 02:40 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 02:45 | 2.6 | 21 | 160 | 25 | 65.3 |
| | | 02:50 | 2.6 | 21 | 160 | 25 | 65.3 |
| | | 02:55 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:00 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:05 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:10 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:15 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:20 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:25 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:30 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:35 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:40 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:45 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:50 | 2.6 | 20 | 160 | 25 | 65.3 |
| | | 03:55 | 2.6 | 20 | 160 | 25 | 65.3 |
| 2 | A | 04:00 | 1.4 | 20 | 160 | 25 | 35.2 |
| | | 04:05 | 1.4 | 20 | 160 | 25 | 35.2 |
| | | 04:10 | 1.4 | 20 | 160 | 24 | 35.2 |
| | | 04:15 | 1.4 | 20 | 160 | 24 | 35.2 |
| | | 04:20 | 1.4 | 20 | 160 | 24 | 35.2 |
| | | 04:25 | 1.4 | 21 | 160 | 24 | 35.2 |
| | | 04:30 | 1.4 | 21 | 160 | 24 | 35.2 |
| | | 04:35 | 1.4 | 21 | 160 | 24 | 35.2 |
| | | 04:40 | 1.4 | 21 | 160 | 24 | 35.2 |
| | | 04:45 | 1.4 | 21 | 160 | 24 | 35.2 |
| | | 04:50 | 1.6 | 21 | 160 | 24 | 40.2 |
| | | 04:55 | 1.6 | 21 | 160 | 24 | 40.2 |
| | | 05:00 | 1.6 | 21 | 160 | 24 | 40.2 |
| | | 05:05 | 1.6 | 21 | 160 | 24 | 40.2 |
| | | 05:10 | 1.4 | 21 | 160 | 24 | 35.2 |
| | | 05:15 | 1.4 | 21 | 160 | 24 | 35.2 |
| | | 05:20 | 1.4 | 20 | 160 | 24 | 35.2 |
| | | 05:25 | 1.4 | 21 | 160 | 24 | 35.2 |
| | | 05:30 | 1.4 | 21 | 160 | 24 | 35.2 |
| | | 05:35 | 1.4 | 21 | 160 | 24 | 35.2 |
| | | 05:40 | 1.6 | 21 | 160 | 24 | 40.2 |
| | | 05:45 | 1.6 | 21 | 160 | 24 | 40.2 |
| | | 05:50 | 1.6 | 20 | 160 | 24 | 40.2 |
| | | 05:55 | 1.6 | 20 | 160 | 24 | 40.2 |
| | | 06:00 | 1.6 | 19 | 160 | 24 | 40.2 |
| | | 06:05 | 1.6 | 19 | 160 | 24 | 40.2 |
| | | 06:10 | 1.6 | 19 | 160 | 24 | 40.2 |
| | | 06:15 | 1.6 | 19 | 160 | 24 | 40.2 |
| | | 06:20 | 1.4 | 19 | 160 | 24 | 35.2 |
| | | 06:25 | 1.4 | 19 | 160 | 24 | 35.2 |
| | | 06:30 | 1.4 | 19 | 160 | 24 | 35.2 |
| | | 06:35 | 1.4 | 22 | 160 | 24 | 35.2 |
| | | 06:40 | 1.4 | 22 | 160 | 23 | 35.2 |
| | | 06:45 | 1.2 | 19 | 160 | 23 | 30.1 |
| | | 06:50 | 1.2 | 19 | 160 | 23 | 30.1 |
| | | 06:55 | 1.2 | 18 | 160 | 23 | 30.1 |
| | | 07:00 | 1.2 | 21 | 160 | 23 | 30.1 |
| | | 07:05 | 1.2 | 20 | 160 | 23 | 30.1 |
| | | 07:10 | 1.4 | 18 | 160 | 23 | 35.2 |
| | | 07:15 | 1.4 | 18 | 160 | 23 | 35.2 |
| | | 07:20 | 1.4 | 18 | 160 | 23 | 35.2 |
| | | 07:25 | 1.4 | 18 | 160 | 23 | 35.2 |
| | | 07:30 | 1.4 | 18 | 160 | 23 | 35.2 |
| | | 07:35 | 1.4 | 18 | 160 | 23 | 35.2 |
| | | 07:40 | 1.4 | 18 | 160 | 23 | 35.2 |
| | | 07:45 | 1.6 | 18 | 160 | 23 | 40.2 |
| | | 07:50 | 1.6 | 18 | 160 | 23 | 40.2 |
| | | 07:55 | 1.6 | 18 | 160 | 23 | 40.2 |
| | End | 08:00 | | | | | |
| | | | | | | | |
| | | Averages | 2.0 | 19.9 | 160.0 | 23.3 | 50.7 |

| | | |
|---|---|---|
| **Average velocity** | **4.82** | **m/s** |
| **Average flow rate** | **0.95** | **m³/s** |
| **Average flow rate** | **0.88** | **m³/s*** |

**Total Particulate Matter - Sampling Data**

| **Blank Filter Weight** | | Weight Collected | |
|---|---|---|---|
| Filter No. | EM - 2112/2 | **0.0001** | g |
| Washings | EM - 2112/1 | **0.0003** | g |
| Total | | **0.0004** | g |

| **Filter Weight Test 1** | | Weight Collected | |
|---|---|---|---|
| Filter No. | EM - 2112/4 | **0.0001** | g |
| Washings | EM - 2112/3 | 0.0004 | g |
| Total | | **0.0005** | g |

| **Particulate Emission Results** | **Blank** | |
|---|---|---|
| Detection Limit | 0.05 | mg/m$^{3}$* |
| Particulate Emission | **0.04** | mg/m$^{3}$* |

| **Particulate Emission Results** | **Test 1** | |
|---|---|---|
| Detection Limit | 0.05 | mg/m$^{3}$* |
| Particulate Emission | **0.05** | mg/m$^{3}$* |

| | | |
|---|---|---|
| Laboratory | SAL | |
| Method Nº & Accreditation Status | Gravimetric | UKAS |
| Date of analysis | 13/11/2015 | |

## Total Particulate Matter - Emission Results

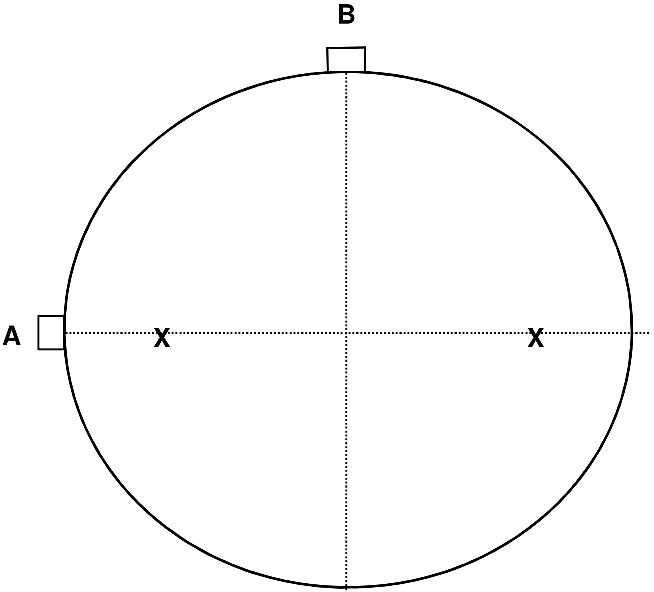
# APPENDIX 3

# Diagram Of The Sampling Location

Diagram of sampling points across the cross section of the duct (not to scale).

Traverse length = 0.50 m

| Point | % of D | Location cm |
|---|---|---|
| 1 | 14.6 | 7.3 |
| 2 | 85.4 | 42.7 |



# General Calculations

**Stack area:**

$$Area\,of\;a\,circle = \frac{\pi .D^2}{4}$$

D = Diameter (m)
π = 3.142

**Pressure conversion:**

1mmH2O = 0.00980665 kPa
1mmH2O = 9.80665 Pa
1 mar = 0.1 kPa

**Water vapour concentration:**
From reference calculations (taken from BS EN 14790):

$$V_{WC(\%)} = \frac{\frac{m_{WC}.V_{mol(std)}}{M_W}}{\frac{m_{WC}.V_{mol(std)}}{M_W} + V_{m(std)}} \times 100$$

VWC (%) = Water vapour content on wet basis, in volume % (m$^3$ of water vapour in m$^3$ of wet gas)
Vm(std) = Dry gas volume measured, corrected to standard conditions (m$^3$)
mWC = Mass of water collected in the impingers (g)
Mw = Molecular weight of water, 18.01534 rounded to 18 (g/mol)
Vmol(std) = Molar volume of water at standard conditions = 0.0224 (m3/mol)

**Gas meter volume at standard conditions (STP)**
From reference calculations (taken from BS EN 14790):

$$V_{m(std)} = y_d \times (V_2 - V_1) \times \frac{T_{std}}{T_m} \times \frac{p_m}{p_{std}}$$

Vm(std) = Dry gas meter volume at standard conditions (m$^3$)
yd = Gas meter calibration coefficient
(V2-V1) = Dry gas meter volume at actual conditions (m$^3$)
Tm = Actual Temperature (K)
Tstd = Standard temperature (273 K)
pm = Absolute pressure at the gas meter (kPa)
pstd = Standard gas pressure (101.3 kPa)

**Isokenetic Ratio (%):**
From reference calculations (taken from EA TGN M2):

$$IsokineticRatio(\%) = \frac{Velocity\ at\ the\ sampling\ nozzle}{Velocity\ of\ the\ stack\ gas} \times 100$$

**Estimating Measurment Uncertainty**
Uncertainty estimates are calculated using the general rule of uncertainty propagation. Guidance is taken from publications including UKAS document M3003 and ISO 20988:2007.

# Flow Calculations

**Velocity:**
From reference calculations (taken from ISO 10780):

$$\bar{v} = KC\sqrt{\frac{T_s\,\Delta\bar{p}}{p_e\,M_s}}$$

$\bar{v}$ = Average velocity (m/s)
*C* = velocity calculation constant = 129
*Ts* = Average stack temperature (K)
*Ms* = Molar mass of gas; assume 29 kg/kmol unless the molar mass is < 27 kg/kmol or > 31 g/kmol
*K* = Pitot calibration coefficient
*Pe* = Absolute gas pressure (kPa)
$\Delta\bar{p}$ = Average pitot tube pressure differencial (kPa)

**Volume flow rate**
From reference calculations (taken from ISO 10780):

$$q_{va} = \bar{v}A$$

*qva* = Average flow rate ($m^3$/s)
$\bar{v}$ = Average velocity (m/s)
*A* = Stack cross-sectional area ($m^2$)

**Volume flow rate corrected for moisture**
From reference calculations (taken from BS ISO 9096):

$$q_m = q_{va}\,\frac{(100 - H_a)}{(100 - H_m)}$$

*qm* = Corrected volume flowrate ($m^3$/s)
*qva* = Volume flow rate at actual conditions ($m^3$/s)
*Ha* = Moisture at actual conditions (%volume)
*Hm* = Reference moisture (%volume)

**Volume flow rate corrected for temperature and pressure**
From reference calculations (taken from BS ISO 9096):

$$q_m = q_{va}\,\frac{(T_m\,p_a)}{(T_a\,p_m)}$$

*qm* = Corrected volume flowrate ($m^3$/s)
*qva* = Volume flow rate at actual conditions ($m^3$/s)
*Ta* = Temperature at actual conditions (K)
*Tm* = Reference Temperatue (K)
*pa* = Absolute gas pressure at actual conditions (kPa)
*pm* = Reference pressure (kPa)

**Volume flow rate corrected for oxygen**
From reference calculations (taken from BS ISO 9096):

$$q_m = q_{va}\,\frac{(20.9 - O_{2,ref})}{(20.9 - O_{2,m})}$$

*qm* = Corrected volume flowrate ($m^3$/s)
*qva* = Volume flow rate at actual conditions ($m^3$/s)
*O2,m* = Actual oxygen concentration (%)
*O2,ref* = Reference oxygen concentration (%)

# Concentration Calculations

**Concentration:**
From reference calculations (taken from BS EN 13284-1):

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

*c =* Concentration
*m =* Mass of substane
*V =* Volume sampled

**Mass Emission**

$$Mass\ emission = c \times q_m$$

*c =* Concentration
*q =* Volume flow rate

**Concentration corrected for oxygen:**
From reference calculations (taken from BS ISO 9096):

$$c_m = c_a \times \frac{20.9 - O_{2,ref}}{20.9 - O_{2,a}}$$

*cm =* Concentration at reference conditions
*ca =* Actual concentration
*O2, ref =* Reference oxygen (%)
*O2, a=* Actual Oxygen (%)

**Concentration corrected for moisture:**
From reference calculations (taken from BS ISO 9096):

Convert wet gas to dry gas

$$c_{dry} = c_{wet} \times \frac{100}{100 - H_a}$$

Convert dry gas to wet gas

$$c_{wet} = c_{dry} \times \frac{100 - H_a}{100}$$

*cwet =* Concentration wet gas
*cdry =* Concentration dry gas
*Ha =* Water vapour content (%vol)

**Conversion of parts per million (ppm) to mg/m$^3$**
From reference calculations (taken from EA TGN M2):

$$Concentration(mg / m^3) = \frac{Concentration(ppm) \times molecular\ weight(g)}{molar\ volume(l)\ at\ a\ given\ temperature}$$

molar volume at 273K = 22.4 litres

**When Converting TOC**

$$Concentration(mg / m^3) = \frac{Concentration(ppm) \times molecular\ weight\ of\ carbon\ in\ span\ gas(g)}{molar\ volume(l)\ at\ a\ given\ temperature}$$

molar volume at 273K = 22.4 litres

# Calculation of Uncertainty Estimates - Manual Monitoring Techniques

$$C_m = \frac{Q_m}{V_{std}}$$

$$V_{std} = V_{T.p} \times \frac{T_{std}}{T} \times \frac{p}{P_{std}}$$

Where:

| | | | | |
|---|---|---|---|---|
| $C_m$ | = | the measured concentration | in | mg/m$^3$ |
| $Q_m$ | = | mass concentration collected in absorber solution and filter | in | mg |
| $v_s$ | = | the volume of the sample solution | in | l |
| $V_{std}$ | = | volume sampled at standard conditions | in | m$^3$ |
| $T_m$ | = | mean temperature of gas meter | in | K |
| $T_{std}$ | = | standard temperature | = | 273K |
| *p=prel+Patm* | = | absolute pressure = gas meter pressure + atmospheric pressure | in | kPa |
| $P_{std}$ | = | standard pressure | = | 101.325 kPa |
| $V_{T.p}$ | = | volume sampled as indicated by the gas meter | in | m$^3$ |

Expression for calculation of the combined uncertainty of the measured concentration

$$\frac{u^2(C_m)}{(C_m)^2} = \frac{u^2(Q_m)}{(Q_m)^2} + \frac{u^2(v_s)}{(v_s)^2} + \frac{u^2(V_{std})}{(V_{std})^2}$$

Expression for calculation of the combined uncertainty of the gas volume

$$V_{std} = V_{T.p} \times \frac{T_{std}}{T_m} \times \frac{p}{P_{std}}$$

Assuming that uncertainties associated with the standard quantities $T_{std}$ and $P_{std}$ are negliable
Expression for calculation of the combined uncertainty of the measured concentration

$$\frac{u^2(C_m)}{(C_m)^2} = \frac{u^2(Q_m)}{(Q_m)^2} + \frac{u^2(v_s)}{(v_s)^2} + \frac{u^2(V_{T.p})}{(V_{T.p})^2} + \frac{u^2(T)}{(T)^2} + \frac{u^2(p_{rel})}{(p)^2} + \frac{u^2(p_{atm})}{(p)^2}$$

$$u(C_m) = \sqrt{\left(\frac{u^2(Q_m)}{(Q_m)^2} + \frac{u^2(v_s)}{(v_s)^2} + \frac{u^2(V_{T.p})}{(V_{T.p})^2} + \frac{u^2(T)}{(T)^2} + \frac{u^2(p_{rel})}{(p)^2} + \frac{u^2(p_{atm})}{(p)^2}\right) \times (C_m)^2}$$

Overall expanded uncertainty (k = 2)

$$U(C_m) = u(C_m) \times k$$

Uncertainty of the measured concentration at oxygen reference concentration

$$u\left(C_{m,O_{2,ref}}\right) = \sqrt{\left(\frac{u^2(Q_m)}{(Q_m)^2} + \frac{u^2(v_s)}{(v_s)^2} + \frac{u^2(V_{T.p})}{(V_{T.p})^2} + \frac{u^2(T)}{(T)^2} + \frac{u^2(p_{rel})}{(p)^2} + \frac{u^2(p_{atm})}{(p)^2} + \frac{u^2(O_{2,meas,dry})}{(21 - O_{2,meas,dry})^2}\right) \times \left(C_{m,O_2,ref}\right)^2}$$

Where:

| | | | | |
|---|---|---|---|---|
| u(Cm,$O_{2,ref)}$ | = | uncertainty associated with the mass concentration at $O_2$ reference concentration | in | mg/m$^3$ |
| Cm,$O_{2,ref}$ | = | mass concentration at $O_2$ reference concentration | in | mg/m$^3$ |
| $O_{2,meas}$ | = | $O_2$ measured concentration | in | % volume |
| u(($O_{2,meas)dry)}$ | = | uncertainty associated to the measured $O_2$ concentration | in | % (relative to $O_{2\ meas}$) |

## Calculation of Uncertainty Estimates - Instrumental Monitoring Techniques

**Model equation**

$$C_{ppm} = C_{reading} + Corr_{fit} + Corr_{0,dr} + Corr_{s,dr} + Corr_{rep} + Corr_{adj} + \sum_{i=1}^{p} Corr_{\mathrm{inf}} + Corr_{\mathrm{int}}$$

Where:

$C_{,ppm}$ = concentration in ppm
$C_{NO,reading}$ = concentration given by analyser
$Corr_{fit}$ = correction of lack of fit
$Corr_{0,dr}$ = correction of zero drift
$Corr_{s,dr}$ = correction of span drift
$Corr_{rep}$ = correction of repeatability of measurement
$Corr_{adj}$ = correction of adjustment
$Corr_{inf}$ = correction of influence quantities
$Corr_{int}$ = correction of interferents

**Calculation of partial uncertainties**

$$u(Corr_{fit}) = \frac{\left(\dfrac{X_{fit,\max}}{100 \times range}\right)}{\sqrt{3}}$$

Where:

| | |
|---|---|
| $X_{fit,max}$ | is the maximum allowable deviation from linearity |

Expressed as % of the range and calculated by applying a rectangular probability distribution

$$u(Corr_{0,dr}) = \frac{X_{0,dr}}{\sqrt{3}} \qquad u(Corr_{s,dr}) = \frac{X_{s,dr}}{\sqrt{3}}$$

$$u(Corr_{rep}) = \max(S_{0,rep} ; S_{srep}) = S_{rep}$$

Where:

| | |
|---|---|
| $S_{r,0}$ | is the standard uncertainty at zero level |
| $S_{r,s}$ | is the standard uncertainty at span level |

$$u(Corr_{adj}) = u(Corr_{loss}) + u(Corr_{cal})$$

$$u(Corr_{loss}) = \frac{C_{j,loss}}{\sqrt{3}}$$

$$u(Corr_{cal}) = \frac{U_{cal}}{2}$$

Where:

| | |
|---|---|
| $u(Corr_{loss})$ | is the uncertainty due to losses in sample line |
| $u(Corr_{cal})$ | is the uncertainty due to losses in sample line |
| $cj,_{loss}$ | is the concentration of sample loss at span level |
| $U_{cal}$ | is the expanded uncertainty of the calibration gas |

$$u(Corr_{inf}) = c_j \sqrt{\frac{(x_{j,\max} - x_{j,adj})^2 + (x_{j,\min} - x_{j,adj}) \times (x_{j,\max} - x_{j,adj}) + (x_{j,\min} - x_{j,adj})^2}{3}}$$

Where:

| | |
|---|---|
| $c_j$ | is the sensitivity coefficient of the influence quantity |
| $x_{j,min}$ | is the minimum value of the influence quantity during monitoring |
| $x_{j,max}$ | is the maximum value of the influence quantity during monitoring |
| $x_{j,adj}$ | is the value of the influence quantity during adjustment |

$$u(Corr_{int}) = \frac{c_j}{Int_{j,test}} \sqrt{\frac{{Int_{j,\max}}^2 + Int_{j,\min} \times Int_{j,\max} + {Int_{j,\min}}^2}{3}}$$

and

$$u(\Sigma Corr_{int}) = \max\left[S_{Int,p} ; S_{Int,n}\right]$$

Where:

| | |
|---|---|
| $c_j$ | is the sensitivity coefficient of the interferent j |
| $Int_{j,test}$ | is the concentration of the interferent j used to determine $c_j$ |
| $Int_{j,min}$ | is the minimum value of the interferent j quantity during monitoring |
| $Int_{j,max}$ | is the maximum value of the interferent j quantity during monitoring |
| $Int_{j,adj}$ | is the concentration of the interferent j in the cal gas used to adjust the analyser |
| $S_{int,p}$ | is the sum of interferents with positive impact |
| $S_{int,n}$ | is the sum of interferents with negative impact |

**Combined uncertainty**

$u(C,_{ppm})$ =

$$\sqrt{u^2(corr_{fit}) + u^2(corr_{0,dr}) + u^2(corr_{s,dr}) + u^2(corr_{rep}) + u^2(corr_{s,vf}) + u^2(corr_{a,press}) + u^2(corr_{temp}) + u^2(corr_{volt}) + u^2(corr_{adj}) + {S_{Int}}^2}$$

**Overall expanded uncertainty (k = 2)** $U(C_m) = u(C_m) \times k$

**Uncertainty of NOx measurements**

$$u(C_{NOx},_{conv}) = \frac{C_{NOx} \times R \times \eta}{\sqrt{3}}$$

Where:

| | |
|---|---|
| $C_{NOx}$ | is the concentration of NOx measured by the analyser |
| R | is the ratio of NO:Nox in the stack gas |
| η | is the NOx converter efficiency |

**Combined uncertainty NOx measurements**

$u(C_{NOx},_{stack})$ =

$$\sqrt{u^2(corr_{fit}) + u^2(corr_{0,dr}) + u^2(corr_{s,dr}) + u^2(corr_{rep}) + u^2(corr_{s,vf}) + u^2(corr_{a,press}) + u^2(corr_{temp}) + u^2(corr_{volt}) + u^2(corr_{adj}) + {S_{Int}}^2 + u^2(corr_{NOx,conv})}$$

**Uncertainty of mass concentration at oxygen reference concentration**

$u(C,_{O2\,ref})$ =

$$\sqrt{u^2(corr_{fit}) + u^2(corr_{0,dr}) + u^2(corr_{s,dr}) + u^2(corr_{rep}) + u^2(corr_{s,vf}) + u^2(corr_{a,press}) + u^2(corr_{temp}) + u^2(corr_{volt}) + u^2(corr_{adj}) + {S_{Int}}^2 + \left(\frac{u^2(O_{2,meas,dry})}{(21 - O_{2,meas,dry})^2}\right)}$$

Where:

$u(C,O_{2,ref})$ = uncertainty associated with the mass concentration at $O_2$ ref. concentration in mg/m$^3$
$C,O_{2,ref}$ = mass concentration at $O_2$ reference concentration in mg/m$^3$
$O_{2,meas}$ = $O_2$ measured concentration in % volume
$u((O_{2,meas})_{dry})$ = uncertainty associated to the measured $O_2$ concentration in % (relative to $O_{2\,meas}$)

# APPENDIX 4

# Uncertainty Estimate For The Measurement Of Total Organic Carbon

| | | |
|---|---|---|
| Analyser Type/Model | Sick Maihak | |
| Reference Oxygen % | 0 | ( 0 = No correction) |

| | | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Test 7 | Test 8 |
|---|---|---|---|---|---|---|---|---|---|
| Limit value | $mg/m^3$ | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| Limit value | ppm | 93.3 | 93.3 | 93.3 | 93.3 | 93.3 | 93.3 | 93.3 | 93.3 |
| Measured concentration | ppm | 221.1 | 223.6 | 171.6 | 145.0 | 117.8 | 127.6 | 343.0 | 190.2 |
| Measured concentration | $mg/m^3$ | 355.4 | 359.4 | 275.8 | 233.0 | 189.3 | 205.1 | 551.2 | 305.8 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Calibration gas | ppm | 74.7 | 74.7 | 74.7 | 74.7 | 74.7 | 74.7 | 74.7 | 74.7 |
| Calibration gas | $mg/m^3$ | 120.1 | 120.1 | 120.1 | 120.1 | 120.1 | 120.1 | 120.1 | 120.1 |
| Analyser range | ppm | 9.3 | 9.3 | 9.3 | 9.3 | 9.3 | 9.3 | 9.3 | 9.3 |
| Analyser range | $mg/m^3$ | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 |

Correction of Lack of Fit

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Lack of fit | % range | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| | $u(Corr_{,fit})$ | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 |

Corrections of Zero and Span Drift (*All drift is calculated for ∴ the residual is assumed to be < 5% u(max) )

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Zero Drift | % range | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $u(Corr_{,0dr})$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Span Drift | % range | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $u(Corr_{,sdr})$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Correction of Repeatability of Measurement

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Repeatability SD at span level | % range | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| (Not reported) | $u(Corr_{,rep})$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Correction of adjustment

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| losses in the line | % range | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| | $u(Corr_{,loss})$ | 0.05 | 0.05 | 0.04 | 0.03 | 0.03 | 0.03 | 0.08 | 0.04 |
| Uncertainty of calibration gas | % range | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| | $u(Corr_{,cal})$ | 2.21 | 2.24 | 1.72 | 1.45 | 1.18 | 1.28 | 3.43 | 1.90 |

Correction of Influence of Interferents

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $N_2O$ | % range | | | | | | | | |
| | $u(Corr_{,N2O})$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $CO_2$ | % range | | | | | | | | |
| | $u(Corr_{,CO2})$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $CH_4$ | % range | | | | | | | | |
| | $u(Corr_{,CH4})$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total of interferent influences | % range | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| $u(\Sigma Corrint) = \max\left[S_{Int,p};S_{Int,n}\right]$ | $u(\Sigma Corr_{int})$ | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 |

Correction of Influence Quantities

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sensitivity to sample volume flow | % range | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 |
| | $u(Corr_{,flow})$ | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| Sensitivity to atmospheric pressure | % range | | | | | | | | |
| (Not reported) | $u(Corr_{,press})$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sensitivity to ambient temperature | % range | -2.40 | -2.40 | -2.40 | -2.40 | -2.40 | -2.40 | -2.40 | -2.40 |
| | $u(Corr_{,temp})$ | -0.28 | -0.28 | -0.28 | -0.28 | -0.28 | -0.28 | -0.28 | -0.28 |
| Sensitivity to electrical voltage | % range | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| (Not reported) | $u(Corr_{,volt})$ | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Maximum standard uncertainty | $u(Corr_{,max})$ | 2.21 | 2.24 | 1.72 | 1.45 | 1.18 | 1.28 | 3.43 | 1.90 |
| 5% of maximum standard uncertainty | $u(Corr_{,5\%})$ | 0.11 | 0.11 | 0.09 | 0.07 | 0.06 | 0.06 | 0.17 | 0.10 |

| Interferent Concentration Variations | Minimum | Maximum | Value at cal | Performance | Units |
|---|---|---|---|---|---|
| $CH_4$ range | 0 | 10 | 0 | 50 | $mg/m^3$ |
| $N_2O$ range | 0 | 0 | 0 | 20 | $mg/m^3$ |
| $CO_2$ range | 8 | 12 | 0 | 15 | $mg/m^3$ |
| Oxygen effect variations | Minimum | Maximum | Value at cal | Performance | Units |
| Oxygen effect | 0 | 20 | 0 | 2 | $mg/m^3$ |

Influence Quantitiy Variations

| | Minimum | Maximum | Value at cal | Performance | Units |
|---|---|---|---|---|---|
| Sensitivity to sample volume flow | 55 | 65 | 60 | 5 | l/h |
| Sensitivity to atmospheric pressure | 99 | 100 | 99 | 1 | kPa |
| Sensitivity to ambient temperature | 278 | 313 | 288 | 10 | K |
| Sensitivity to electrical voltage | 187 | 250 | 230 | 5 | V |

| Measurement uncertainty | | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Test 7 | Test 8 |
|---|---|---|---|---|---|---|---|---|---|
| Combined uncertainty | ppm | 2.23 | 2.26 | 1.75 | 1.50 | 1.23 | 1.33 | 3.44 | 1.94 |
| Combined uncertainty | $mg/m^3$ | 3.59 | 3.63 | 2.82 | 2.40 | 1.98 | 2.13 | 5.53 | 3.11 |
| Combined uncertainty at oxygen reference | $mg/m^3$ | 3.59 | 3.63 | 2.82 | 2.40 | 1.98 | 2.13 | 5.53 | 3.11 |

Expanded uncertainty expressed with a level of confidence of 95%, k=2

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Overall uncertainty | ppm | 4.5 | 4.5 | 3.5 | 3.0 | 2.5 | 2.7 | 6.9 | 3.9 |
| Overall uncertainty | $mg/m^3$ | 7.2 | 7.3 | 5.6 | 4.8 | 4.0 | 4.3 | 11.1 | 6.2 |
| Overall uncertainty relative to measured value | % | 2.0 | 2.0 | 2.0 | 2.1 | 2.1 | 2.1 | 2.0 | 2.0 |
| Overall uncertainty relative to range | % | 47.9 | 48.4 | 37.6 | 32.0 | 26.4 | 28.4 | 73.7 | 41.5 |
| Overall uncertainty relative to ELV | % | 6.0 | 6.0 | 4.7 | 4.0 | 3.3 | 3.6 | 9.2 | 5.2 |

The uncertainty evaluation has been carried out in accordance with UKAS requirements.

# Uncertainty Estimate For The Measurement Of Total Particulate Matter

**Total Particulate Matter**

| Symbol | Mass concentration of TPM | Units |
|---|---|---|
| *Cm* | 0.05 | mg/m$^3$ |
| *Cm at O2 ref* | N/A | mg/m$^3$ |

| | | |
|---|---|---|
| Filter | 0.10 | mg |
| Washings | 0.40 | mg |

| Symbol | Reference Oxygen | Units |
|---|---|---|
| *O2,ref (0=No Correction)* | 0 | % |

| Symbol | Daily emission limit value | Units |
|---|---|---|
| *DELV* | 20.0 | mg/m$^3$ |

Mass of Particulate

| Symbol | Source of Uncertainty | Value | Units | Probability Distribution | Divisor | *ci* | *Ui* |
|---|---|---|---|---|---|---|---|
| $u$(calBal) | Calibration | 0.1180 | mg | Normal | 2 | 1 | 0.0590 |
| $u$(repBal) | Repeatability Filter | 0.0110 | mg | Normal | 1 | 2 | 0.0220 |
| $u$(repBal) | Repeatability Washings | 0.0300 | mg | Normal | 1 | 2 | 0.0600 |
| $u$(driftBal) | Drift | 0.0312 | mg | Rectangular | $\sqrt{3}$ | 1 | 0.0180 |
| $u$(resBal) | Resolution | 0.0050 | mg | Rectangular | $\sqrt{3}$ | 1 | 0.0029 |
| $u$(aceBal) | Residual acetone | 0.0400 | mg | Normal | 2 | 1 | 0.0200 |
| *u(buoBal)* | Air buoyancy | 0.0015 | mg | Normal | 1 | 1 | 0.0015 |
| $u$(mass) | Combined Uncertainty | - | | Normal | - | - | 0.0911 |
| $u$(mass)/mass | Relatve | 0.500 | mg | - | - | - | 1.8763 |
| | | | | | | $u$(mass)$^2$/mass$^2$ | 3.520556 |

| | | | | |
|---|---|---|---|---|
| U(Wm) | Expanded Combined Weighing Uncertainty As Percentage of DELV k=2 | ± | 0.91 | % |

Volume of sampled gas

| Symbol | Source of Uncertainty | Value | Units | Probability Distribution | Divisor | *ci* | *Ui* |
|---|---|---|---|---|---|---|---|
| $u$(calV$_{T,p}$) | Calibration | 0.0505 | m$^3$ | Normal | 2 | 1 | 0.0252 |
| $u$(repV$_{T,p}$) | Repeatability | 0.0051 | m$^3$ | Normal | 1 | 1 | 0.0051 |
| $u$(driftV$_{T,p}$) | Drift | 0.0278 | m$^3$ | Rectangular | $\sqrt{3}$ | 1 | 0.0161 |
| $u$(resV$_{T,p}$) | Resolution | 0.0002 | m$^3$ | Rectangular | $\sqrt{3}$ | 1 | 0.0001 |
| $u$(V$_{T,p}$) | Combined Uncertainty | - | - | Normal | - | - | 0.0303 |
| $u$(V$_{T,p}$)/V$_{T,p}$ | Relatve | 10.298 | m$^3$ | - | - | - | 0.0029 |
| | | | | | | $u$(Vm)$^2$/Vm$^2$ | 0.000009 |

Temperature of the DGM

| Symbol | Source of Uncertainty | Value | Units | Probability Distribution | Divisor | *ci* | *Ui* |
|---|---|---|---|---|---|---|---|
| $u$(calTi$_m$) | Calibration | 1.0 | K | Normal | 2 | 1 | 0.5000 |
| $u$(calTc$_m$) | Calibration | 1.0 | K | Normal | 2 | 1 | 0.5000 |
| $u$(resT$_m$) | Resolution | 0.1 | K | Rectangular | $\sqrt{3}$ | 1 | 0.0577 |
| $u$(driftT$_m$) | Drift | 1.0 | K | Rectangular | $\sqrt{3}$ | 1 | 0.5774 |
| $u$(T$_m$) | Combined Uncertainty | - | - | Normal | - | - | 0.9147 |
| $u$(T$_m$)/Tm | Relatve | 296.3 | K | Normal | - | - | 0.0031 |
| | | | | | | $u$(Tm)$^2$/Tm$^2$ | 0.000010 |

Atmospheric Pressure

| Symbol | Source of Uncertainty | Value | Units | Probability Distribution | Divisor | *ci* | *Ui* |
|---|---|---|---|---|---|---|---|
| $u$(P$_{atm}$) | Metrological Office | 300 | Pa | Normal | $\sqrt{3}$ | 1 | 173 |
| $u$(P$_{atm}$) | Combined Uncertainty | - | - | Normal | - | - | 173 |
| $u$(P$_{atm}$)/P | Relatve | 101300 | - | Normal | - | - | 0.0017 |
| | | | | | | $u$(P$_{atm}$)$^2$/P$^2$ | 0.000003 |

Relative DGM Pressure

| Symbol | Source of Uncertainty | Value | Units | Probability Distribution | Divisor | *ci* | *Ui* |
|---|---|---|---|---|---|---|---|
| $u$(P$_{rel}$) | DGM Pressure | 40 | Pa | Normal | 1 | 1 | 40 |
| $u$(P$_{rel}$) | Combined Uncertainty | - | - | Normal | - | - | 40 |
| $u$(P$_{rel}$)/P | Measured pressure | 101798 | - | - | - | - | 0.0004 |
| | | | | | | $u$(Prel)$^2$/P$^2$ | 0.0000002 |

Oxygen reference concentration

| Symbol | Source of Uncertainty | Value | Units | Probability Distribution | Divisor | *ci* | *Ui* |
|---|---|---|---|---|---|---|---|
| $u$((O$_2$,meas)dry)rel | Measurement of oxygen | 0.20 | % | Normal | 1 | 1 | 0.2000 |
| | Uncertainty of oxygen correction | - | - | - | - | - | N/A |
| | Measured Oxygen | N/A | % | | | $u$(Orel)$^2$/O$^2$ | N/A |

Measurement uncertainty

| | | | | | | |
|---|---|---|---|---|---|---|
| u(Cm) | Combined Standard Uncertainty | | | ± | 0.13 | mg/m$^3$ |
| u(Cm) at ref O$_2$ | Combined Standard Uncertainty | | | ± | N/A | mg/m$^3$ |

Expanded uncertainty expressed with a level of confidence of 95%, k=2

| | | | | | | |
|---|---|---|---|---|---|---|
| U(Cm) | Expanded Combined Uncertainty | *k = 2* | | ± | 0.26 | mg/m$^3$ |
| U(Cm,rel) | Expanded Combined Uncertainty | *k = 2* | | ± | 530.7 | % |
| U(Cm,rel,ELV) | Expanded Combined Uncertainty | *k = 2* | | ± | 1.3 | % |

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor (k = 2), providing a level of confidence of approximately 95%
The uncertainty evaluation has been carried out in accordance with UKAS requirements.